CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Valley Transportation Authority Advanced Transit Bus Vehicle-Grid-Integration Project

Implementing Smart Charging on Bus Transit Agency's Electrifying Bus Fleet

October 2022 | CEC-500-2022-012

PREPARED BY:

Primary Authors:
Tina Yi-Hsuan Hu
Melissa Benn
Doug Davenport

Prospect Silicon Valley
1608 Las Plumas Ave
San Jose, CA 95133
(215) 917-6941
www.Prospectsv.org

Contract Number: EPC-16-058

PREPARED FOR:
California Energy Commission

Jeffrey Sunquist
Project Manager

Mike Petouhoff
Office Manager
ENERGY SYSTEMS RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGMENTS

The authors thank the California Energy Commission (CEC), which provided the funding for this research. Staff at the CEC who supported this project include Jeffrey Sunquist, Qing Tian, and many others.

The authors offer sincere thanks to the Santa Clara Valley Transportation Authority for being the site owner and major partner for this project and contributing match funding, subcontractor resources, and support throughout the project. The authors thank all the subcontractors who worked on this project, including ChargePoint, the National Renewable Energy Laboratory, Trapeze, Clever Devices, Proterra, CALSTART, NOVAworks, Energy Solutions, and the Zero Net Energy Alliance. The authors also thank all project partners for contributing tirelessly to ensure the project's success.

Emerging technology played an essential role in this project, and the authors would like to thank and acknowledge the support and collaboration offered by the technical advisory board members for helping to spread the word to accelerate the progress of fleet electrification.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy, advanced clean generation, energy-related environmental protection, energy transmission, distribution, and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer including:

- Providing societal benefits
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply
- Supporting low-emission vehicles and transportation
- Providing economic development
- Using ratepayer funds efficiently

Valley Transportation Authority Advanced Transit Bus Vehicle-Grid-Integration Project is the final report for the Valley Transportation Authority Advanced Transit Bus Vehicle-Grid-Integration project (Contract Number: EPC-16-048) conducted by Prospect Silicon Valley. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

The *Advanced Transit Bus Vehicle-Grid-Integration Project* brought together national leaders in advanced transit and energy systems, targeting critical real-world needs to scale, exploring revenue-generating grid services, and managing electric transit fleets and charging assets.

Santa Clara Valley Transportation Authority (Valley Transportation Authority) plans to meet California's statewide objective of a fully zero-emission bus fleet by 2040. Electrification is an essential part of that strategy and requires a shift in vehicle type and changes in energy and fueling strategies, operations, and other business factors. This was a $3 million project that developed and demonstrated advanced charging controls and reduced costs by using an integrated, smart charging platform. The project also supported the Valley Transportation Authority's long-term electric-bus infrastructure strategy for comprehensive bus electrification.

The project was led by Prospect Silicon Valley, and partners included the Valley Transportation Authority, Proterra, Trapeze, National Renewable Energy Lab, ChargePoint, Clever Devices, CALSTART, and NOVAworks. The 3-year project leveraged the Valley Transportation Authority's commitment to purchasing up to 10 all-electric buses as the first step toward electrifying its nearly 500 bus fleet. The project team built on the strategies, technologies, and partnerships from numerous existing vehicle-grid integration efforts to implement a world-class electric transit fleet showcase and significantly advance California's clean energy mandates. The project included robust workforce development and statewide engagement of transit and technology leaders to accelerate broad adoption of the advanced strategies demonstrated.

Keywords: Bus fleet electrification, Vehicle-grid integration, Smart Charging, Energy Storage, Energy Management Software Platform

Please use the following citation for this report:

Hu, Tina Yi-Hsuan, Melissa Benn, and Doug Davenport. 2021. *Valley Transportation Authority Advanced Transit Bus Vehicle-Grid-Integration Project*. California Energy Commission. Publication Number: CEC-500-2022-012.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

Introduction

Greenhouse gases generated by human activities have been the single most significant driver of climate change since the mid-twentieth century. In 2018, transportation generated 169.5-million metric tons (or 41 percent) of California's greenhouse gas emissions. These trends jump-started California's policies for reducing greenhouse gas emissions from transportation broadly and from transit fleets in particular. California's ambitious environmental goals include reaching 100 percent transit conversion to zero-emission vehicles by 2040, with 50 percent conversion by 2030. Electrifying the state's nearly 12,000 transit buses will reduce greenhouse gas emissions by an estimated 19 million metric tons in the three decades from 2020 to 2050.

Transit agencies face significant challenges in switching to zero-emission buses. Electric transit buses (e-buses) are significantly more expensive than fossil fueled buses. E-buses have not been integrated with critical commercial-operational tools, and the emerging electric vehicle and vehicle charging industries have focused primarily on passenger vehicles. Transit agencies have also found that, in addition to being expensive, planning for zero-emission vehicle conversion is complex. Finally, reaching the state's renewable goals requires transferring current energy service technologies and opportunities to transit fleets.

The Santa Clara Valley Transportation Authority (Valley Transportation Authority) *Advanced Transit Bus Vehicle-Grid-Integration Project* addressed many of these issues. It brought together national industry leaders to research, develop, and demonstrate a viable pathway for transit agencies to scale up to full electrification. The team developed advanced hardware and software that fully integrated existing operations with an innovative energy management system that monitors and manages new costs, efficiencies, and operations for fueling buses with electricity instead of with fossil fuel.

Project Purpose

The Valley Transportation Authority plans to fully electrify its nearly 500 bus transit fleet by 2040. This transition requires that the agency change its vehicles, energy and fueling strategy, operations, and other ancillary factors. The project team analyzed these significant impacts and made recommendations to the Valley Transportation Authority on how best to design, develop, and demonstrate a new e-bus fleet.

Valley Transportation Authority installed five chargers and five e-buses as a first step in electrifying its bus fleet. The project team designed a system that reduced e-bus charging costs by managing energy demand and integrating it with existing operations. The team developed both a smart charging system and an energy management platform that integrated onboard telematics and route planning. Researchers incorporated these features into commercial fleet management tools for the agency's fully integrated energy management system. The system is also designed to grow with future expansion of the agency's long-term infrastructure strategy for comprehensive bus electrification. The 3 year, $3 million project examined options, demonstrated transferable solutions, and provided key insights that will benefit other California transit agencies as they make their own transitions to zero emission vehicles. To further support the sustainability of transit agencies and the communities they serve, the project team also developed tailored training so that workforces can design, develop, operate, upgrade, and maintain infrastructure for the new systems.

Project Approach

Project Team

The Valley Transportation Authority was the project's host, end user, and operations manager. Prospect Silicon Valley provided strategic management and analyzed best practices, commercialization opportunities, and barriers. ChargePoint provided chargers and the energy management platform. The National Renewable Energy Laboratory provided analysis, measurement, verification, and explored revenue-generating grid services. Energy Solutions advised the project team on communications and broad recommendations for the state. The manufacturer of the Valley Transit Authority's E-buses, Proterra, Inc., provided transfer initiatives. The Zero Net Energy Alliance collaborated with Prospect Silicon Valley on knowledge transfer in its role as project manager for the California Energy Commission's *California E-Bus to Grid Integration Project* (EPC-16-065) with the Antelope Valley Transit Authority in Lancaster, California. NOVAworks supported workforce-education initiatives.

Research, Development, and Deployment

The Valley Transportation Authority's goal of electrifying its entire bus fleet guided the team's approach in creating an architecture that supports e-buses, chargers, bus yards, and vehicle-grid integration capabilities. The team first assessed current fleet operations to determine the potential for integrating e-buses into current operations. The team concluded that e-buses could replace around 70 percent of the agency's bus trips. Project members also examined charging strategies and determined that smart charging, which uses a controller to determine the best times to charge at the lowest operating cost, effectively reduced peak power energy consumption.

The team next explored whether e-buses could provide grid services that would offset energy costs. The challenge was aligning the timing of bus charging with the need for grid services. Buses typically charge at night when the value of grid services is low. Since most programs would produce little to no value given the agency's bus-driving schedules, the project team did not pursue grid services (though a detailed assessment for future consideration was provided).

Armed with these fundamentals, the team identified the hardware and software requirements for integrating the new e-buses with the agency's regular operations while simultaneously fine-tuning e-bus performance and managing costs. Since the cost of electricity varies based on time of day, peak demand, and other factors, effectively managing when and how long buses are charged significantly impacts their cost. Optimizing the charging function required a complex algorithm and an automated system. The team created an overall design and identified tasks for software development in each project phase. The design also provided essential information for assessing security risks and outlining a security policy. The software development effort required collaboration with multiple vendors and partners to ensure effective communication and data flows across the system.

In Phase 1, *Integrated System Deployment*, the team successfully deployed five e-buses and five charging stations and developed the new energy management platform. This required the modification of existing software and included: software that supported both operator and vehicle scheduling, fleet management modules (which track vehicles and states of charge and communicate with the buses), and a maintenance-data management system.

The project team also developed automated capabilities that integrated the agency's complex existing transit-scheduling and operations software. The team modified commercial electric vehicle charging and energy management applications to tailor them to the transit agency environment. The new system also communicated with hardware devices including charging stations and the mobile sensors and computers installed on the e-buses. By the end of Phase 1, the team had successfully integrated all system components with the energy management platform except for the bus-routing software. As a result, the system successfully monitored the energy statuses of the five e-buses and generated charging plans that guided agency staff on charging plans for each bus. The software effectively managed bus charging based on an energy and cost minimization strategy.

