California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

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

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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 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 that was proposed for funding in the CEC's notice of proposed awards April 8, 2021. 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. The Center for Transportation and the Environment partnered with The Mobility House and Sage Energy Consulting (Sage) to complete the analyses. These analyses 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. 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 project team found that use of a charge management system provided significant savings by limiting charging spikes and avoiding high demand charges. Furthermore, photovoltaic and battery energy storage systems under net energy metering 3.0 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 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 bidirectional 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

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EXECUTIVE SUMMARY

School bus fleet electrification is proceeding rapidly with more than 24,000 school buses in California. The transition to an all-electric fleet can be complex and challenging for many school districts unsure of which technology and equipment their districts need. This final report 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 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, a technology company whose goal is to drive the transition to sustainable energy sources, 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, an energy consulting company focused on energy savings and decarbonization, 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. Net Energy Metering 2.0 and 3.0 are billing mechanisms that allow consumers to sell the excess electricity that they produce for credits towards their electric bill.

The project team consists of:

- The Center for Transportation and the Environment: As the project lead, the Center for Transportation and the Environment managed the work and compiled the analysis into the final report.
- The Mobility House: The Mobility House defined 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 in California's Central Valley. The district has added 11 electric school buses to its fleet and operates 111 buses that serve 55 schools.

The primary project goal 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 project objectives 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 value will be measured against a scenario without using vehicle-to-grid energy transfer.

The project team made the following conclusions:

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, ongoing costs for alternating current charging are 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, a computerized control system in charge of regulating the flow of electricity, 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 (PV) 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 the 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 (V2G) charging can produce revenue, but it is unclear if this revenue 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 situation in the future.

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 and Electric Company’s (PG&E) 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 PG&E 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.
- V2G 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 5 to 10 years and vehicle-to-grid use should continue to be researched as policies and technology change.

CHAPTER 1: Introduction

Project Background

In 2021, the California Energy Commission (CEC) awarded funding to the Center for Transportation and the Environment (CTE) to analyze the lowest way to charge electric school buses (ESB) for Stockton Unified School District (SUSD). The results were to develop a blueprint for SUSD that could be used by other school districts when planning for building infrastructure to support ESB deployments. CTE began work on the project in early 2022 with a goal of completing the work by the end of the calendar year. CTE enlisted the help of two contractors for the effort: The Mobility House and Sage Energy Consulting. These two contractors were tasked with using modeling tools to evaluate different scenarios to determine what might work for SUSD when optimizing its ESB project for cost. Options for cost savings included charge energy management, photovoltaic systems with battery storage, and vehicle to grid schemes to help manage grid demand. This report outlines the project, challenges, next steps, and recommendations for potential future analysis.

Project Team

Center for Transportation and the Environment

The Center for Transportation and the Environment (CTE) works to improve the health of the 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[1], helps clients plan and implement their transition to zero-emission transportation across light-, medium-, and heavy-duty applications.

Project Overview and Approach

This project was intended to support the analysis and design of the most cost-effective charging system to support a fully electric school bus fleet for SUSD. The proposed blueprint seeks to answer several questions that are critical to understand and support cost-effective widespread adoption of electric school buses. The blueprint is expected to promote the development of the most cost-effective infrastructure plan that considers all financial costs and benefits. Those costs and benefits include charging units (EVSE), installation costs, additional local PV generation or battery storage or both, alternative utility tariffs, lower Level 2 AC charging versus higher-capability Level 3 DC charging, as well as a combination of both.

The team conducted the following analyses to determine what technologies could be used cost-effectively, explore the effect of different electricity rates/tariffs, and eventually draw conclusions and recommendations for how a school district could effectively plan and build infrastructure to support a 100 percent ESB fleet.

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 + battery-electric storage system (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 kilowatt (kW) and 50 kW chargers
    a. Stationary bus
    b. Current operations at a 1:1 bus to charger ratio

[1] An NV5 Company is a provider of technology, conformity assessment, and consulting solutions for public and private sector clients supporting infrastructure, utility, and building assets and systems.

c. Current operations at a 2:1 bus to charger ratio

2. Analyze the minimum average export rate to provide net cost savings to SUSD under current operations

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. These analyses provided input into the results and recommendations for a lowest-cost charging scenario for SUSD that could be used by other districts.

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.

Task 1 sought to establish the lines of communication and procedures for implementing this Agreement. For Task 1, CTE completed the following:

- 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
- Presented findings and recommendations during the final meeting

Task 2 sought 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.

