Olivine, Inc.

Pittsburg USD Electric School Bus Final Project Report

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Olivine works at the forefront of the changing electricity market, providing infrastructure and services that enable distributed and aggregated resources to effectively and efficiently support the electricity grid. Olivine has designed and deployed first-of-a-kind, proof-of-concept projects, and an integrated Olivine Community™ Energy experience for energy providers and utilities. For more information, visit www.olivineinc.com

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Table of Acronyms

ACC	Avoided Cost Calculator
BEV	Commercial Battery Electric Vehicle
BMS	Battery Management System
CAISO	California Independent System Operator
CPUC	California Public Utilities Commission
DER	Distributed Energy Resource
DOE	Department of Energy
DR	Demand Response
E-Bus	Electric Bus
E-Fleet	Electric Fleet
EIM	Energy Imbalance Market
EV	Electric Vehicle
EVSE	Electric Vehicle Charging Station
GHG	Greenhouse Gas Emissions
kW	Kilowatt
kWh	Kilowatt-Hour
NAESB	North American Energy Standards Board
NEM2A	Net Energy Metering Aggregation
NSCEP	National Service Center for Environmental Publications
OEM	Original Equipment Manufacturer
OpenADR	Open Automated Demand Response
PG&E	Pacific Gas & Electric
PUSD	Pittsburg Unified School District
PV	Photovoltaic
RSC	Renewable Self-Consumption
TCO	Total Cost of Ownership
TOU	Time-of-Use

UI	User Interface
V1G	Vehicle to Grid (1-way, traditional, power flow from grid only)
V2G	Vehicle to Grid (2-way power flow)
VGI	Vehicle to Grid Integration
WEQ	Wholesale Electric Quadrant
XSP	Excess Supply Pilot

1 Executive Summary

Olivine partnered with Pacific Gas & Electric (PG&E) and Liberty PlugIns on a pilot project to provide Pittsburg Unified School District (PUSD) with a low-cost[1], configurable electric fleet (E-Fleet) charge management system that is capable of optimizing one-directional charging (V1G)[2] towards specific goals defined by the fleet manager, including: maximizing charging from on-site renewable generation, providing grid support services, reducing carbon emissions, and providing bill management. The full infrastructure implemented at PUSD during the pilot included nine level two chargers[3] installed to serve four electric school buses from two different manufacturers. PUSD expects to grow their E-Fleet as funds become available. Additionally, the school district installed 200 kW of on-site renewable generation, 160 kW of solar PV and 40 kW of vertical axis wind turbines, in parallel with this pilot. The goals of this pilot included reducing the total cost of ownership of electric buses for school districts and understanding how medium and heavy-duty fleet vehicles can act as distributed energy resources during periods of high renewable penetration. This project was funded by PG&E as part of California's Senate Bill 350 (Clean Energy and Pollution Reduction Act) Transportation Electrification Priority Review Projects.

The pilot demonstrated that low-cost, non-networked charging stations paired with a single networked charger controller can be utilized in a configurable electric vehicle charging station (EVSE) solution to meet the charge control needs of school districts and support a variety of sophisticated charging approaches. Leveraging technology and hardware partners and having EV charge management expertise on the project team that can deploy intelligent, automated E-Fleet charge management systems and software is key to project success. The E-Fleet charge management system met the project goal of minimizing fuel costs by shifting charging to the less expensive off-peak time-of-use period and implementing a round-robin technique[4] to manage demand charges. While PUSD did not

[1] Non-networked charging stations paired with a single networked charger controller may have a lower procurement cost for cost-conscious customers than internally networked EVSEs; however, additional set-up and maintenance logistics may be incurred when coordinating with more than one hardware provider and multiple devices.

[2] The pilot focused on implementing one-directional charging (V1G).

[3] Level two chargers charge vehicles at 240 volts and typically have max power flow from 9.6 kW to 19.2 kW.

[4] Round-robin charging is the act of charging buses in alternating intervals in order to limit the number of chargers that are on simultaneously.

end up having enough buses to require switching to a rate tariff with a demand charge during the pilot, the round-robin charging technique will be valuable if PUSD switches to a different rate tariff with a demand or subscription charge, like PG&E's Commercial Battery Electric Vehicle (BEV) rate, in the future. Additionally, these charge management strategies may help reduce the cost to electricity ratepayers by reducing congestion on the existing power distribution infrastructure and costly distribution system upgrades. School districts looking to electrify their fleets should consider a low-cost, configurable EVSE solution as demonstrated in this pilot as an alternative to more expensive networked charger stations.

The project team leveraged existing infrastructure and deployed new, low-cost hardware to monitor on-site renewable generation and perform coincident renewable self-consumption through charge control. Additionally, PUSD's E-Fleet provided grid support services by participating in PG&E's Excess Supply Pilot (XSP). Both experiences provided valuable insights on how electric school bus fleets can be a resource to the electrical grid during periods of high renewable generation. Development of automated load management systems and software would help accelerate load and capacity management applications of electric vehicles.

Through test phase analysis and system modeling, the project team determined PG&E's BEV rate tariff is more compatible with the Net Energy Metering Aggregation (NEM2A)[5] program than PG&E's A-6 rate tariff, because it allows PUSD to simultaneously minimize both greenhouse gas (GHG) emissions and their utility bill. For most school bus fleet utilization patterns, the BEV rate tariff (or similar) should be considered as it incentivizes midday charging when GHG emissions are typically lowest in California.

The project team overcame numerous challenges borne out of the deployment of new and innovative technologies such as electric buses. The largest challenge faced was with the on-board school bus battery management systems (BMS), which were not designed with managed charging in mind. The project team worked closely with bus original equipment manufacturers (OEMs) and other school districts to communicate the importance of managed charging functionality and develop solutions. While the project team was unable to resolve the BMS issue with either school bus model, they were able to develop a work around for one of the two bus models. Moving forward, it is imperative that school districts demand managed charging support in their school bus procurements and that OEMS

[5] PG&E's Net Energy Metering Aggregation (NEM2A) program NEM2A allows a customer to utilize excess generation from a qualified resource and apply that excess generation credit proportionally across multiple meters that are either on the same property or adjacent properties.

prioritize this functionality in future bus design, otherwise school districts risk significant and unnecessary charging costs. Additionally, development of this managed charging functionality is necessary for E-Fleets to provide load and capacity management at a larger scale in the future.

Much ground has been covered in this pilot, with numerous lessons from basic school bus electrification to demonstrations of advanced functionality with on-site renewable generation. This report serves to inform decision makers at school districts, their utility counterparts and regulators to enable a smoother transition to E-Fleets and push the envelope on transportation decarbonization beyond just electrification. Future school bus electrification projects should leverage the lessons learned and recommendations from this pilot to help lead the way to California's emissions reduction goals.

2 Project Overview

2.1 Introduction

Olivine partnered with Pacific Gas & Electric (PG&E) and Liberty PlugIns on a pilot project to provide Pittsburg Unified School District (PUSD) with a low-cost, configurable electric fleet (E-Fleet) charge management system that is capable of optimizing one-directional charging (V1G) towards specific goals defined by the fleet manager, including: maximizing charging from on-site renewable generation, providing grid support services, reducing carbon emissions, and providing bill management.

2.2 Project Goals

The project goals outlined in the scope of work included:

- Reduce the total cost of ownership (TCO) of electric buses for school districts by:
    - Minimizing infrastructure costs: Working closely with school partners to find efficiencies in infrastructure installation
    - Minimizing fuel costs: Managing charging to reduce electric usage during expensive, peak times
- Inform how medium and heavy-duty fleet vehicles can act as distributed energy resources during periods of high renewable penetration by testing incentive mechanisms for compensating fleet operators to adapt charging schedules to align with renewable generation

2.3 Project Funding and Partners

This project was funded by PG&E as part of California's Senate Bill 350 (Clean Energy and Pollution Reduction Act) Transportation Electrification Priority Review' Projects. Olivine partnered with PG&E, Pittsburg Unified School District (PUSD), and Liberty PlugIns on this pilot project.