In Phase 2, *Scaling and Additional Features*, the team extended system capabilities, increased smart charging benefits, prepared for future scaling, and collected enough data to verify the project's benefits. The team integrated the Trapeze-Ops bus-scheduling system with the energy management platform to provide routing, scheduling, vehicle maintenance data, and system availability. With these integrations completed, the team tested and validated all energy management platform functions.

Another goal for Phase 2 was to demonstrate the ability to meet charging and operational needs when there are more e-buses than chargers. Bus delivery and other delays required workarounds to successfully simulate, test, and verify energy management platform functions for managing bus charging sequencing.

Throughout the project, the team helped the Valley Transportation Authority train key employees on the new systems. Training bus operators about brake regeneration - recovering energy while braking to recharge the batteries - and other energy-saving strategies was a critical factor in driving down energy consumption.

Project Results

The Valley Transportation Authority's *Advanced Transit Bus Vehicle-Grid-Integration Project* successfully applied vehicle-grid integration advancements to a commercial e-bus fleet and implemented smart charging. The team designed an energy services and management system that integrated commercial fleet management tools with California Energy Commission-funded vehicle-grid integration platforms, implemented cybersecurity protocols, and created an architecture that supported the transition of an entire bus fleet to zero emission vehicles. Researchers provided the Valley Transportation Authority with simulation and analytical tools to support further planning and improvements and developed materials for workforce training. The new system effectively reduced energy consumption. The e-buses consumed 1.8 kilowatt hours per mile (kWh/mi), compared with 2.25 kWh/mi for diesel-electric hybrids; the e-buses also averaged 23.1 miles-per-gallon equivalent while hybrid buses averaged 5.8 miles per gallon. The agency saved 25,500 gallons of diesel fuel over the course of the project and avoided 261 metric tons of greenhouse gas emissions. The integrated system will additionally allow the agency to realize future savings in operating, infrastructure, and maintenance costs.

This project, though essentially a small-scale deployment of vehicle-grid integration, laid a critical foundation for the Valley Transportation Authority's complete fleet electrification by incorporating time for testing, training, and calibrating existing operations.

Key Challenges and Lessons Learned

Challenges arose from working with new technologies across multiple vendors' products, including product and service delays, the need to develop interfaces with multiple vendors' products, and troubleshooting communications with new hardware and software technologies. While the team adopted existing industry standards, there were no communications standards for an energy management platform.

Although the COVID-19 shelter-in-place orders disrupted Valley Transportation Authority operations, the team created workarounds and still achieved the project's primary goals. Project team members identified faulty assumptions about how some aspects of the new system would interact with existing operations. They therefore devised targeted training and communications about system requirements for personnel, adjusted data collection parameters, and developed new procedures.

Future projects should note that using new technologies like these will impact the commissioning process and the schedule. Agencies must allow ample time for engineering, purchasing, and contract processes when developing their timelines for similar public transit bus electrification projects. The Valley Transportation Authority and other transit agencies must continually review new technologies to identify best-available options. The National Renewable Energy Laboratory's simulation tools will help the agency predict the impacts of different bus purchasing decisions. Like the buses, chargers are a capital investment, and the evolving industry will deliver increasingly advanced products over time.

Technology/Knowledge Transfer/Market Adoption

The project's knowledge transfer activities communicated to fleet managers the benefits of including an integrated energy management platform in their long-term electrification strategies and creating programs that address California's electric vehicle labor market readiness. Knowledge transfer teams increased understanding of opportunities for: (1) expanding e-bus energy management systems in California; (2) educating and engaging a diverse set of stakeholders; (3) engaging those stakeholders on the project's framework, economic and energy outcomes, challenges and approaches, and policy considerations; (4) conducting outreach and education through events; and (5) disseminating technical resources.

Prospect Silicon Valley and the Zero Net Energy Alliance established a joint technical advisory committee to oversee this project and the *California E-Bus to Grid Integration Project* with the Antelope Valley Transit Authority. The committee included representatives from more than 100 transit agencies, policymakers, and utilities, in addition to companies in the e-bus vehicle, charging, and vehicle-grid integration supply chain.

The team worked with CALSTART to produce a best-practices guide, *Best Practices on E-Bus and Grid Integration: A Guide for California Transit Fleets*. This guide summarizes lessons learned from the Valley Transportation Authority and Antelope Valley Transit Authority projects and reviews other projects and literature. It addresses the technological, operational, and workforce issues required to successfully integrate electric buses into an existing transit fleet. The guide is available at no charge from the CALSTART website.

The project team engaged NOVAworks to create educational tools for high school, college, adult school, and university institutions. These materials introduce students to the theory and practice of vehicle-grid integration, with the long-term goal of creating pathways to employment and graduate engineering programs.

Project team members presented project findings and recommendations at industry conferences, symposia, workshops, panels, webinars, and technical advisory committee meetings. The knowledge transfer team successfully engaged more than 100 organizations and individuals about project goals and methods and the unique challenges of fleet electrification.

Benefits to California Ratepayers

Electrifying transit fleets provides significant benefits to transit agencies and the communities they serve. The e-bus vehicle-grid integration system developed and demonstrated in this project produced specific benefits to the Valley Transportation Authority, including:

- **Reduced Energy Consumption**. Smart charging reduced peak power use between 31 percent and 65 percent over unmanaged charging, and nearly eliminated the use of grid energy during peak and partial-peak periods in summer and winter. Driver training programs augmented with system data improved driver efficiency. Valley Transportation Authority's e-buses rated an average of 1.8 kWh/mi, beating Proterra's prediction of 2.1 kWh/mi and the Valley Transportation Authority's diesel-electric hybrids' 2.25 kWh/mi. Valley Transportation Authority e-buses averaged 23.1 miles per gallon equivalent (MPGe) while hybrid buses averaged 5.8 MPG. Over two and a half years, the agency saved more than 25,500 gallons of diesel fuel.
- **Reduced Range Anxiety**. Extensive driver training ensured that e-buses completed 85 percent of Valley Transportation Authority's existing routes, which averaged 170 miles. With drivers trained to maximize use of regenerative breaking, the buses can go more than 200 miles on a single charge.
- **Reduced Costs.** In the future, the Valley Transportation Authority expects lower operating costs since e-buses have fewer maintenance issues than diesel-hybrid buses. These reductions will not be offset by higher energy costs since the cost per mile for the two bus types is roughly equivalent. The project enabled the agency to reduce the electrical infrastructure required for 100 percent fleet electrification by taking advantage of Pacific Gas and Electric Company's (PG&E) *Electric Vehicle Fleet* program. Since the project significantly minimized charging, operating costs were reduced by adopting PG&E's Business EV2 rate program.
- **Sustainability Benefits**. The vehicle-grid integration project also helped the Valley Transportation Authority realize its sustainability objectives. Based on the diesel fuel saved over the project, the agency saved 261 metric tons of greenhouse gas emissions. The e-buses generated 84.0 percent lower carbon dioxide emissions and 81.2 percent lower nitrogen oxides emissions than the hybrid bus; e-buses also eliminate emissions of sulfur oxides.

- **Data, Tools, and Analysis**. The system delivers rich data on driver, vehicle, and charger performance, and the Valley Transportation Authority is learning how to use this data to make improvements and realize even more savings. The National Renewable Energy Laboratory created a simulation tool that predicts miles and energy use for route and bus technology configurations. A financial performance model analyzes several metrics on cost and performance for e-buses and overall site performance.
- **The Groundwork for Future Work**. This project prepared the Valley Transportation Authority for its next step toward total fleet electrification. That agency plans to develop a smart microgrid system to augment charging from the electric grid. It includes a second-life lithium-ion battery system for energy storage, a photovoltaic system for energy generation, and a control system to manage the flow of energy between the photovoltaic system, the grid, and the energy storage system. The system will also manage stored energy and grid-supplied energy used to charge the e-buses. Once the new system is developed, the Valley Transportation Authority will integrate it with the energy -management platform developed in this project to fine tune its e-bus charging plans.

CHAPTER 1: Introduction

Project Context

California's ambitious mandates for zero emissions vehicles (ZEVs) include 100 percent transit conversion to ZEVs by 2040[1]. Nearly 12,000 transit buses will become electrified by that date, reducing greenhouse gases (GHGs) by 19-million metric tons between 2020 and 2050.[2]

Transit agencies must overcome many obstacles in changing out their fleets from fossil-fueled to ZEVs. Electric buses are more expensive than fossil-fueled ones and do not use commercial-operational tools.[3] Planning for widespread conversion is also complex and costly. Finally, reaching the state's broader renewable-energy goals requires responsive energy services that also ensure electric grid reliability.

In practical terms, the public transit industry has developed its own tools, operations, and protocols while the emerging electric vehicle (EV) and EV charging industry has focused primarily on passenger vehicles. Meeting California's ZEV transit goals requires bringing together innovators of both industries to design and develop new systems that maximize their respective expertise and capabilities. It also requires transferring the technologies and opportunities provided by vehicle-grid integration (VGI) to transit fleets.