Task 3 sought 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 defined charging profiles for lowest-cost charging with AC and DC charging and 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.

Task 4 sought 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, San Joaquin Valley Clean Cities, World Resources Institute

(WRI), and AlphaStruxure. As a result of these stakeholder reviews, CTE summarized the overall findings for a nontechnical audience.

Task 5 sought to develop an initial and final project fact sheet that describes the CEC-funded project and 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 for Task 6. 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 California.

CHAPTER 2: SUSD Operating Scenarios and Constraints

The "Operating Scenarios and Constraints" document served as the technical foundation for the project. The document lays out the school district profile, vehicle operating requirements, available charging windows, and site diagrams. SUSD is a medium-sized school district in California's Central Valley. SUSD serves more than 36,000 students at 55 schools, providing regular school routes, special education routes, and extracurricular activities.

The district's fleet is composed of 46 full-size conventional buses, 56 short conventional buses, and 11 full-size ESBs for a total of 113 buses. The fleet is parked at one location in Stockton. SUSD has installed 24 chargers to service the ESB fleet: 20 BTC AC chargers at 16.8 kW and four DC fast chargers at 50 kW. The DC fast chargers are not compatible with the district's current ESB fleet; however it has four ABB fast chargers on order that can charge the ESBs.

Vehicle Operation

A total of 18 buses, including 11 ESBs, operate on morning and afternoon runs for SUSD's weekly regular service. 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. All routes have midday lay-over time that could be used for charging, if required to meet service. The district's weekly special education transportation service is serviced by 45 buses with 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. Although the special education routes are longer than the regular routes, each route has some time available for midday charging.

Charging Infrastructure

Costs to install electric charging infrastructure vary 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 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 does expect the broad trends to continue however, with AC charging being less expensive per bus and per kW than DC charging.

SUSD Transition Plans

SUSD’s 84 active buses are composed 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 (CEC), the San Joaquin Valley Air Pollution Control District, and utility rebates from PG&E. In all, SUSD secured $8.3 million for 11 electric school buses and charging infrastructure for 24 buses. The 11 ESBs were placed into service in August 2021. SUSD’s goal is to transition all the school district’s buses to ESBs. Based on SUSD’s replacement schedule it is feasible for the district to reach a 100 percent ESB fleet by 2034. SUSD is procuring additional ESBs as it works through its 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.

CHAPTER 3:
Lowest Cost ESB Charging for SUSD Analyses

This section summarizes the analyses conducted under the project.

CEM 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 analysis investigated three scenarios, including all AC chargers, all DC chargers, and a combination of AC and DC chargers.

The analysis showed that all charging options successfully charged the buses, and that charge management results in significant savings, making a CEM system worthwhile. This result 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-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 analyzed how self-consumption of PV energy would affect cost for AC charging only. The analysis looked at costs for each season. The results showed that CEM optimizing for self-consumption with a PV system can save roughly 45 percent in the summer and up to roughly 60 percent during the fall.

Distributed Energy Resources: PV and BESS

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.

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.

The financial feasibility analysis assessed both cash purchase and third-party power purchase agreement (PPA) financing. 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 alone 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 ongoing cost of BESS. BESS typically provides 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 able to provide only savings through energy arbitrage.

Sage conducted a subsequent analysis to look at charging the buses on the PG&E BEV-2-S tariff using CEM to optimize for self-consumption of PV generation. The analysis findings show that optimizing bus charging when PV is available improves the value of PV and benefits SUSD.

V2G Revenue 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 AC and DC chargers under three scenarios. Sage took a bottom-up approach to analyze the minimum average export rate needed to provide net cost savings to SUSD under current operations.

V2G Revenue, Profit, and Cost for SUSD Using a Day-Ahead Real-Time Pricing Tariff for AC and DC Chargers

The TMH analysis used a "day-ahead hourly real-time pricing" (DAHRTP) rate, a real-time rate for eligible electric Vehicle (EV) customers that includes a component to compensate for V2G energy export. TMH modeled the charging and discharging behavior of a vehicle to maximize profit while fulfilling all driving requirements using two charger models for an entire year. From the analysis, 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 19.2kW and 50 kW charger, respectively, using the charging and discharging strategies evaluated. 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.

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

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

Minimum Average Export Rate to Provide Net Cost Savings to SUSD Under Current Operations

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. 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 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. This analysis includes two known incentive opportunities that are available to V2G customers: PG&E's V2G pilot program and CPUC's Emergency Load Reduction Program (ELRP). The results showed that 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.