2.4 Infrastructure at Pittsburg USD (PUSD)

The full infrastructure implemented at PUSD during the pilot included nine 19kW level two chargers installed to serve four electric school buses from two different manufacturers. PUSD expects to grow their E-Fleet as funds become available. Additionally, the school district installed 200 kW of on-site renewable generation, 160 kW of solar PV and 40 kW of vertical axis wind turbines, in parallel with this pilot.

The full infrastructure implemented at PUSD during the pilot included nine ClipperCreek CS-100[6] level two chargers and deployment of four electric school buses, two LionC[7] buses and two Blue Bird All American RE Electric[8] buses. PUSD expects to grow their E-Fleet as funds become available. The Lion buses were placed into operation prior to the pilot test phases, while the first Blue Bird bus arrived in Sept 2019 and the second Blue Bird bus arrived in Jan 2020. Olivine controls the ClipperCreek chargers with a Liberty PlugIns HYDRA-RX[9] charger controller. Additionally, the school district installed 200 kW of on-site renewable generation, 160 kW of solar PV and 40 kW of vertical axis wind turbines, in parallel with this pilot.

As shown in Figure 1, the electric bus chargers are on a dedicated EV meter, while the solar PV and wind turbines share a facility meter with the school administrative offices. The chargers were placed on a dedicated EV meter to minimize distance to the bus parking spots, minimizing trenching, operations disruptions and behind-the-meter infrastructure upgrades. The solar PV started generating credits in August 2019 under PG&E's Net Energy Metering Aggregation (NEM2A) Program. In April of 2020, the wind turbines were granted permission to operate and added to the overall credit generation.

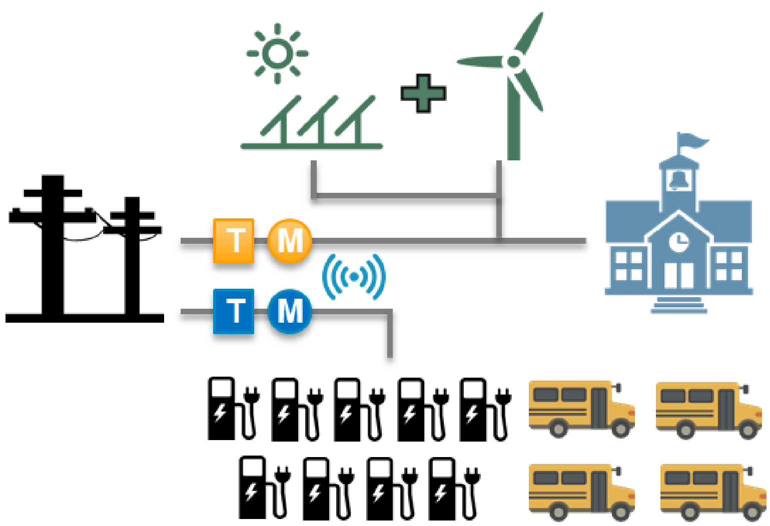

Figure 1: PUSD Meter Configuration

[6] ClipperCreek CS-100: store.clippercreek.com/cs-100-70-amp-80-amp-ev-charging-station

[7] LionC: thelionelectric.com/en/products/electric

[8] Blue Bird All American RE Electric: blue-bird.com/buses/allamerican/all-american-re-electric-bus

[9] Liberty PlugIns HYDRA-RX: libertyplugins.com/products/hydra-rx-high-power-charger-control-system

2.5 Project Test Phases

The four test phases outlined in Table 1 were executed through the pilot project. Except where noted, each test phase adds to the previous test phase functionality, thus the pilot progresses to more sophisticated charging approaches.

#	Test Phase	Description	Duration
1	Static Charging	Charged buses on static schedules, ensuring the buses' energy needs were met while minimizing both demand[10] and volumetric charges; analyzed opportunities for charge flexibility	May 1, 2019 - May 31, 2019
2	Excess Supply Pilot (XSP) Participation	Began participating in PG&E's XSP, responding to load increase events during periods of high renewable penetration on the electrical grid	August 14, 2019 - November 20, 2019
3	Renewable Self-Consumption (RSC)	Began performing RSC based on exports to the electrical grid from on-site renewables; temporarily paused XSP participation to better understand the impacts of RSC	December 9, 2019 - January 31, 2020
4	Renewables Optimization	Performed RSC and participated in XSP to demonstrate the system's ability to respond to both wholesale and local renewable generation, maximizing self-reliance and minimizing grid related emissions	February 1, 2020 - April 30, 2020

Table 1: Project Test Phases

[10] PUSD was on PG&E's A-6 rate tariff for the duration of the pilot. The demand charge management strategy was implemented because the project team initially thought PUSD's EV meter would eventually switch to PG&E's A-10 rate tariff, which has a demand charge, once their fleet became large enough.

3 System Design

3.1 Introduction

The E-Fleet charge management system implemented at PUSD was designed to support a multitude of use cases. The system demonstrated the ability of a single cloud-connected Liberty PlugIns HYDRA-RX charger controller to enable the control of lower-cost, non-networked chargers. Olivine DER™ implemented charge control algorithms to provide bill management and emissions reduction. Many different data sources and systems were integrated into Olivine DER™ in order to achieve system awareness to inform charge control. Each system component was designed to minimize cost and leverage existing infrastructure where possible. Olivine DER™ executed load shift to the off-peak time-of-use (TOU) period, round-robin charging to minimize peak demand, RSC, and load shift to oversupply during XSP events. For future use cases, Olivine DER™ also enables wholesale market participation.

3.2 Communications and Metering

Olivine worked with project partners to deploy new system components such as the Rainforest Automation EAGLE-200, the Liberty PlugIns HYDRA-RX charger controller, and Geotab devices on new electric buses while leveraging existing system components such as PG&E's two utility meters. Table 2 describes the purpose of each system component and how the data provided by each component was utilized to accomplish the project objectives. Figure 2 displays the data and power flows between the system components and infrastructure deployed at PUSD.

System Component	Purpose	Data Usage
Liberty PlugIns HYDRA-RX Charger Controller	Enables control of non-networked chargers via the cloud, leveraging the OpenADR standard; Provides real-time energy usage data for each charger	Charger energy data is an input to the smart charging algorithm and GHG emissions calculations and is visualized in the E-Fleet User Interface
Rainforest Automation EAGLE-200	Via a Zigbee connection to the smart meter, provides real-time facility meter data	Facility meter data is an input to the RSC algorithm

PG&E Utility Meters (Facility and EV)	Provides interval meter data for facility and EV utility meters	Meter data is an input to the RSC algorithm and XSP performance calculations
Geotab Bus Telemetry Devices	Provides trip data such as distance, start time, and stop time and provides bus location data	Telemetry data is an input to the smart charging algorithm and GHG emissions calculations