The Valley Transportation Authority (VTA) *Advanced Transit Bus Vehicle-Grid-Integration (VGI) Project* brought together national industry leaders to commercialize and scale electric transit fleets to support California's transition to renewable energy. Led by Prospect Silicon Valley (ProspectSV), the project's world-leading partners included the Santa Clara VTA, ChargePoint, Proterra, United States Department of Energy's (DOE's) National Renewable Energy Lab (NREL), Energy Solutions, Clever Devices, CALSTART, Pacific Gas and Electric (PG&E), and NOVAworks.

This project's primary goals were first to assess the viability of various low-to-zero emission transit bus options and grid services for the VTA. Second, as the VTA installed its first batch of chargers and e-buses in its first step toward electrifying its nearly 500 bus fleet, the project team deployed a smart-charging system and an energy management platform that integrated charging activities with onboard telematics and route planning.

Across the state, transit agencies like the VTA are working to reduce transit-fleet emissions to meet the state's 2040 goal. The state's top 100 urban-transit agencies carried over 530-million passengers by bus in 2018; all of these buses will be replaced by ZEVs.[4]

---

[1] These goals are set out in SB 350 and SB 375 and in CARB Innovative Clean Transit regulations.

[2] "California transitioning to all-electric public bus fleet by 2040," California Air Resources Board (website).

[3] "An average diesel transit bus costs around $500,000, compared with $750,000 for an electric bus." Horrox, James and Mathew Casale, Electric Buses in America: Lessons from Cities Pioneering Clean Transportation, (Environment Research, and Policy Center, Frontier Group, October 2019), p.11.

[4] "Urban Transit Ridership," California Energy Commission (website).

The 3-year project built on strategies, technologies, and partnerships from existing VGI efforts to create a world-class electric transit fleet. This project contributes an essential step on the path to a more sustainable future for the state's sixth-largest transit agency.

Advancement Toward State Goals

Meeting California's ZEV goals for transit buses presents multiple challenges. These include developing more responsive grid assets; implementing advanced-management tools such as smart charging and demand-charge management; establishing revenue-generation opportunities, such as demand response and wholesale-energy services; and providing integrated tools for commercial-fleet management. This project addresses these challenges by exploring and implementing opportunities provided by vehicle-grid VGI.

VGI encompasses all the ways EVs can provide benefits or services to the electric grid, EV owners, and society by streamlining interactions between EVs and the grid. Smart charging (V1G) shows a customer's unidirectional electricity management through managed charging and response to existing utility rates, essentially managing EV charging to reduce utility costs. Vehicle-to-grid (V2G) shows bidirectional management of electricity where vehicles both charge from the grid and provide power to the grid, thus optimizing costs expended and services provided to the grid.[5] Scaled VGI e-buses can in this way drive down the costs of responsive grid assets and deliver lower-cost energy services.

The *California Vehicle-Grid Integration (VGI) Roadmap* outlines a path that enables EVs to provide grid services while still meeting customer-driving needs. The VTA VGI project addresses several needs articulated in Track 1 and Track 3 of the roadmap process.[6] These include assessing and demonstrating the value of applying VGI to the commercial transit fleet market by:

- Determining the value and potential of VGI by assessing its impacts to the electricity and the value of those impacts
- Confirming VGI market potential by establishing market certainty and defining its adoption potential
- Scaling up earlier pilot concepts

The project recognizes the roadmap's goal for technology development by:

- Improving performance by reducing costs and therefore enhancing the technologies' performance
- Testing the performances of enabling technologies
- Coordinating with existing research, development, and demonstrations (RD&D)
- Ensuring that results are published
- Identifying research gaps for further study

The California Public Utilities Commission (CPUC) has laid the path to phase out fossil-fueled generators from the state's demand-side resource mix by 2018. An essential element of the *Scaled and Responsive Distributed Energy Resources* (DER) plan is adding DERs through the

---

[5] "DRIVE OIR Vehicle-Grid Integration Working Group," California Public Utilities Commission (website).

[6] California ISO, 2014 California Vehicle-Grid Integration (VGI)Roadmap.

investor-owned utility (IOU) *Demand Response Auction Mechanism* (DRAM) program and the proposed California Independent System Operator (California ISO) distributed energy resource provider (DERP) initiative. Commercializing e-bus fleets with VGI comprises one of the largest market segments for bringing these resources to the state with less complexity than fragmented resources such as private EVs, and at lower cost than others.

Multiple state policies target job creation and workforce readiness. This project enhances VTA's ongoing workforce-development efforts to include VGI and strengthens the community's talent pipelines required to support advanced transit e-bus energy management.

Senate Bill (SB) 350 (Author, Chapter, Statutes) prioritizes mass adoption of clean-energy technologies within under-served communities. The law also mandates cleaning air pollution in neighborhoods hit first and worst with pollution. The project supports the VTA, which, like many transit fleets, provides critical mobility to underserved communities; it serves 44-million riders and an underserved community of an estimated half a million people.

Project Goals and Objectives

The project targeted specific needs for scaling VGI-enabled e-bus fleets across the state. The primary project goals and objectives follow.

- **Develop and Demonstrate a Robust Value-Added, Real-World Business Case**: Establish advanced VGI in a major bus fleet; address fleet operations and grid needs related to emerging electrified transit fleets in California. Strengthen the business case for e-buses and energy services, accelerating adoption.
    - **Deploy an Integrated System**: Using e-buses acquired by partner VTA, initially deploy 10, 40-foot electric e-buses (and up to an additional 25), combined with charging infrastructure and energy-services software for a fully operational and integrated system.
    - **Explore Energy Services**: Explore the potential for energy services, including smart charging (time-of-use pricing, peak load reduction, demand charge mitigation) and retail energy services (demand response [DR], excess energy). Explore wholesale services (frequency regulation, spin, non-spin) and identify the groundwork for full bidirectional energy services (V2G).
    - **Integrate Management Tools**: Operationally link the critical tools required to support scaling e-bus services across the VTA and the state. This work includes integrating Clever Devices' fleet-management applications with a platform covering e-bus and diesel-electric hybrid vehicles. Clever Devices is a transit-fleet management platform that supports one-in-three transit buses nationally. Its integrated platform enables fleet managers to manage critical metrics and configuration including state of charge (SOC), dispatch, charge, and energy-service configurations. It also includes integrating ChargePoint hardware with VTA's automated logic controls for integrated energy management.
    - **Develop Comprehensive Operational Analytics**: Refine the duty-cycle and charging management with real-time battery-degradation analysis and make recommendations for fleet managers and decision makers.

    - **Ensure Robust Cyber Security**: Assess risk factors across interfaces and implement premium-grade security features with leading industry partners.
- **Assess and Provide Direction for Scaled Deployment**: Develop the analytic and implementation roadmap for complete agency electrification and statewide transit adoption.
    - **Assess Fleet-Scale Services**: Develop strategy and costs for fleet-wide e-bus deployment including infrastructure requirements, utility costs, revenue (considering uni- and bi-directional grid services), photovoltaics (PV), and storage.
    - **Assess State-Scale Application**: Develop a model of statewide e-bus deployment including roles for energy services, PV, and storage. Assess total grid services and transit agency benefits including bi-directional power, DR, and ancillary services. Include cost-benefit analyses for local agencies.
- **Support Accelerated Commercialization and Readiness**: Provide a platform for commercializing project technologies and strategies including integration with key VGI platforms (under development) and an integrated workforce program.
    - **Integrate VGI Platforms**: Integrate energy management with a demand clearing house for utility awareness and the XBOS-V open source open architecture (BMOSS) for BEMS/VGI coordination, both under development (CEC PON 14-310).
    - **Recommend State Codes and Regulations Input**: Develop state and utility recommendations on codes, rates, communications standards, and incentives.
    - **Initiate Ongoing E-Bus VGI Solutions Program**: Establish a statewide working group and transit-agency partnership to promote best practices and provide hands-on assistance for VGI-enabled e-bus deployment.
    - **Enable Workforce Readiness**: Through workforce boards, community colleges, and labor unions ensure that training programs for current and future talent pools include advanced-energy management for e-buses.

Project Partners and Roles

Santa Clara Valley Transportation Authority, VTA, was the project host and end user, and integrated all operations. VTA is an independent district that provides sustainable, accessible, community-focused transportation options (bus, light rail, and paratransit services) that are innovative, environmentally responsible, and contribute to the region's vitality. The VTA serves more than 35 million riders annually and an underserved community of half-a-million people.

Prospect Silicon Valley, (ProspectSV), provided strategic management, analyzed commercialization opportunities and barriers, and provided overall project management that met California Energy Commission (CEC) requirements. A nonprofit "clean tech" innovation hub, ProspectSV, focused on advanced mobility and energy solutions for urban communities.

ChargePoint provided chargers and the energy management platform. An electric vehicle infrastructure company, ChargePoint, designed, developed, and manufactured hardware and software for electric vehicles and continues to expand the world's leading EV charging network. After the project began, ChargePoint acquired and integrated Kisensum, the energy management platform developer.

National Renewable Energy Laboratory (NREL) provided analytics, measurement and verification, and explored revenue-generating grid services.

Energy Solutions advised the project team on communications and state recommendations. Energy Solutions is an employee-owned company focused on creating large-scale environmental impacts through cost-effective, market-based carbon, energy, and water management.