CHAPTER 4: Lowest Cost to Charge Summary

This project evaluated 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 1 and Table 2 summarize the results by scenario.

Table 1: 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	39.7%	40.6%	26.6%	53%
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: CTE

Table 2: 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	0.29 $/kWh
Minimum export rate for net annual profit, with incentives	0.19 $/kWh	0.19 $/kWh

Source: CTE

The following are key findings from the analysis:

AC vs. DC vs. AC and DC Charging Cost Under Current BEV Rate

The team evaluated the feasibility and charging scheme under the current time-of-use 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 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 about $7,000 saved per year. However, this amount will not justify the additional cost of DC charging throughout the site. This result demonstrates that AC charging can meet SUSD's needs at a 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. 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 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 costs. 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 increase 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 revenue 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.

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. 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 are clearer.

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 offer incentives for the 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.

CHAPTER 5: Issues and Challenges With the Project

CTE experienced several challenges in developing the blueprint. All were eventually overcome by keeping the lines of communication open between CEC staff and the project team. Issues included:

Project start-up delays — The initial project contract was extended as a result of timeline delays. These delays were due to challenges related to parallel project collaboration and critical personnel changes. Personnel changes on the CTE and CEC teams created some additional timeline delays as new personnel were trained onto the project.

Analysis challenges — Due to multiple partners being involved throughout the analysis, collaboration was a necessary part of the project, and setting up meetings across teams and time zones was challenging. The iterative nature of the project caused timelines to slip as one partner waited for input from another before being able to begin the next iteration. Analyses sometimes took longer than anticipated. In addition, as the project team worked through the analysis, additional iterations became necessary and contributed to the changing timelines.

Stakeholder engagement — By far, the most challenging aspect of the project was getting the external stakeholders fully engaged. In some cases, the project team's primary contact left the organization, forcing the team to build a new relationship to get the new person on board. CTE had challenges getting stakeholder meetings set up because of busy stakeholder schedules and delayed response times. Even once a call was scheduled, stakeholders didn't show up or postponed at the last minute. Persistence finally paid off, and CTE was able to get all planned stakeholders scheduled for a call to review the results and gather feedback. CTE was able to add two organizations to the initial list.

CHAPTER 6:
Best Practices to Support Market Adoption of Future Electric Fleets

CTE developed a *Guidebook for Deploying Zero-Emission Transit Buses*[4], 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 for your 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.
- Identify available local, state, and federal funding opportunities to support the procurement of ZEB technology.

Fueling infrastructure strategy and cost

[4] Guidebook for Deploying Zero-Emission Transit Buses, available at https://nap.nationalacademies.org/read/25842/chapter/1

- 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 battery electric bus 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 among 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 before 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, 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 are developed for fair and accurate reporting of metrics, especially when compared to non-ZEB vehicles.

CHAPTER 7:
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 that prepares students for technical careers. SUSD engaged with Weber Tech to discuss this project in-depth, but the project has not yet been completed because of differing curriculum goals. More time is needed for SUSD and Weber Tech to standardize a curriculum to train and certify students in vehicle electrification.

As 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.

- Coordinate operations and maintenance training before 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.

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 its operations, maintenance, and facilities staff on the safe and efficient operation and maintenance of ESBs. The district 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.

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

CHAPTER 8: Stakeholder Review

CTE prepared a presentation summarizing the analysis results for review by various stakeholders, including school districts, financing partners, community-based organizations, and utilities. This section outlines the targeted stakeholders and their feedback provided during the reviews.

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 using only AC chargers but has purchased some DC chargers for its special education routes. The project results recommend that the district purchase only AC chargers because most bus/route combinations can be met with lower power charging. SUSD should use the DC chargers that it has 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. The district can pay for the cheaper rate of energy and sell it back to PG&E at the NEM 2.0. Knodt found the NEM 2.0 and NEM 3.0 analysis extremely valuable. Knodt also pointed out that the district's service runs year-round because two-thirds of its service runs are special-education summer school routes. This finding 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. Knodt reported that the district has solar panels in its 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 offer enough incentives for the technology to benefit the district. However, Knodt 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.

Knodt enjoyed learning about this research and is excited to implement the results into the district's operations. He also recommended that the project team share these results with other types of transportation groups. For example, he pointed to a nonprofit 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 Stockton region has some of the worst air quality in the country.