Table 2: Communication and Metering System Components

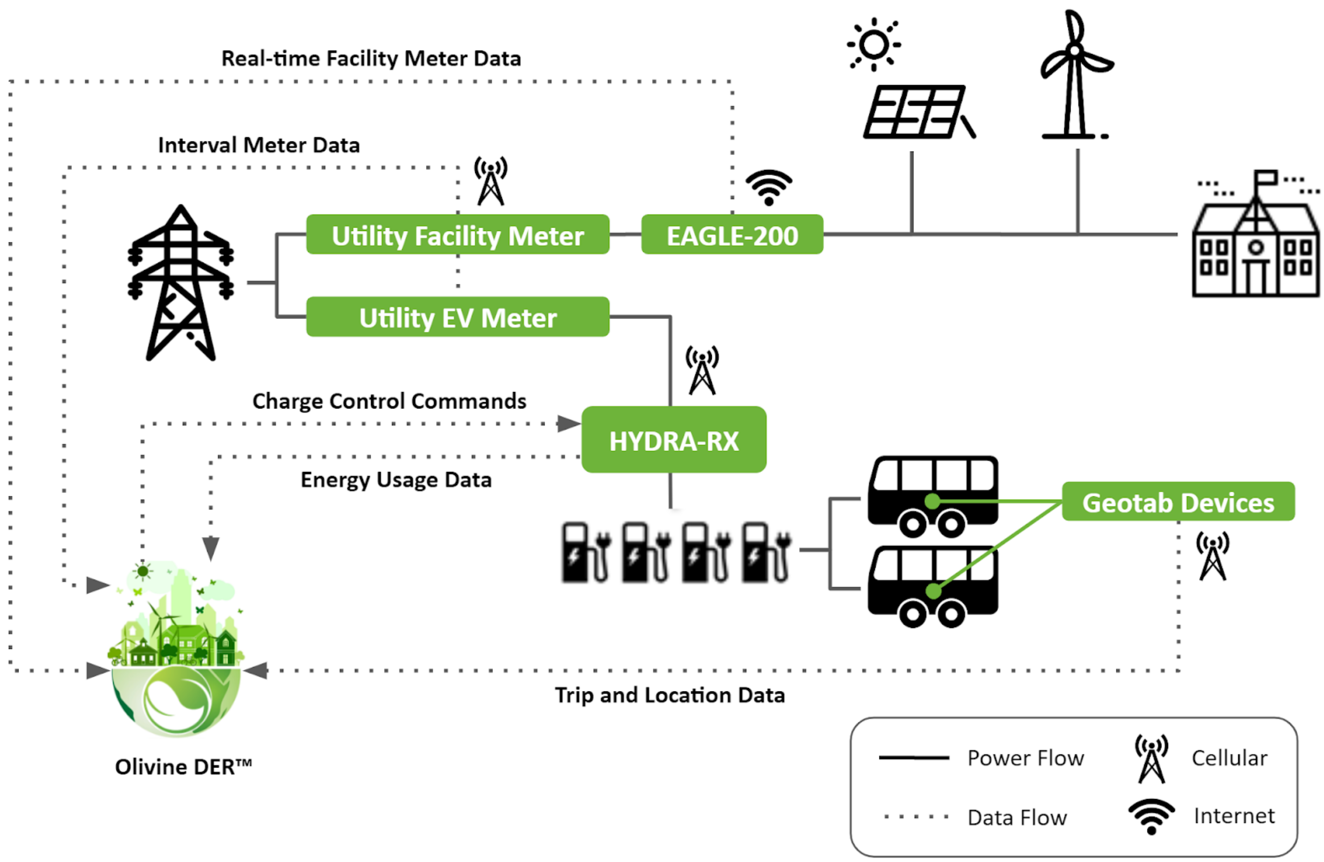

Figure 2: Communications and Metering Diagram

3.3 E-Fleet User Interface

Olivine developed a web-based E-Fleet User Interface (UI) for PUSD to help them better manage their electric bus fleet. The E-Fleet UI supports day-to-day operations of the E-fleet by providing engaging informational displays about bus charging activity, GHG emissions performance, and amount of exports to the electrical grid from the on-site renewables.

As shown in Figures 3 and 4, the E-Fleet UI Dashboard page contains ‘Site Energy’, ‘Current Fleet Activity’, and ‘Greenhouse Gas Performance’ panels. The ‘Site Energy’ panel displays the daily amount of energy exported to the grid by the renewables against the daily amount of energy utilized to charge the E-fleet. The ‘Current Fleet Activity’ panel displays the current charge rate of every active bus. The ‘Greenhouse Gas Performance’ panel displays the amount of GHG emissions corresponding to charging the E-fleet against avoided emissions from a comparable diesel fleet with the same utilization.