Proterra, Inc., provided the e-buses and advised the team on technology integration. Proterra is a leader in the design and manufacture of electric transit vehicles and EV technology for heavy-duty vehicles.

CALSTART supported knowledge-transfer initiatives. CALSTART is a nonprofit organization that works nationally and internationally to develop clean, efficient transportation solutions. CALSTART connects elements of the clean-energy sector and offers customized services, information, and programming.

ZNE Alliance collaborated with ProspectSV on knowledge transfer goals and activities in its role as project manager for the Energy Commission's *California E-Bus to Grid Integration Project* with Antelope Valley Transit Authority (AVTA) in Lancaster, California. A 501(c)(3) not-for-profit organization, ZNE Alliance's projects develop and deploy integrated strategies, maximize value streams, and achieve return-on-equity (ROI) and greenhouse gas (GHG) reductions.

NOVAworks supported workforce education initiatives. A nonprofit, federally funded employment and training agency, NOVAworks provides customer-focused workforce development services. NOVAworks leverages regional relationships with education and training organizations to identify prospective talent, develop training and career pathways, and connect trained workers with employment opportunities at transit and related agencies throughout the region.

Technology Partners

Clever Devices, a leader in public transportation technology, helped integrate fleet management applications with the ChargePoint Energy Management Platform. These modules support service management, route and schedule adherence, and voice and data communications, among other functions. The EV-monitoring system also tracks the locations and current states of charge for electric vehicles.

Trapeze, a leader in transit operations management and a long-time technology partner of the VTA, helped integrate operator bidding, dispatch, and time-keeping software with ChargePoint's energy management software platform.

Project Summary

The VTA VGI project achieved several innovations and advantages for the VTA. It translated VGI advancements for a commercial e-bus fleet, implemented V1G, and explored retail and wholesale energy services for potential future V2G implementation. The team designed an energy-services and management system that integrated leading commercial-fleet management tools with key Energy Commission-funded VGI platforms, implemented cyber-security protocols, and created an architecture that supports the fleet's transition to ZEV. The project also developed curricula for training a workforce to support California's transition to ZEV transit vehicles.

CHAPTER 2:
Project Approach and Deployment

The VTA's ultimate goal of electrifying its entire fleet drove the team's approach in creating hardware and software to support adding e-buses, chargers, bus yards, and VGI capabilities and capacities over time. The approach built on and expanded the VTA's existing vendor and community relationships and the knowledge gleaned from the CEC's VGI projects, particularly the *California E-Bus to Grid Integration Project*.

Needs Assessment and Scoping

The team first assessed current fleet operations to determine the potential for integrating e-buses and explored whether e-buses could provide grid services to offset energy costs. Armed with these fundamentals, researchers identified hardware and software requirements for integrating the new e-buses into the existing operation. This enabled them to create an overall design and identify specific tasks for software development in three phases. The design also provided essential information for assessing security risks and outlining a security policy framework.

Assessing the Current Fleet Operation

In the fall of 2017, VTA's bus fleet consisted of 461 buses. All buses operated on diesel fuel, and roughly half had a hybrid diesel-electric drive train. The project team analyzed VTA's bus fleet operation data for integrating e-buses into the operation and addressed the ultimate goal of growing to a fully electrified fleet. It also reviewed one month's operation logs to determine bus travel patterns.

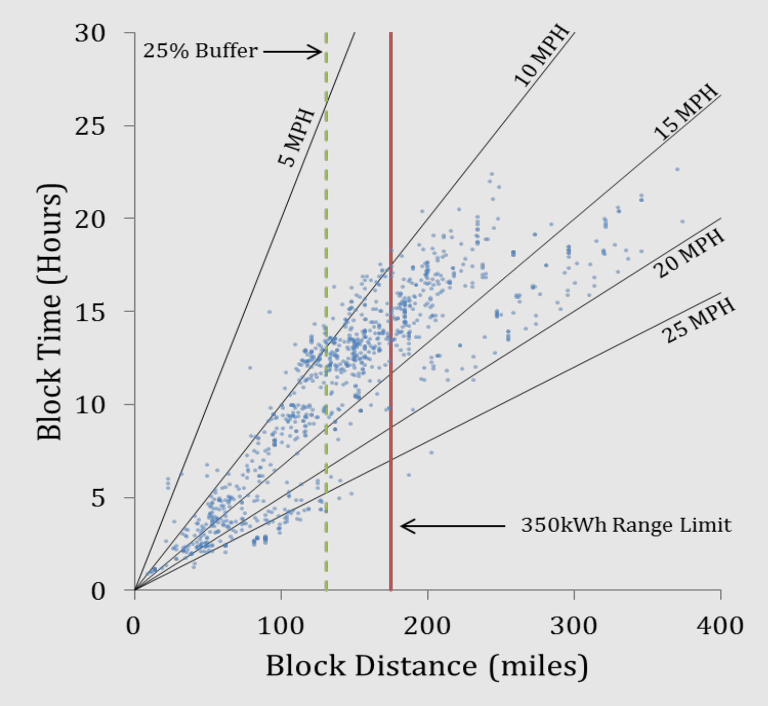
In the VTA operation, each bus is assigned to a "block" that includes multiple routes of timed runs. Buses can complete more than one block in a day and multiple buses are needed to complete all the runs in each route. By analyzing the blocks, the team determined the number and types of blocks serviceable by electric buses. Specifically, the average speed and range of a block determined whether the battery would be sufficient to power a bus for the entire block, or a combination of blocks, assigned for a given day.

The buses used the Proterra Catalyst E2, which contains batteries with 350 kWh of usable energy. Assuming an electric bus efficiency of 2 kWh/mile, the maximum range of the Proterra buses is about 175 miles.[7] Figure 1 shows that the buses averaged 10 to 15 mph with a range of around 150 miles. The team identified factors that impacted efficiency, including ambient temperature, humidity, and driver behavior, among others. The vertical red line in Figure 1 shows a 25 percent buffer to accommodate these efficiency differences.

---

[7] National Renewable Energy Laboratory, Foothill Transit Battery Electric Bus Demonstration Results, January 2016, vii.

Figure 1: Comparison of Distance Versus Travel Time for Each Block



Source: National Renewable Energy Laboratory.

Initial findings showed that battery electric buses (BEBs) or e-buses could accommodate most VTA blocks. Including a 25 percent buffer reduced that number. However, there were many routes less than 100 miles that were currently available, and VTA discussed constructing a new set of blocks that could maximize e-buses benefits and use. The next section refines these estimates and explores these opportunities more fully.

Assessing Long-Term Electrification Opportunities

In 2018, NREL project team members analyzed the long-term potential of VTA's transit bus electrification and assessed the economic impacts of partial and total electrification. The team used a revenue operation and device optimization model to determine the best operation and lowest-cost solutions at different levels of electrification.[8]

The team also found that battery electric buses (BEBs) could replace around 70 percent of VTA's transit bus fleet trips.[9] It identified the benefits and drawbacks of five methods for improving these results including: increasing charger power, purchasing larger vehicle batteries, using on-route charging, purchasing additional buses, and redesigning routes and blocks. The team developed a strategy that enabled full-fleet electrification by increasing charger power and allowing intraday charging as proxies for those options. This method allowed them to analyze the impacts and the trade-offs of full-fleet electrification.

---

[8] Revenue Operation and Device Optimization Model (RODeO) (Denholm, Eichman, Margolis, 2017; Eichman, Townsend, Melaina, 2016; Eichman, Flores-Espin, 2016.) The model can simultaneously determine the optimal charging patterns for hundreds of buses. It also considers existing electricity consumption at the facility, on-site renewables, credits and incentives, financing structure, taxes, and debt.

[9] This assumes 40' BEB with 350kWh of usable storage and a 60' BEB with 550kWh of usable storage.

The team examined two charging strategies: immediate charging, when a bus is charged as soon as it arrives, and smart charging, which uses a controller to determine the best times to charge at the lowest operating cost. The team found that smart charging reduces peak power consumption, which can be reduced by between 31 and 65 percent when compared with immediate charging. This translates directly to lower demand charges and lower costs for system upgrades.

Figure 2 shows the total lifetime net present value (NPV) costs for different scenarios. Given the cost and operating assumptions, the results show that smart-charging scenarios are within plus-or-minus 4 percent of the lifetime NPV cost of a diesel-electric hybrid. The scenarios with full-fleet electrification (including intraday charging) are at 4 percent lower cost, while those with partial-fleet electrification (without intraday charging) are 2 to 3 percent higher. It was also found that increasing solar PV in the yards can reduce lifetime NPV costs. Conversely, adding storage does not necessarily reduce lifetime NPV costs for e-buses that are already efficiently charging.

This analysis assumes that buses operate as expected and does not include additional costs for intraday charging or electrical infrastructure upgrades. These items have a wide range of costs from zero dollars to millions of dollars and can significantly affect project economics. However, the analysis provides the VTA with the projected costs and impacts of long-term bus electrification. More discussion regarding costs is warranted between VTA partners and utilities.