Knodt reported that a full transition to ESBs is a priority for the district, especially given the aggressive transition timeline in California. The district has been extremely proactive in its procurement and deployment of ESBs, but district officials still feel the stress of being able to transition to 100 percent. SUSD has five active grants for 66 new buses. Of these, 40 would be large general-education buses, and the other 26 would be smaller-capacity special-education buses with wheelchair lifts. SUSD will need to retire 45 special education buses soon, so it is trying to get more replacement buses. The temporary plan is to procure 56 more electric buses in the next 18 months. Knodt 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.

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 looking at large ESB fleet deployments. CTE met with AlphaStruxure on December 20, 2022, to review the CEC blueprint projects methods and results. The AlphaStruxure team reported that it has worked with roughly five other school bus projects and is excited to comment on this market because it believes there could be an opportunity to work together in the ESB market in the future.

From the transit side, the AlphaStruxure team suspects that people are vastly underestimating the costs of charging infrastructure and thinks 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 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 information 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 members 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 ways that it could align with the self-consumption analysis. It is 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 are not enough data on what this looks like over time, although it may add an additional capital cost. AlphaStruxure expressed concerns about the cost of battery degradation 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.

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. There are more than 75 active coalitions around the country working with communities to implement energy-efficient technologies. SUSD is 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 district's unique fleet needs. The team also recommended rural districts consider incorporating solar technology and was 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 it would like to see out of this project. It was excited about the results, however, as it thinks that the final blueprint could help the team learn more about electric buses and guide it through the different charging options for districts in the 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 it has not seen charging scenario analysis of this type before and was excited that it was being researched. PG&E was also grateful to be looped into the stakeholder calls, as the calls relate directly to its own research plans and customer relationships.

PG&E reported it believes V2G is coming although it will be a slower ramp-up than it would prefer. Overall, it is excited about the idea of it and has a few pilots lined up to test different use cases for V2G. It plans 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 capacity of the grid to handle future scaling of electricity storage and is hopeful that ESBs will be able 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. It also has learned more about how to best support electric vehicle charging around off-peak times. PG&E had initially recommended charging at night, but it now realizes there are benefits to charging during peak solar time instead. Overall, it is expecting a lot of shifting around consumer use and ways that people will choose to charge their electric vehicles as they become more widely available. It is concerned about the current uncertainty of how consumer use will impact the grid throughout the day, so it is especially excited about research 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 bidirectional charger. For example, they asked if a bidirectional charger has more expensive management systems and wondered how significant the cost of battery degradation would be. This question 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 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 is concerned that the current lack of data around V2G technology could harm school districts expecting a greater monetary benefit than currently exists. However, WRI is generally optimistic about nonmonetary V2G benefits like grid resiliency. WRI follows the benefits closely so that it can best support districts 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. It was interested comparing 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 contrast was not explored in CTE's analysis but is worth further research.

WRI is also strongly recommending Level 2 charging because of the lower cost and was 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. 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.

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 situation 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 number 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.

GLOSSARY

ACTIVE LOAD MANAGEMENT (ALM) — Steps taken to reduce power demand at peak load times or to shift some of it to off-peak times. This may be with reference to peak hours, peak days or peak seasons. The main thing affecting electric peaks is air-conditioning usage, which is therefore a prime target for load management efforts. Load management may be pursued by persuading consumers to modify behavior or by using equipment that regulates some electric consumption.

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 use energy that is stored in rechargeable battery packs. BEVs sustain power through the batteries and therefore must be plugged into an external electricity source 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 seven major areas of responsibilities are:

1. Advancing State Energy Policy
2. Achieving Energy Efficiency
3. Investing in Energy Innovation
4. Developing Renewable Energy
5. Transforming Transportation
6. Overseeing Energy Infrastructure
7. Preparing for Energy Emergencies

CHARGE ENERGY MANAGEMENT — A control system (often computerized) designed to regulate the flow of electricity between energy-consuming systems.

DEMAND RESPONSE — Providing wholesale and retail electricity customers with the ability to choose to respond to time-based prices and other incentives by reducing or shifting electricity use, particularly during peak demand periods, so that changes in customer demand become a viable option for addressing pricing, system operations and reliability, infrastructure planning, operation and deferral, and other issues. (Source: Dan Delurey, U.S. Demand Response Coordinating Committee).

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.

Vehicle-to-Grid (V2G): Using a modified charging system and control software, energy flow between a PEV battery and the electrical grid can be bidirectional. This allows the grid to discharge from the battery during moments of high demand and charge the battery during periods when demand is lower than the power produced within the grid. By selling this capacity to utilities, V2G can ameliorate the cost of PEVs.