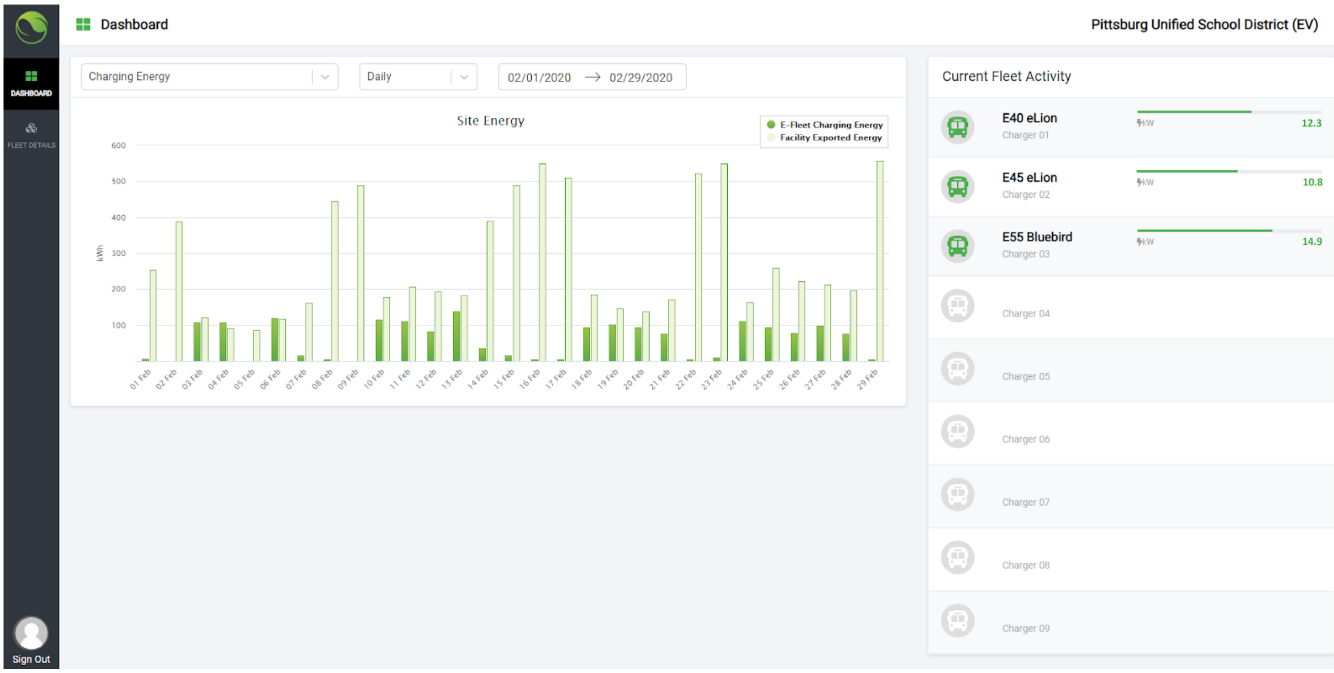

Figure 3: E-Fleet User Interface Dashboard – Charging Energy

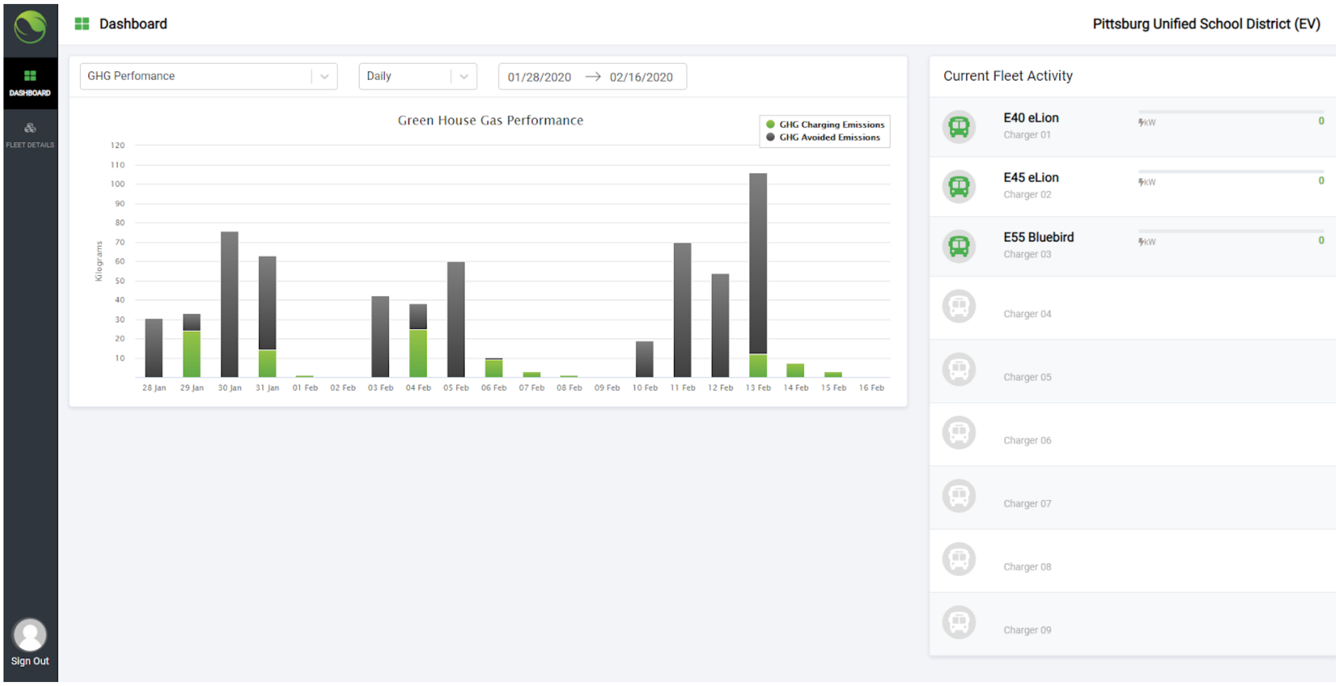

Figure 4: E-Fleet User Interface Dashboard - Greenhouse Gas (GHG) Performance

4 Optimization Methodologies

4.1 Introduction

The E-Fleet charge management system deployed at PUSD ingests multiple data streams to provide operational insights and enable optimized charge management. In addition to scheduling charging around TOU rates and minimizing demand charges, the system monitors on-site renewable generation and controls charging in real time to implement renewable self-consumption under PG&E's NEM2A program. The E-Fleet charge management system also enables the electric buses to provide grid services through participation in PG&E's XSP demand response (DR) program.

The project team experienced significant challenges with controlling charging of both the Lion and Blue Bird buses. Olivine worked closely with Liberty PlugIns and ClipperCreek to develop an EVSE solution to this issue for the Lion buses, but unfortunately this solution did not work for the Blue Bird buses. With no viable solution on the EVSE side, Olivine worked closely with Blue Bird and the drivetrain manufacturer, Cummins, for a solution on the vehicle side, but the manufacturers were unable to roll out a solution in the timeline of this project. Without the ability to control charging, the chargers paired to the Blue Bird buses were always scheduled on. These challenges and efforts to develop solutions are discussed further in the Lessons Learned section below.

4.2 Time-of-Use (TOU) Optimization

For the duration of the project, PUSD's EV utility meter was on PG&E's A-6 rate tariff[11] which abides by a TOU schedule, meaning energy prices vary based on whether the consumption occurs during peak, part-peak, or off-peak periods. The E-fleet charge management system shifts charging from the middle of the day to the nighttime off-peak TOU period (9:30 PM to 8:30 AM) to take advantage of the lower energy rate.

4.3 Demand Charge Management Via Round-robin Charging

Minimizing peak demand was another important factor in the development of the charging schedule. The demand charge management strategy was implemented because the project team initially thought PUSD's EV meter would eventually switch to PG&E's A-10 rate tariff, which has a demand charge, once their fleet became large enough. While PUSD did not end up having enough buses to exceed the

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[11] "Electric Schedule A-6." Tariffs: Electric Rate Schedules, Pacific Gas & Electric, www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_A-6.pdf.

A-10 threshold during the pilot, this element of the schedule design will be valuable if PUSD switches to a different rate tariff with a demand or subscription charge, like PG&E's BEV rate, in the future. The ClipperCreek chargers can only charge at discrete levels, so they are either completely on or completely off with the exception of chargers 1 and 2 that were modified to provide a low-power maintenance mode for the Lion buses, which is discussed further in the Lessons Learned section below. With this constraint in mind, a round-robin approach was implemented.

Round-robin charging is the act of charging buses in alternating intervals in order to limit the number of chargers that are on simultaneously. During the pilot, only the two Lion buses were capable of charge control. As such, the round-robin charging alternated between chargers 1 and 2 in 30-min intervals. Contrast this strategy with a non-optimized schedule, also known as unmanaged charging, where all buses charge at the same time, causing a spike in the demand. The alternating schedule is also superior to a sequential schedule where each bus is fully charged before transitioning to charge the next bus, because it ensures that the fleet will charge more evenly. If any issues arise during the charging, the round-robin strategy minimizes the likelihood any bus is left in a low charge state. Round-robin charging only occurs Sunday nights through Thursday nights, because the buses are only dispatched on the weekdays.

Figure 5 displays the start of the round-robin nighttime charging schedules for chargers 1 and 2. Charger 1 is on from 9:30 - 10 PM and then charger 2 is on from 10 - 10:30 PM with the pattern continuing throughout the off-peak TOU period. The round-robin technique easily scales to larger fleets by either increasing the number of buses that are on simultaneously or by extending the window of round-robin charging. The E-fleet charge management system designs the schedule based on the fleet's energy requirements, ensuring all of the buses are fully charged by morning dispatch while minimizing the number of buses on simultaneously.