Figure 2: Comparing Lifetime Net Present Value

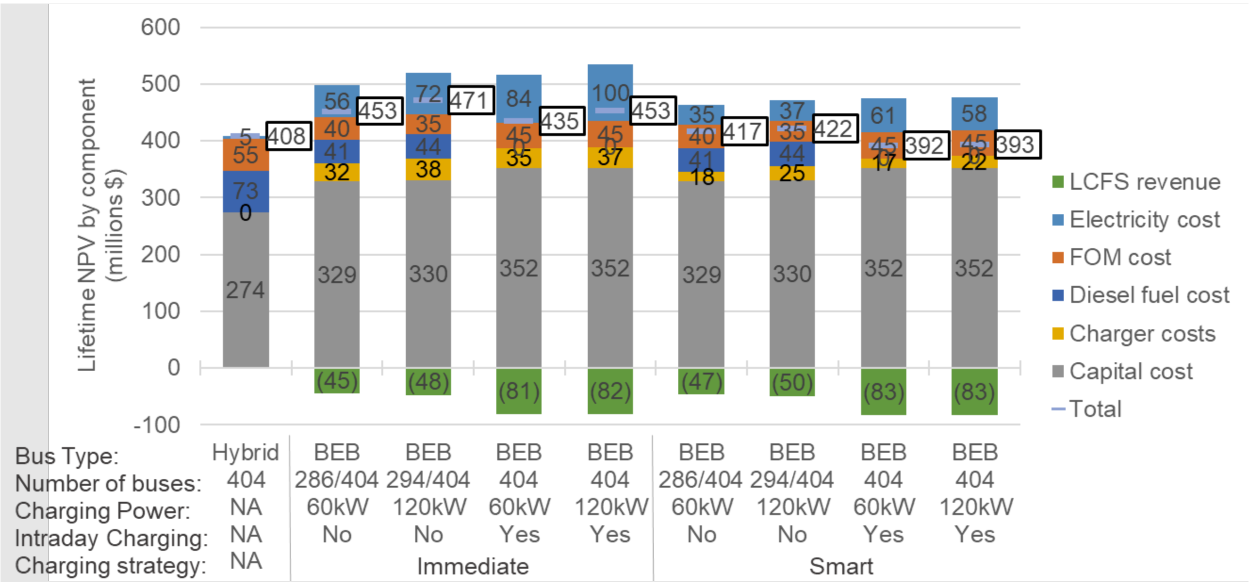


Figure 2 compares the net present value of diesel-electric hybrid buses, battery electric buses using immediate charging, and battery electric buses using smart charging.

Source: National Renewable Energy Laboratory.

Assessing Grid Services Options

The NREL project team explored the possibility of VTA e-buses providing both wholesale and retail grid services. The team considered the following CPUC programs: *Base Interruptible Program* (BIP), *Capacity Bidding Program* (CBP), peak-day pricing (PDP), *Excess Supply Pilot*

(XSP), and *Supply Side II DR Pilot* (SSP II). Team members also evaluated participation through the proxy demand resource (PDR) and reliability demand response resource (RDRR) California ISO market enhancements.[10] (Appendix A for the full report summarized in this section.) The biggest challenge for e-buses to provide grid services is aligning the timing of bus charging with available services. VTA bus charging begins at around 9 p.m. and ends by 6 a.m. the following day, as shown in Figure 3.

Figure 3: Typical Operating Times for Valley Transportation Authority Buses by Block

Figure 3 shows the hours each block is in operation (dark) and the hours it is available for charging (light). Blocks are available for charging from 9 p.m. to 6 a.m. the following day.

Source: Data collected by VTA and presented by National Renewable Energy Laboratory.

However, most of the DR events for retail programs (BIP, CBP, PDP) occur between 2 p.m. and 9 p.m., buses are not in the yard to provide load reduction to the utility. XSP and SSP have flexible scheduling for participation, allowing buses to provide services from 9 p.m. to 1 a.m. or 1 a.m. to 5 a.m. The question then becomes, how much value do markets offer during those times? For XSP, the value depends on when events are called. Since there haven't been

---

[10] See a description of these services provided by the California Public Utilities Commission.

many use cases, there isn't enough data to determine event timing. VTA should consider event calls for XSP in the future.

The value of SSP participation depends on the ancillary-services market values at the time. Participating directly as a PDR resource is likely more valuable but participating in SSP may be easier and lower in cost, so the project team recommends that VTA explore SSP costs. SSP may be lower cost because it doesn't require purchasing a "gateway" for connecting with the ancillary service markets like the PDR program does. It may also be easier to implement because the VTA would only interact with the utility instead of with the California ISO, which would likely reduce both effort and paperwork.

Participation in the DRAM is unlikely based on e-bus availability. The DRAM value is not publicly available but would probably be less than $50/kW-month.

The team investigated the PDR and RDRR programs and found the value for participating in energy markets uncertain and difficult. For a bus travelling an average of 130 miles per day, the estimated ancillary-service market value would be around $315/kW-year for spinning reserve, or around $659/kW-year (excluding impacts when reserves are called). The VTA should also consider application and infrastructure costs when evaluating PDR and RDRR programs.

Changing driving patterns for e-buses could substantially change opportunities for providing grid services. Returning buses to the transit hub to charge for two to four hours during the day would increase the potential for using more low-cost solar power and extracting better value from retail DR programs and wholesale market participation.

There is another opportunity to increase ancillary-services revenue. As ridership decreases in the evening, ancillary-service prices increase. If electric buses were to arrive at 5 p.m. or 6 p.m. and be immediately connected with chargers, they could support the grid as the load fell after the evening-peak electricity load. This potential value would have to be balanced with the utility rate (particularly considering the time-of-use bins) to avoid on-peak costs.

Summarizing, buses are typically not charging when grid services are available, and when they are charging, the value for grid services is low. Most of the programs would therefore produce little-to-no value unless VTA shifted its bus-driving patterns. Given this assessment, the project team did not incorporate grid services into the project but nevertheless did provide a detailed assessment to the VTA for future consideration.

Assessing System-Integration Requirements

For the VTA project, the software developers' challenge was to integrate EV requirements into the agency's normal operations while optimizing e-bus performance and managing cost. The team identified the following specific endeavors and analyses required for meeting this challenge.

- Integrate e-bus use into transit functions such as scheduling, vehicle assignment, vehicle servicing and maintenance, transportation dispatch, and service management. VTA's existing or newly implemented software packages support these functions.

- Address the issues of managing electricity rather than fossil fuels for vehicles. Although conceptually this process is the same, managing EVs requires separate processing paths, resources, and data.
- Minimize the cost of electricity while meeting vehicle demand. The cost of electricity varies based on time of day, peak demand, and other factors. Effectively managing the time of day, duration of charging, and load shedding can significantly impact the cost of deploying vehicles. Optimizing the charging function, especially when there are more vehicles than chargers, requires a complex algorithm and an automated system.
- Effectively control and execute the charging function with new VGI software by optimizing the charging schedule and integrating the automated system that controls charger operation.

Deploying a VGI software solution to address these challenges included the following development tasks:

- Develop new automated capabilities that the complex environment of VTA's existing and newly implemented transit-scheduling and operations software.
- Modify commercial electric vehicle charging and energy management applications to adapt to this environment.
- Communicate with hardware devices including charging stations and mobile sensors and computers installed on the EVs.

Integrated-System Design

Software-System Design

The new VGI software fully used VTA's existing software packages but required modifications to the following packages to support integration and interoperability:

- Trapeze OPS bidding, dispatch, and time-keeping software uses schedule information from Trapeze FX and supports operator and vehicle assignments.
- Clever Devices fleet management applications include several modules. The computer-aided dispatch/automatic vehicle location (CAD/AVL) and service management software support vehicle pull-out/pull-in, service management, route and schedule adherence, voice and data communications, and other functions. The Electric Vehicle Monitoring System (EVMS) tracks current state of charge for EVs and determines when vehicles are in the yard.
- SAP provides VTA's maintenance system of record including the official list of active vehicles. It supports vehicle servicing and maintenance and updates vehicle availability for service.

The VGI solution also included this ChargePoint software:

- ChargePoint charging system manages the physical chargers and controls the charging process.
- ChargePoint Energy Management Platform (EMP) optimizes charging schedules and minimizes the cost of charging. It controls charging through the integration of application programming interfaces (APIs) with the ChargePoint charging system,

Clever Devices API (provided by Clever Devices), and Trapeze API (provided by Trapeze).

The software integration design included specifying which software packages would fulfill specific business tasks as well as specifying and developing their interfaces with necessary modifications.

Hardware Design

Appendix B presents more detailed specifications for project hardware. The basic specifications for the buses, chargers, and mobile telematic communications devices follow, with photographs shown in Figures 4, 5, and 6.

Electric Buses

- Five Proterra Catalyst E2 buses (VTA commissioned three more buses by the end of the project).
- 440 kWh battery, 352 kWh usable, Li-ion NiMnCo (NMC).
- 2-speed drive train, carbon-fiber body.

Smart Chargers

- Five ChargePoint Express (CPE) 250 smart chargers, power factor – 0.99 (VTA has a sixth charger, an older model, for backup.).
- Type: DC fast charging; each charger has 2 modules.
- Input: minimum 400 volt 3-phase AC 80A, maximum 480 volt 3-phase AC 100A.
- Output: 62.5 kW (single, can be combined for 125 kW), 200-1,000 volt DC, maximum 156A).
- Charger connectivity: LAN, WAN, remote-system monitoring.
- Liquid cooling, operating temperature -30° to 50° C.