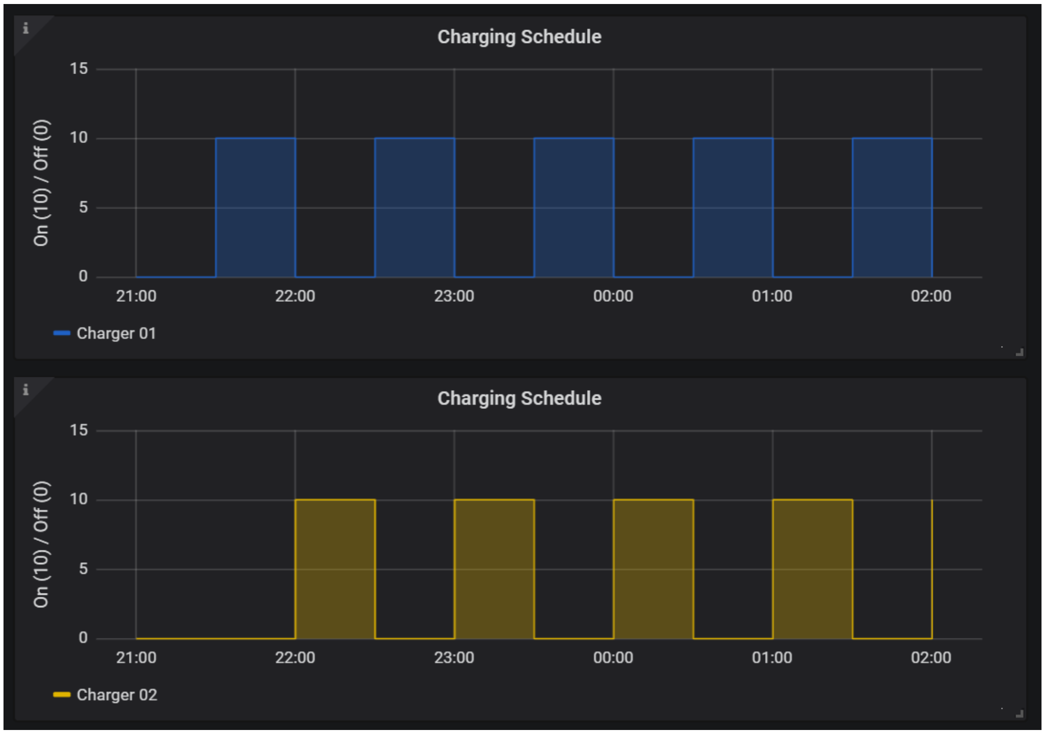

Figure 5: Round-robin Charging Schedule for Two Chargers

4.4 Participation in Pacific Gas & Electric's (PG&E) Excess Supply Pilot (XSP)

California is rapidly making the transition towards a low-carbon electric grid. This transformation and the rise of renewables, particularly solar, presents new challenges for grid operators. One challenge is the potential for oversupply of renewable generation in the middle of the day. The two dominant tools in the California Independent System Operator's (CAISO) toolbox that exist today to mitigate oversupply conditions include curtailing renewables or exporting them using the real time energy market, the Energy Imbalance Market (EIM). PG&E's XSP[12] serves to test a potential tool to address these integration challenges by assessing the ability of demand response participants to increase their loads above typical use in response to periods of over-supply.

As part of this pilot, participation in the XSP was identified as a means of gaining insight into how medium and heavy-duty fleet vehicles can act as distributed energy resources during periods of high renewable penetration and how to adapt charging schedules to better align with renewable generation. PUSD's electric buses were aggregated to create a single dispatchable resource. The resource was available to be dispatched 7-days a week, with the restriction that during weekdays, the availability

[12] "PG&E Excess Supply Pilot." Olivine, Inc, www.olivineinc.com/services/our-work/xsp/.

hours were between 9am-1pm. During XSP events, the E-fleet charge management system scheduled all the chargers to turn on for the entire duration of the event to increase the overall site load. The resource's monthly nomination quantity, a predefined target capacity value, for the XSP was initially 30 kW and was later reduced to 8 kW. The nomination was adjusted to account for the team's better understanding of the electric bus aggregation's capabilities and the Lion's lower utilization, as discussed in later sections. School districts may benefit from adjusting the XSP nomination quantity to match varying bus utilization throughout the school year.

PUSD was granted modifications on some of the participation requirements because the standard XSP participation requirements would have been infeasible due to the operational needs of the electric school buses. The first modification allowed PUSD to nominate a capacity below the minimum required capacity of 30 kW. The second modification reduced the availability hours from a 5-hour contiguous block to a 4-hour contiguous block to accommodate the operational needs of the E-buses.

For event days, dispatches would be delivered on a day-ahead basis to mimic the timeline for participation in the CAISO day-ahead energy market. Load increase event performance was calculated using the well-established 10-in-10 CAISO Type 1 baseline methodology[13] which is also used by traditional demand response.

4.5 Performing Renewable Self-Consumption (RSC)

Renewable-self consumption (RSC) was implemented in this pilot to leverage PUSD's recently installed on-site renewables. During test phases 3 and 4 of the pilot, PUSD performed coincident RSC, meaning the buses were scheduled to charge when the renewables were exporting to the grid above a predefined threshold. The school district's goals of showcasing emissions reduction and energy self-reliance motivated the decision to perform coincident RSC as opposed to non-coincident RSC. The E-Fleet charge management system continuously monitored the real-time facility meter data and commanded chargers to turn on when the on-site renewables exported energy to the electrical grid. The number of chargers commanded to charge depended on the rate of renewables export to the grid.

[13] The CAISO Type 1 methodology is based on the North American Energy Standards Board (NAESB) Baseline Type-I methodology which is described in the NAESB WEQ Business Practice Standards WEQ-015, Measurement and Verification of Wholesale Electricity Demand Response. The basis for a Type 1 methodology is that it uses historical whole-premises data to determine a counterfactual of expected usage outside of the DR event.

To distribute bill credits for excess generation to both the facility and EV meters, PUSD participated in PG&E's NEM2A program[14]. NEM2A allows a customer to utilize excess generation from a qualified resource and apply that excess generation credit proportionally across multiple meters that are either on the same property or adjacent properties. Figure 6 and the following numbered descriptions describe an example of the Lion bus E45 performing RSC at PUSD.

Figure 6: Example of PUSD Performing Renewable Self-Consumption

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[14] "Net Energy Metering Aggregation Overview." Understand Net Energy Metering Aggregation, Pacific Gas & Electric, www.pge.com/en_US/for-our-business-partners/interconnection-renewables/net-energy-metering/nem-aggregation.page.

1. The Lion electric bus E45 drove about 55 kilometers on an afternoon route.
2. The renewable energy generation exceeded the energy required by the facility from about 10:30 AM to 4:30 PM, so the excess energy was exported to the electrical grid.
3. Olivine's RSC algorithm automatically detected that the facility was exporting excess energy and scheduled the charger on.
4. When the Lion electric bus E45 arrived back from its afternoon route, it was plugged into charger 2 and immediately started charging due to the RSC charging commands. Typically, the bus would not charge during this time of day due to the higher energy prices.
5. Shortly after the facility stopped exporting excess energy to the electrical grid, the RSC algorithm stopped charging, delaying the remaining charging to the evening off-peak TOU period when the price of energy is lower.
6. When the TOU period switched to off-peak, the E-Fleet charge management system automatically turned the chargers back on with the typical round-robin nighttime schedule.
7. Throughout the night, the Lion E45 bus continued to charge on a round-robin schedule until its battery was full.

5 Environmental Impacts

5.1 Observed Pilot Impacts

PUSD's electrification efforts are rooted in a desire to reduce pollution and GHG emissions. Figure 7 displays the GHG emissions during pilot test phase 1 (May 1, 2019 through May 31, 2019). The 'Charging Emissions' are the GHG emissions corresponding to charging the electric buses at PUSD. The 'Avoided Emissions' is the difference between the equivalent diesel emissions and the 'Charging Emissions', i.e. the amount of emissions PUSD reduced each day from utilizing their electric buses instead of diesel buses. During test phase 1, PUSD had two Lion buses, but only one was utilized regularly. As the E-Bus utilization increases and their fleet grows, the avoided emissions will increase.

The observed charging emissions shown in Figure 7 were calculated with the EV utility meter data and average hourly emission rates from the California Public Utilities Commission's (CPUC) 2019 Avoided Cost Calculator (ACC) Electric Model[15]. The avoided emissions in Figure 7 were calculated using the Geotab trip distances, an average of the quarterly diesel fuel efficiencies published in the U.S. Department of Energy's (DOE) Case Study - Propane School Bus Fleets[16], and a diesel emissions rate published by the U.S. Environmental Protection Agency's (EPA) Office and Transportation and Air Quality[17].

Note that the diesel emissions occur at different times than charging emissions for the same bus service, because the diesel emissions occur during the trips, while charging emissions occur before and after trips. As such, Figure 7 displays the avoided emissions only on days where the buses ran routes.

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[15] "ACC Electric Model." Cost Effectiveness, California Public Utilities Commission, www.cpuc.ca.gov/General.aspx?id=5267.

[16] "Case Study - Propane School Bus Fleets." Alternative Fuels Data Center, US DOE: Energy Efficiency and Renewable Energy, afdc.energy.gov/files/u/publication/case-study-propane-school-bus-fleets.pdf.

[17] "Greenhouse Gas Emissions from a Typical Passenger Vehicle." EPA: National Service Center for Environmental Publications (NSCEP), Environmental Protection Agency, nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100U8YT.pdf.