Mobile Telematics Communication Device

- Clever Devices IVN4 intelligent vehicle network.
- Intel Atom 1.6 GHz integrated I/O co-processor; 2-GB RAM; 4 Ethernet ports with internal switches; WIFI 802.11b/g/n (optional); Cellular internal modem (optional).
- 32-channel receiver; GPS and GLONASS positioning systems.
- Dead reckoning via odometer and internal gyroscope.

Figure 4: Proterra Catalyst E2 Buses

Figure 4 (a) Proterra Catalyst E2 Bus (b) VTA Proterra Catalyst E2 Bus

Source: Photograph in Figure 4 (a) provided by Proterra; in Figure4 (b) provided by VTA.

Figure 5: ChargePoint Express Chargers

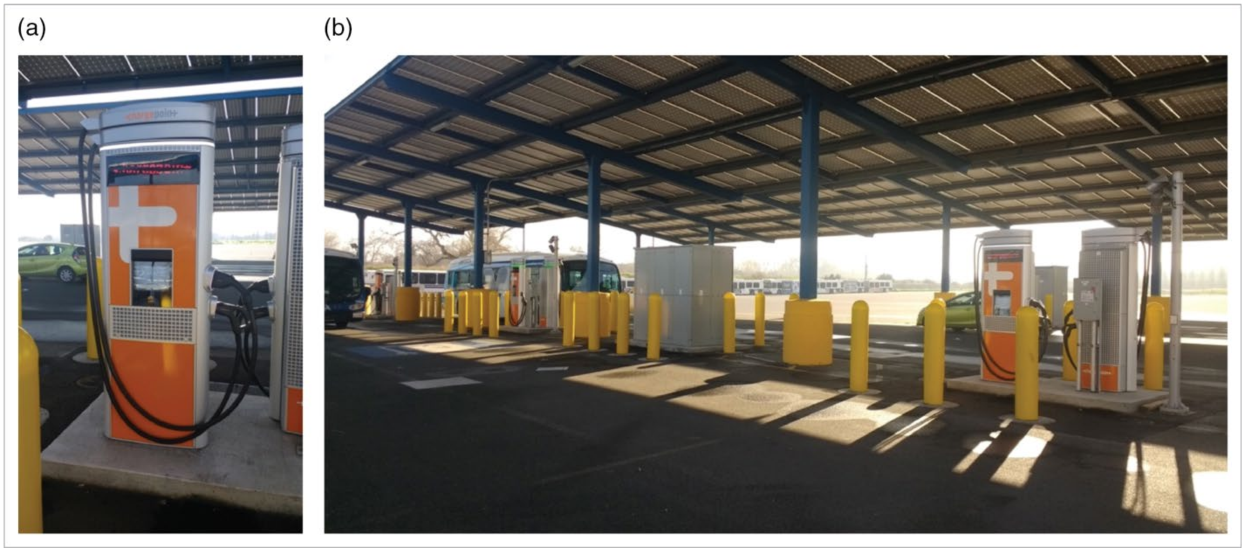


Figure 5 (a) ChargePoint Express (CPE) 250 Smart Charger (b) Smart Charger in the Cerrone Bus Yard.

Source: Photographs taken by ProspectSV staff.

Figure 6: Clever Devices On-Board Communication Devices

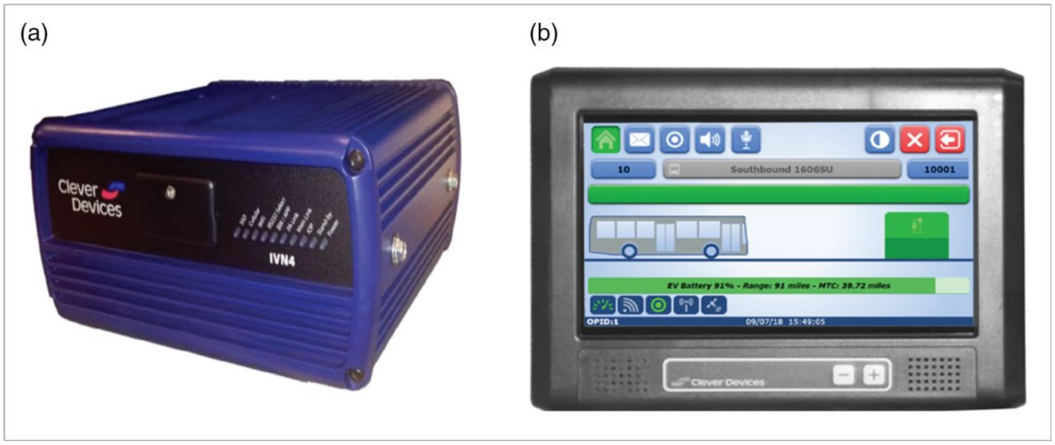


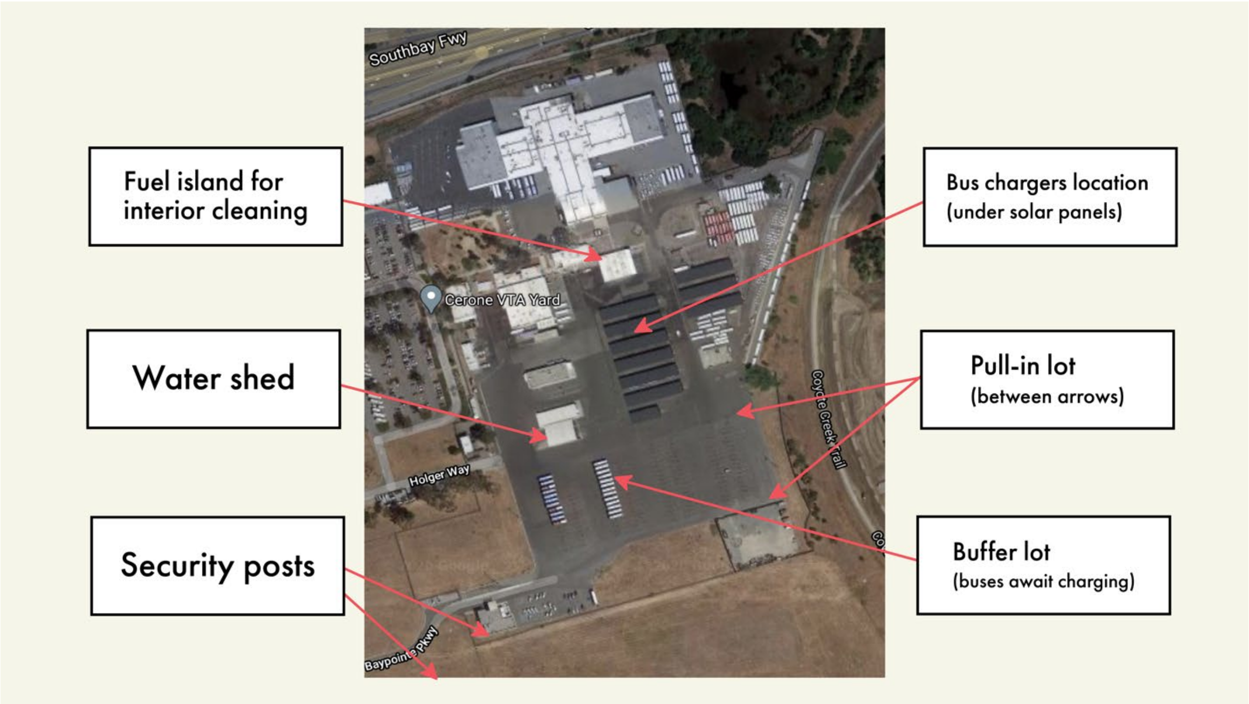
Figure 6 (a) Clever Devices IVN4 Intelligent Vehicle Network is an onboard computer that manages transportation applications to collect and transmit data in real time. (b) Clever Devices On-Board System communicates with subsystems to gather and present charging, energy usage, and performance data to the bus operator.

Source: Photographs provided by Clever Devices.

Physical Layout Design

VTA has three main bus yards: Cerrone, Chaboya, and North. The initial five electric buses were sent to the Cerrone Bus Yard. Figure 7 shows its physical layout.