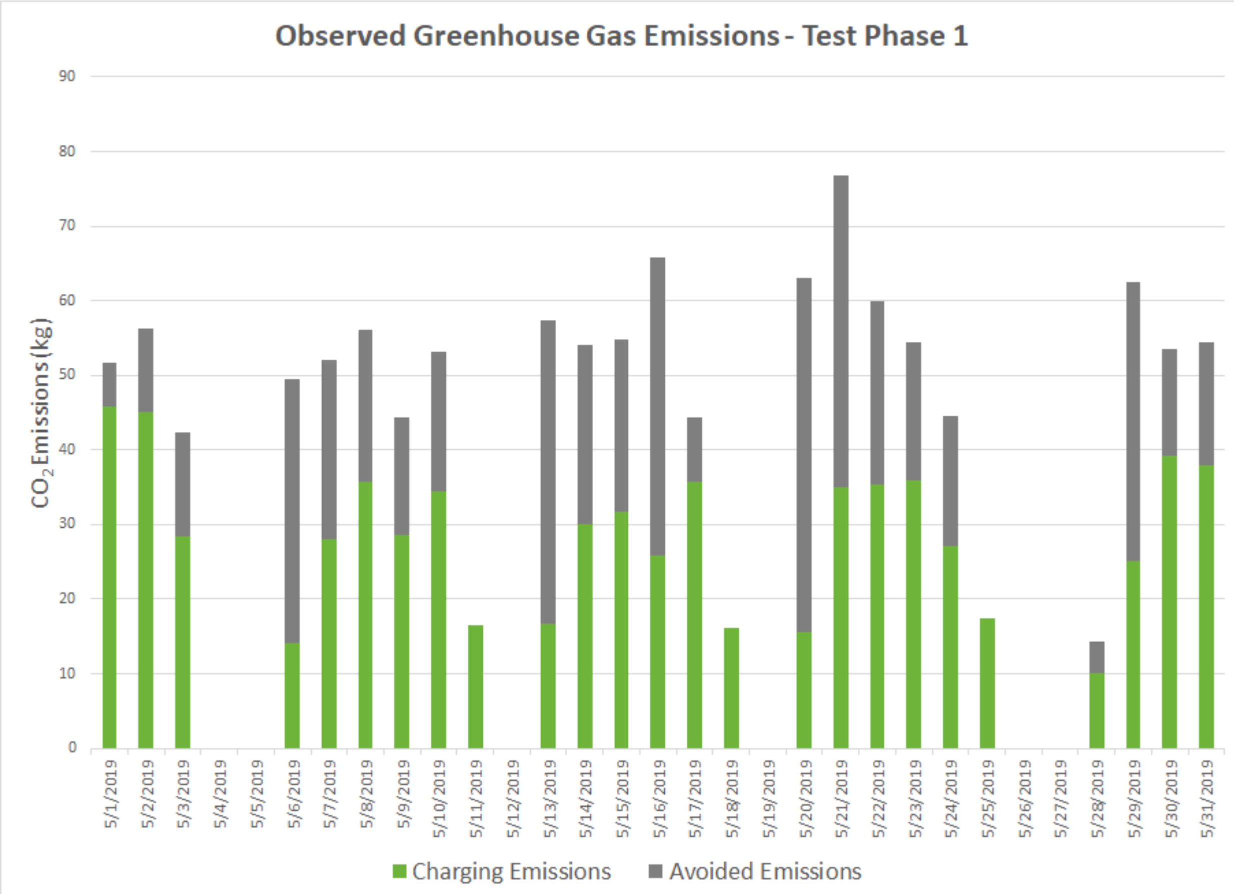

Figure 7: Observed GHG Emissions - Test Phase 1

5.2 Modeled Pilot Impacts

The low bus utilization and inability to control the charging of the Blue Bird buses made it difficult to fully execute the various use cases, especially in the later test phases. To fully capture the environmental and financial impacts of the use cases, PG&E developed a model of four electric buses at PUSD for test phases 3 and 4. Energy and operational model parameters were determined based on analyzing Hydra meter data and Geotab trip data. PG&E created two versions of the model, one where charging is optimized for PUSD's current A-6 rate tariff and the other for PG&E's new Commercial Battery Electric Vehicle (BEV) rate tariff[18]. The charging strategies in the A-6 model version reflect what was implemented at PUSD during the pilot, whereas the optimization for the BEV model charges quite

[18] "Electric Schedule BEV." Tariffs: Electric Rate Schedules, Pacific Gas & Electric, www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_BEV.pdf.

differently due to the introduction of a midday super off-peak period as well as the concept of a subscription charge.

Figure 8 displays the monthly modeled GHG emissions under the different rate tariffs compared to the equivalent diesel emissions. The modeled emissions were calculated using the same methodology as the observed emissions except the modeled energy needs and miles driven were used in place of the observed data.

The BEV model charging emissions were lower than the A-6 model charging emissions for eight of the nine modeled months, because more midday charging occurred during the super off-peak TOU period in the BEV model version than in the A-6 model version. The average hourly emissions rates are lower during the middle of the day, as there is more solar generation on the electrical grid than at night.

The emissions difference between the A-6 model and the BEV model was small because the fleet was responding to frequent RSC charge commands during the middle of the day in the A-6 model. The A-6 rate tariff does not have a demand or subscription charge, so when export was sufficient, all four buses could charge simultaneously without peak demand concerns. However, the BEV rate tariff has a subscription charge, so the model restricted simultaneous charging to two buses at all times.

If PUSD wanted to lower their emissions further while on the BEV rate, they could increase their subscription charge and charge more buses simultaneously, shifting more energy consumption from the nighttime to midday. If PUSD did not perform RSC and instead charged all their buses at night, the difference between the A-6 modeled emissions and the BEV modeled emissions would have been much greater.

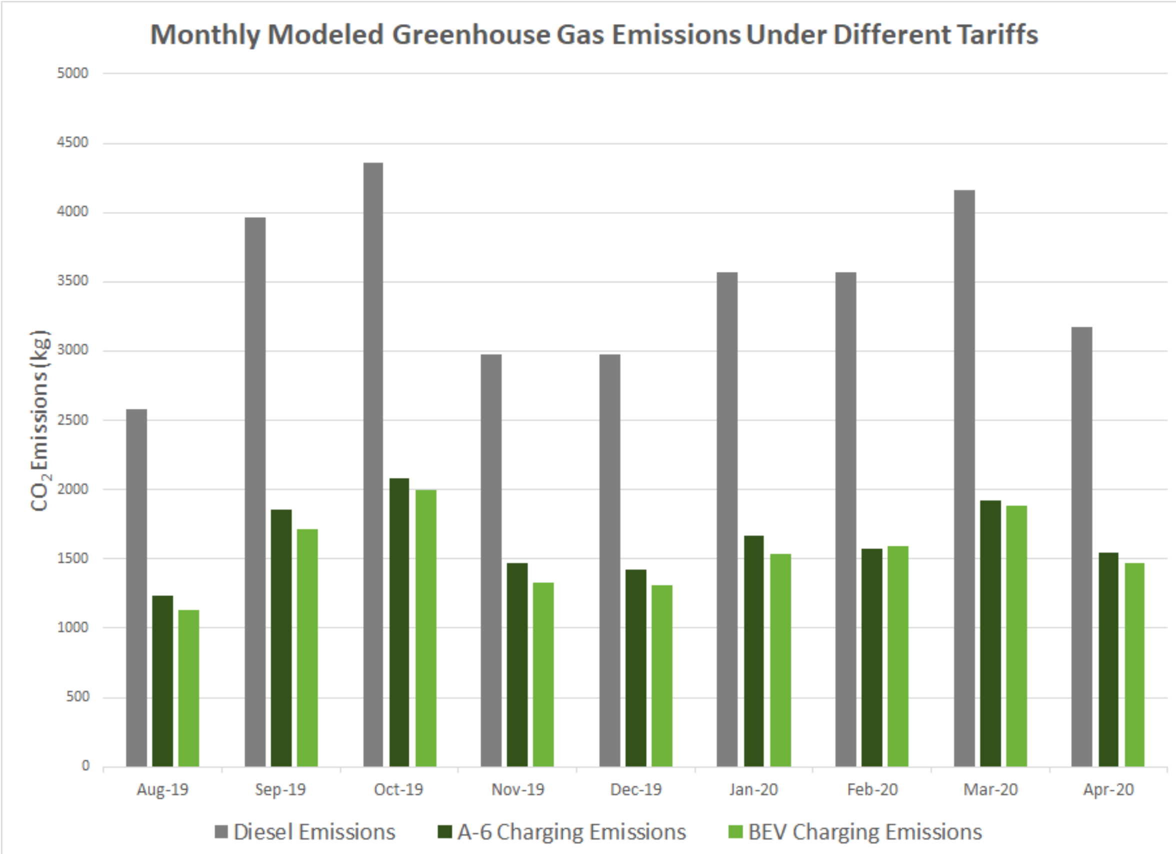

Figure 8: Monthly Modeled GHG Emissions Under Different Tariffs

6 Successful Pilot Outcomes

The pilot demonstrated several accomplishments that directly align with the initial project goals outlined in the scope of work. These accomplishments were achieved despite encountering the inevitable challenges that come with the deployment of new and innovative technologies such as electric school buses. Table 3 lists some of the pilot accomplishments, identifies the specific pilot goal they relate to, and describes how each accomplishment provides value to future school bus electrification projects.

Pilot Goal	Successful Outcome	Value to Future School Bus Electrification Projects
Reduce the total cost of ownership by minimizing infrastructure costs	Implemented a low-cost EVSE charging solution to support pilot use cases	Validated that a low-cost, configurable EVSE solution can meet the charge control needs of school districts and support sophisticated use cases
Reduce the total cost of ownership by minimizing fuel costs	Shifted Lion buses' charging to the off-peak TOU period	Implemented two charging techniques that can easily be replicated at other school districts to minimize their utility bills
	Demonstrated round-robin charging to manage demand and subscription charges	
Inform how medium and heavy-duty fleet vehicles can act as distributed energy resources during periods of high renewable penetration	Performed real-time RSC	Identified key lessons learned for integrating EVs with on-site renewables that can be disseminated to other school districts
	Participated in PG&E's XSP, receiving 55 total dispatches for load increase events	Demonstrated E-Fleets with consistent and frequent utilization can provide value to the electrical grid as a distributed energy resource and paved the way for other school

		districts to participate in similar programs
Additional Accomplishments	Developed an E-Fleet UI for fleet managers	Identified low-cost ways to collect and utilize data from multiple sources for both fleet managers and for more data-minded operations that can be leveraged in other medium and heavy-duty projects
	Developed an operations dashboard to provide data rich visuals from which to monitor the system and gain operational insights	

Table 3: Successful Pilot Outcomes

7 Lessons Learned

7.1 Non-Networked Chargers Can Provide Bill Management via Centralized Charge Control

A key lesson learned is that non-networked chargers paired with a centralized charge control system with communications can achieve sophisticated charge control, including bill management and emissions reduction. When paired with other sources of data and infrastructure already in place, the system can provide rich feature and data sets for districts. This learning suggests an alternative, lower cost path for school districts to manage their E-Fleet charging needs, as opposed to ensuring each charger itself is networked.

7.2 Electric School Buses are Not Designed to Handle Charge Control

The project team experienced significant challenges controlling charging of both the Lion and Blue Bird buses that impacted the project's ability to fully perform use cases such as participation in PG&E's XSP and performing RSC. A key design element to keep things easy for the school district is that the buses should always be plugged in when not on routes, and the E-Fleet charge management system should automatically manage the charging. As previously described in the Optimization Methodologies section, the chargers are scheduled off during the day (except for RSC and XSP periods) and do not turn on until the round-robin charging during the off-peak TOU period starts at 9:30 PM. However, both the Lion and Blue Bird buses are designed to shut down their battery management systems (BMS) within a factory specified number of minutes of being plugged in if they do not receive any charge. The BMS does not turn back on unless the charge cable is unplugged and replugged or the bus driver starts the bus. While the BMS is off, the bus will not accept any power from the chargers. Thus, if a driver arrives back from an afternoon route and plugs the bus in while the charger is scheduled off, the bus will turn off and not accept any energy when the charger turns on at 9:30 PM.

Olivine worked closely with Liberty PlugIns and ClipperCreek to develop a work around to this issue for the Lion buses that involves charging the buses on a low-power maintenance mode when the charger is scheduled off to prevent the bus from falling asleep. Once scheduled on, the charger provides full power to the bus. This work around enabled Olivine to shift a majority of the Lion bus's charging to the off-peak TOU period and ensured the buses will respond to RSC and XSP charge commands given they have battery capacity.

Olivine tried implementing the same work around on the Blue Birds, but the low-power maintenance mode did not prevent the Blue Bird from shutting down. With no viable work around on the EVSE side, Olivine worked closely with Blue Bird and the drivetrain manufacturer, Cummins, to find a solution on the vehicle side. Despite significant engagement from Olivine, PG&E, and other school districts experiencing similar issues, Blue Bird and Cummins were unable to roll out a solution in the timeline of this project. Without the ability to control charging, the chargers paired to the Blue Bird buses were always scheduled on. Therefore, the Blue Bird buses charged as soon as they were plugged in after morning and afternoon routes, which was typically during peak or part-peak TOU periods, and were unable to participate in XSP or respond to RSC commands.

Through working with bus original equipment manufacturers (OEMs) to develop solutions, it became apparent that they had not prioritized charge management in the design of these electric buses. It is important to note that these charge control issues originate in the bus, not the charging infrastructure. It is likely the project team would have faced the same challenges if any other EVSE charging solution was deployed. The Olivine team has learned of similar challenges from other medium and heavy-duty charge control projects. The project team hopes that their efforts to shed light on these issues and communicate the importance of designing systems that can accommodate charge management will motivate OEMs to prioritize this functionality in the future, thereby making electric bus energy costs manageable for school districts.

7.3 Low Bus Utilization Limits Emissions Reduction Opportunities

Several pilot test phases were impacted by low utilization of the buses due to unforeseen maintenance needs and bus driver shortages. The Lion and Blue Bird buses were both out-of-service for significant periods of time during the pilot due to unforeseen maintenance needs. In addition to long out-of-service periods, PUSD had a shortage of bus drivers throughout the pilot and had to utilize buses with the highest seat counts to ensure all students could be transported to school. The Lion buses could not hold as many passengers as the Blue Bird and diesel-engine buses, which resulted in significantly lower utilization due to the driver availability constraints. Lastly, PUSD stopped utilizing the E-Fleet in mid-March (test phase 4) because the school district transitioned to distance learning due to COVID and students no longer required transportation to school.

When the buses are not utilized regularly, their batteries stay fully charged and are unable to respond to RSC and XSP charge commands. This negatively impacted PUSD's XSP performance during test phase 4 and their ability to perform RSC throughout the pilot. The buses also use idle power for battery thermal management, battery top-up, and other needs. With lower utilization, this extra maintenance energy usage can become a more significant portion of the overall energy needs. Thus, the project finding is that the more electric miles driven, the more efficient the electric bus energy utilization becomes, and emissions reductions can be maximized.

7.4 Buses Can Perform for XSP During Periods of High Utilization

The pilot demonstrated, through participation in PG&E's XSP during test phase 2, that consistently utilized E-Fleets have the potential to become a valuable resource to the electrical grid during periods of high renewable penetration. Over the course of the pilot, Olivine dispatched 55 XSP events, totaling 109 event hours. During test phase 2, the Lion buses were utilized regularly, which enabled the resource to increase its load relative to the baseline in 41 of the 57 event hours, averaging a 5.15 kW increase in load across all event hours. Note that the XSP performance during Phase 4 showed that underutilized E-Fleets are not able to provide the same value to the electrical grid during periods of high renewable penetration.