Figure 7: Arial View of Valley Transportation Authority Cerrone Bus Yard



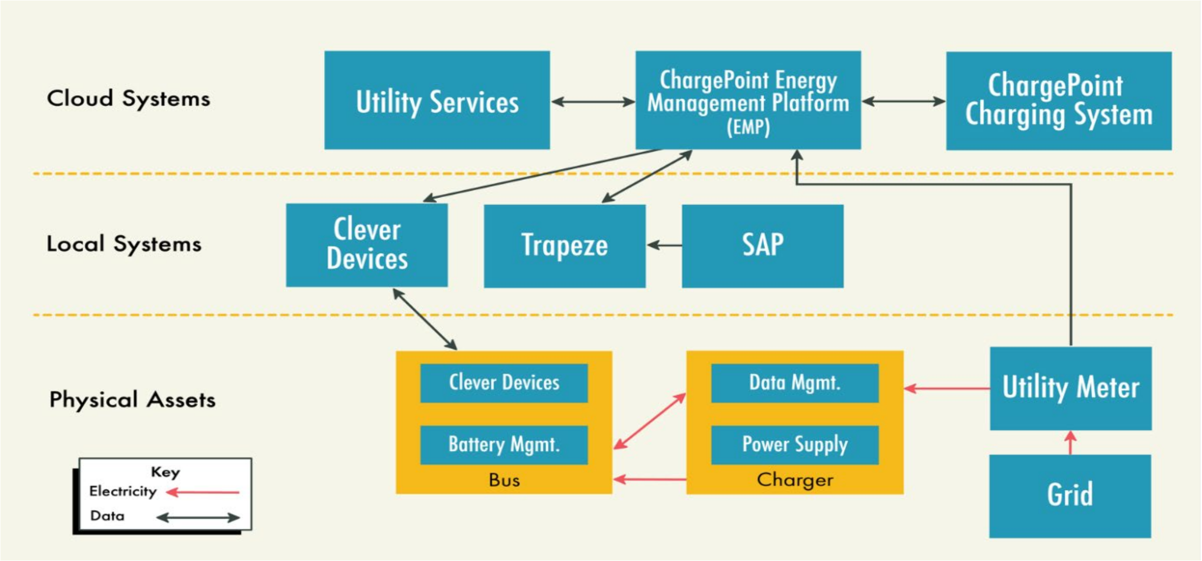
In addition to the electric buses, the Cerrone yard has all of the support equipment for operating and repairing the buses, as well as solar panels for on-site power generation.

Source: Figure created by Prospect SV using image from Google Maps: Imagery @2021 CNES / Airbus, Maxar Technologies, U.S. Geological Survey, USDA Farm Service Agency Map data @2021

Data and Electricity Flow

Figure 8 shows the layers of the system architecture and the flow of electricity and data between the components and those layers.

Figure 8: Integrated System Design



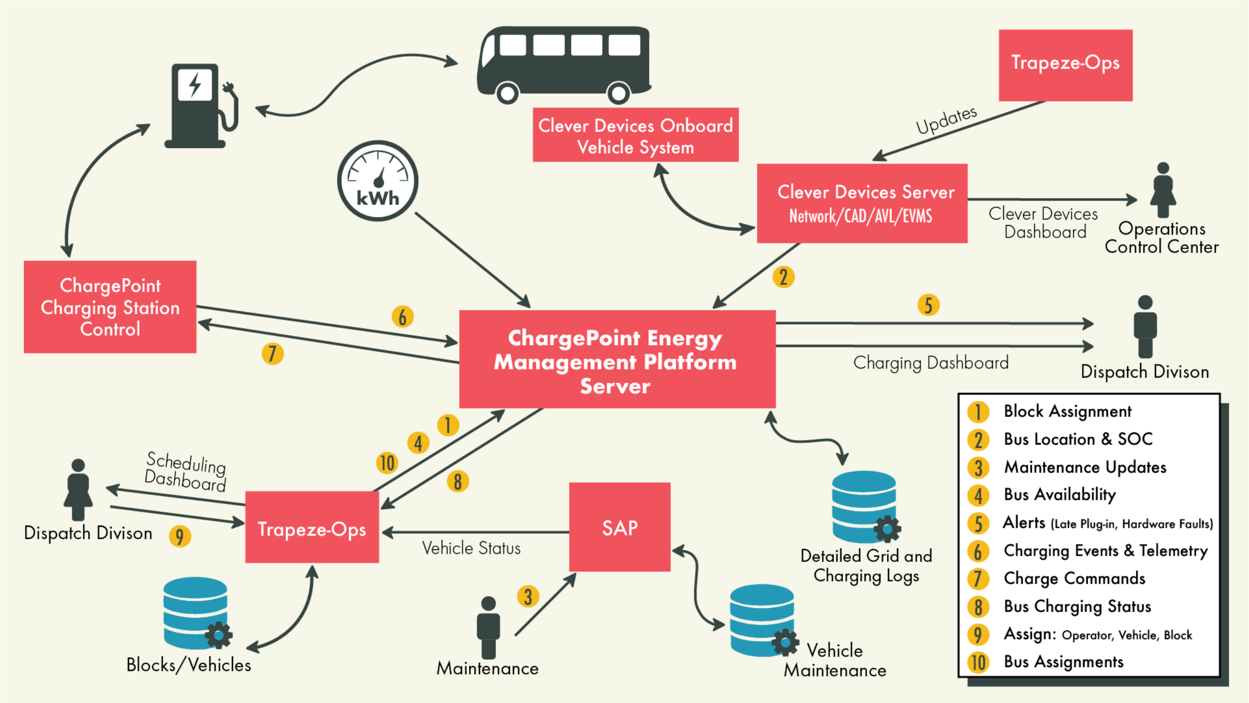
Source: Figure conceptualized by Intueor Consulting, Inc.; created by ProspectSV.

The Trapeze OPS server is hosted on the VTA server. The ChargePoint EMP server receives charging status, metrics, and EV bus telematics from ChargePoint's cloud server. The ChargePoint EMP server and the Trapeze-Ops server exchange EV bus scheduling and charging-status data. The ChargePoint EMP server also receives power and energy readings from a meter located at the site's utility connection.

Data Flow

Figure 9 illustrates how data flows through the infrastructure and vehicle components. The circled numbers in Figure 9 are described below the diagram:

Figure 9: Data Flow of System Architecture



Source: Figure conceptualized by Intueor Consulting, Inc.; created by ProspectSV.

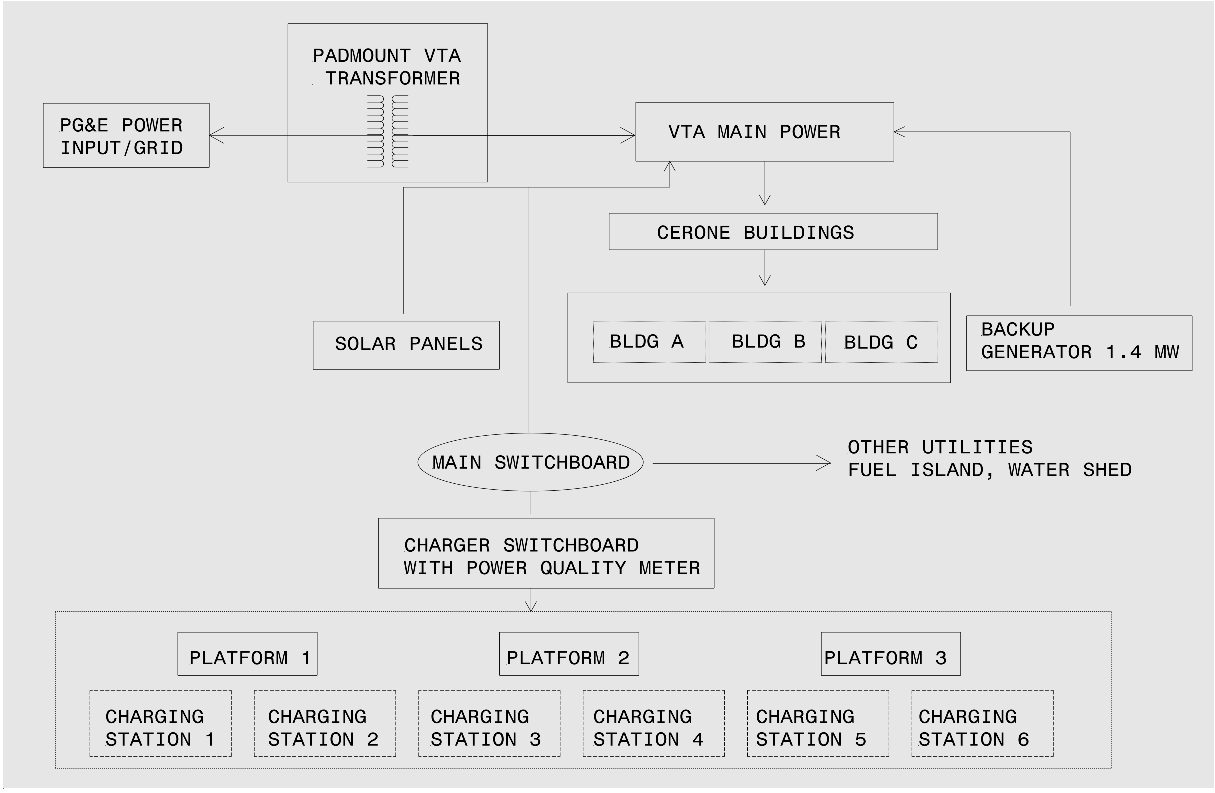
1. **Block Assignments**. A block is a collection of runs or routes completed by a single bus in a single day. Trapeze-ops assigns runs and routes to a block and conveys these assignments to the EMP via the scheduling dashboard.
2. **Bus Location and SOC**. The bus's exact coordinates and SOC are communicated from the Clever Devices onboard vehicle system to the Clever Devices server to ChargePoint's energy management platform.
3. **Maintenance Updates**. Maintenance staff updates SAP with the status of a vehicle's maintenance and return to service.
4. **Bus Availability**. When assigning buses to blocks, the system determines bus availability by checking for bus maintenance status and SOC. SAP communicates vehicle maintenance status to Trapeze-Ops and EMP conveys charging status to Trapeze-Ops.
5. **Alerts** (late plug-ins or hardware faults). The EMP charging dashboard presents alerts to the dispatch division about vehicle status (such as loss of communication with bus number 7501, charger 4 fault code, 23 unavailable).
6. **Charging Events and Telemetry**. The ChargePoint charging station control sends the EMP charging events data such as power at various intervals, energy added, AC supply and DC output, and utility cost. It also sends the telemetry data collected from the Clever Devices onboard vehicle system, such as location and SOC.
7. **Charge Commands**. Based on need, the EMP creates and sends charging commands to the ChargePoint charging station control (for example charge the bus at 20 kW or turn off charging when SOC reaches 75 percent).