Figure 9 provides an example of the event day load compared to the baseline for a 2-hour long XSP event on October 9, 2019 from 11 AM to 1 PM. The ability of the E-fleet to respond to a dispatch signal for the entire duration of the event (yellow) is clear by the large difference between the load and the baseline. Extending the pilot XSP results from two buses to larger fleets and higher utilization, the project team believes that electric school bus fleets can provide meaningful load increase for excess supply management programs, such as XSP.

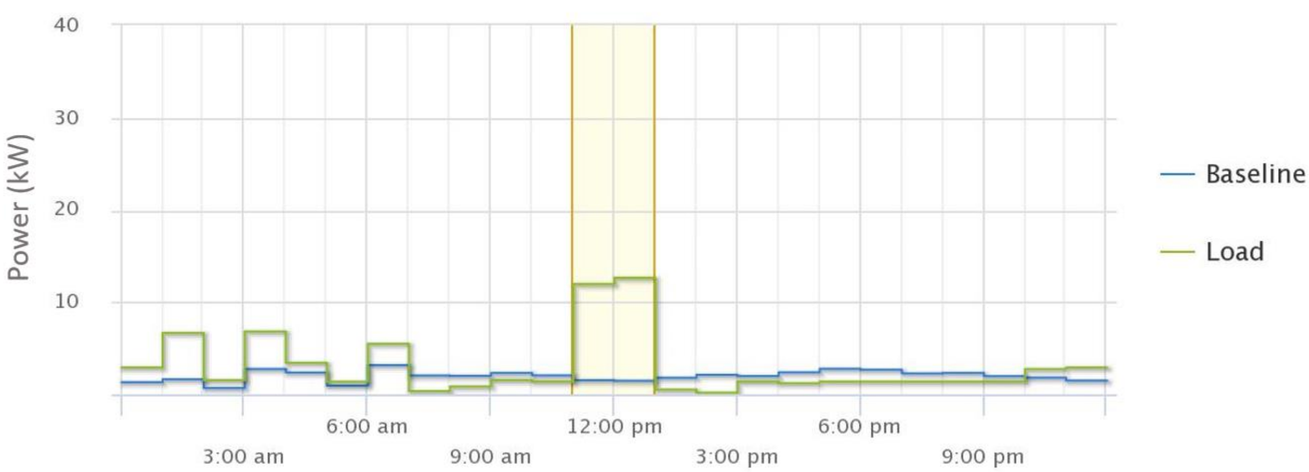

Figure 9: PUSD's XSP Event Performance on October 9, 2019 11 AM – 1 PM

7.5 PG&E's Commercial Battery Electric Vehicle (BEV) Tariff Enables Cooptimization of Bill Management and Emissions Reductions

Through modeling and implementation of the test phases, the project team determined PG&E's BEV rate tariff is more compatible with the NEM2A program because it allows PUSD to simultaneously minimize both greenhouse gas emissions and their utility bill. It also avoids costly grid upgrades and reduces the cost of electricity supply while aligning charging with periods of clean, low-cost energy. To minimize the utility bill on PG&E's A-6 rate tariff, the buses should prioritize charge during the nighttime off-peak period when electricity costs are lowest. PUSD would then be compensated for any remaining peak and part-peak credits accrued on the EV meter under NEM2A at their corresponding TOU rates at the yearly true-up. However, to minimize the GHG emissions, the buses should charge when renewable penetration on the grid is highest, which is typically during the middle of the day when A-6 rates are highest. Under the BEV rate, PUSD would not have to choose between minimizing the utility bill and minimizing GHG emissions, because the BEV tariff has a super off-peak TOU period from 4:00 AM to 2 PM and an off-peak TOU period from 2 to 4 PM (as well as from 9 PM to 9 AM). About 95 percent of the RSC charge commands issued during the pilot were during these super off-peak and the off-peak periods.

7.6 Fleet Tracking Solutions May Not Provide E-Bus Specific Data

Olivine worked closely with bus OEMs, drivetrain manufacturers, vehicle tracking providers, and the school district to access and utilize bus telematics data. The project team learned that Lion did not have telematics data and Blue Bird did not share telematics data with third parties. Instead, Olivine was able to leverage PUSD's existing fleet tracking solution (Geotab) for basic vehicle telematics such as trip distance and bus location. Olivine integrated with Geotab's systems to access this bus telematics data.

The Geotab telematics data was tailored towards diesel-engine buses and did not provide E-bus specific telematics data such as state of energy (SOE) and charge connector status. Access to E-bus specific telematics data would provide a more accurate picture of each bus's state, allowing the E-Fleet charge management system to make more informed charging commands. Olivine worked directly with Geotab throughout the pilot to support the development of functionality to collect E-bus specific telematics data. Olivine deployed Geotab's engineering data loggers on both the Lion and Blue Bird buses to facilitate the reverse engineering of this E-bus specific telematics data. While this functionality was not developed in the timeline of this pilot, the project team encourages Geotab to continue this effort to ensure E-bus telematics data will be available to PUSD and other school districts in the future.

8 Recommendations for Future School Bus Electrification Projects

8.1 Develop a Project Plan and Strong Project Team

Deploying electric school buses can be a significant undertaking for districts with limited staff to support the transition. Leveraging technology and hardware partners and having EV charge management expertise on the team that can deploy intelligent, automated E-Fleet charge management systems and software is key to success. Recommendations from this project team include planning for the possibility of unplanned out-of-service periods for bus maintenance as the industry improves electric bus design and reliability. The electric buses may not be a one for one replacement for their existing fleet. Thus, the buses could initially experience low utilization as school districts adjust operations, routes, drivers, etc. The project team should also engage with the local utility interconnection team early in the process to develop an understanding of the interconnection timeline and requirements, especially if integrating with on-site renewables or if installing a dedicated EV meter.

8.2 Ensure Bus Size and Functionality Support District Goals

With the ever-growing variety of electric bus manufacturers and sizes, bus selection can be critical in maximizing vehicle utilization. Ensure the bus size (number of passengers) meets the needs of the school district and is compatible with the school district's driver availability. Perhaps most importantly, school districts need to insist that the buses be capable of managed charging. Prior to purchasing any buses, districts should explicitly confirm with the bus manufacturer that the bus model is capable of the level of controlled charging desired. This project revealed electric bus OEMs have not made controlled charging a priority.

8.3 Consider a Low-cost Configurable EVSE Solution

A key recommendation from this project is that school districts can and should consider a low-cost, configurable EVSE solution such as non-networked chargers paired with a single networked charger controller to manage charging as opposed to the more expensive approach of utilizing all networked chargers. This project showed a low-cost, configurable solution can meet the charge control needs of the school district and can support a variety of use cases. Note while this type of EVSE solution can achieve similar control to a more expensive networked charger solution, it may require more integration and coordination between software and hardware system providers.

8.4 Select a Utility Rate that Incentivizes Midday Charging

For most school bus fleet utilization patterns, the BEV rate tariff should be considered (or a similar tariff that incentivizes midday charging). In California and other areas that have large solar portfolios, charging the E-fleet during the middle of the day as opposed to at night typically results in lower GHG emissions because of the high-penetration of solar energy on the electrical grid. If the project wants to leverage on-site renewables, this tariff design makes integration easier because the buses charging schedule will align with most of the renewable generation.

8.5 Leveraging Existing Metering and Data Collection Infrastructure

Districts should leverage existing technology and infrastructure to control costs while extending functionality. As shown in this project, districts can leverage any existing fleet telematics system, such as Geotab, to gain access to bus telematics data to provide operational insights to the E-Fleet charge management system. Smart meters can be paired with additional hardware to provide real time energy data. Charge control systems like the Hydra can also provide more granular metering. Eventually, fleet telematics systems and electric bus manufacturers may be able to provide E-bus specific data.