8. **Bus Charging Status**. The ChargePoint station control conveys the SOC to the EMP, which conveys it to Trapeze-Ops for bus availability and bus assignments.
9. **Assign**. Dispatchers assign operators and can overwrite existing assignments via the Trapeze-Ops scheduling dashboard; Trapeze-Ops then conveys this information to the EMP.
10. **Bus Assignments**. Based on bus availability, operator assignments, and SOC, Trapeze-Ops assigns blocks to buses and conveys these assignments to the EMP.

Electricity Flow

The block diagram in Figure 10 illustrates the flow of electricity within the Cerrone facility from the PG&E grid to the chargers and other facility loads. It also shows the connection between the solar panels and PG&E's electric grid.

Figure 10: Flow of Electricity



Source: Diagram by VTA.

As indicated in Figure 10, VTA's main power comes through the PADMOUNT transformer before it's routed to buildings A, B, and C. In the event of a power outage, staff connects a 1.4 MW generator to the main, which then acts as a source. Although not directly used by VTA, the 969 kW solar panel produces another source of power and sends it back to PG&E, earning partial credits for the VTA.

A switchboard, connected to the VTA's main, divides electricity between other utilities and chargers. The chargers are equipped with a separate switchboard that distributes power. The six charger units are mounted on three elevated platforms, each housing one charger cable for charging the buses.

Cybersecurity of System Design

Once the team completed the system design, the VTA's cybersecurity analyst assessed the proposed system's security and provided the VTA with strategies to mitigate identified threats and risks. The assessment ensured the security of all physical assets (such as buses, chargers, routers, servers), software (applications, operating systems, APIs, embedded system components), and codes used by applications, from cyberattacks. It also ensured network security by isolating segments carrying sensitive data using firewalls and gateways when interfacing with external systems and applying other industry-standard network-security protocols. The analysis also provided tools for ensuring that Cloud providers additionally protect VTA systems and data from cyberattacks.

The ongoing cybersecurity policy framework enables the VTA to assess the security of the VGI system periodically and systematically during operations as they evolve.

Project Deployment

The team divided the project into three phases. The primary goals of each phase and key outcomes and challenges for phases 1 and 2 follow.

Phase 0: Deployment Planning

The key goals of Phase 0 operation included commissioning five Proterra e-buses, five ChargePoint CP250 charging stations, and one backup ChargePoint CP200 charging station at the Cerrone yard.[11] Other goals included operating the e-buses without automated charging or energy management, assigning e-buses only to routes that consumed 75 percent or less of the battery energy, and setting charge times to seven hours or greater per bus at 60 KW per hour. Unfortunately, the delivery and commissioning of the e-buses were delayed to Phase 1.

Phase 1: Integrated System Deployment

Phase 1 Key Outcomes

Phase 1 deployment began on November 1, 2019 and ended on January 9, 2020. For this phase, VTA commissioned and deployed five Proterra e-buses, five ChargePoint CP250 charging stations, and one backup ChargePoint CP200 charging station at Cerrone yard.

The team successfully deployed the ChargePoint EMP. The team integrated the EMP with Clever Devices On-Bboard telematics and with the VTA dispatch data on bus scheduling and charging, which the VTA operations team manually entered. The team integrated all VTA-VGI system architecture elements in Phase 1 with the exception of the Trapeze-Ops bus-routing system. Subcontracting issues caused the Trapeze/EMP integration to be delayed until Phase 2.

The EMP monitored the energy status of all five Proterra e-buses and generated charging plans that guided VTA operations staff on charging plans for each bus. EMP's charge-planning software managed bus charging and adopted an energy-cost-minimization strategy. The

---

[11] The VTA initially installed CP200 charging stations and upgraded to CP250 when they became available in 2019.

software routinely delayed evening charging, waiting for the arrival of lower time-of-use tariff costs before charging the buses to full power.

In preparation for Phase 1 deployment, ChargePoint trained VTA Cerrone Yard's maintenance foreperson, bus-operator trainer, and scheduler on EMP. The project team also developed an operations training manual.

In this phase, the team began gathering data to compare diesel-hybrid and electric buses both with and without energy management and smart charging.

Phase 1 Key Challenges

- **Delays**. Phase 1 deployment was delayed and extended because of significant delays in receiving products and services. Extremely high demand for the Proterra buses delayed delivery, and manufacturing issues caused additional delays. For example, the buses did not come with the right parts, including the Clipper-card payment booths that took six months to install. Minor design issues took several months to resolve. Unscheduled bus maintenance caused delays in project deployment since the buses were under warranty so Proterra service technicians had to come on site to fix them. There were also delays with the delivery and installation of ChargePoint chargers.
- **Bus Availability**. In theory, each of the Proterra buses would drive one of a limited set of blocks each day. In practice, buses were occasionally unavailable due to maintenance activity (waiting on parts) or were not needed on a particular day. As Phase 1 did not include automated integration of dispatching and maintenance data into the EMP, a workaround required VTA's operational staff to enter data manually into the EMP.
- **EMP Dashboard Screens**. The original design intended that dispatchers and yard personnel would interact continuously with the EMP's dashboard screens for receiving information and then acting on its guidance. In practice, this did not happen in Phase 1. Dispatchers and yard personnel, arriving in the morning to fully charged EV batteries, had no incentive to monitor the EMP dashboard or follow its guidance on when and where to plug or unplug vehicles. As a result, there was a disconnect between the EMP's charging plans and actual bus-charging activity. To address this information and communications gap, the team planned additional EMP training for Cerrone yard staff in Phase 2.
- **Charging Plans**. The team erroneously assumed that an EV's energy consumption could be predicted using the number of driving miles per block. This, in turn, would theoretically enable the EMP to charge a battery with only enough energy to meet the block's mileage requirement. This prediction proved unreliable because of variations in driver behavior, ambient temperatures, and other factors. Consequently, VTA personnel preferred the buses to be fully charged, minimizing the risk of depleting a battery en route. This charge-to-full strategy significantly limited the EMP's options for conserving energy costs.
- The team determined that it needed to use a broader set of factors to calculate each bus or block's energy-efficiency ratio (kWh/mile). Over time the database would grow along with the duration of EMP deployment, improving accuracy and predictability.
- **Managing SOC Threshold**. Phase 1 confirmed the project team's expectation that low ambient temperatures would significantly affect an e-bus SOC. The VTA has an e-bus

SOC threshold of at least 10 percent SOC while in service. To address this, from 4 a.m. to 4:20 a.m., VTA operated a defrost heat pump for 20 minutes to heat the bus to its maximum interior temperature of 81°F (27.2°C). The heat drops the SOC from 99 percent to 95 percent, followed by charging for 30 minutes to bring the SOC back to 98 or 99 percent. To further mitigate this issue, VTA implemented intensive training for bus drivers to get maximum energy from regenerative braking, uniform acceleration, and minimum heating, ventilation, and air conditioning (HVAC) use. These actions helped achieve the target 178 miles with a 352 kWh and 10 percent SOC remaining at an incredible efficiency of 1.8 kWh/mil.

- **Operations Issues**. Near the end of Phase 1, VTA's system-wide overhaul of its bus services and routes led to longer blocks than in the prior bus service plan. This change required further training to ensure that bus drivers could make those blocks within the designated buffer of 10 percent SOC.

Phase 2: Scaling and Additional Features

Phase 2-Key Outcomes

Phase 2 deployment was scheduled from April 10, 2020 to July 2, 2020. Due to delays, however, it began in September 2020 and ended in December 2020; new buses and troubleshooting continued into early 2021. Phase 2 goals included extending system capabilities, increasing smart-charging benefits, preparing for future scaling, and collecting data to verify project benefits.

The team integrated the Trapeze-Ops scheduling system with the EMP to provide routing, scheduling, and maintenance data. The interface was developed between EMP and SAP to import vehicle and battery characteristics and vehicle availability. With these integrations complete, the team tested and validated all the EMP functions.

The VTA planned to add five more buses, but because of delivery delays only three additional buses arrived before the end of Phase 2. Once the additional Proterra buses arrived, the team installed the Clever Devices EVMS system.

Another goal for Phase 2 was to further minimize energy costs by having more e-buses than chargers. This ratio limited bus charging to a value sufficient to comfortably complete the assigned block instead of fully charging the buses (as happened in Phase 1). Bus delivery and other delays required workarounds to simulate, test, and verify EMP functions for managing bus charging sequences when the bus-to-charger ratio would no longer be one to one. To simulate this sequencing, the team limited the number of chargers to buses by limiting the five buses to three chargers instead of five.

Phase 2: Key Challenges

COVID-19. COVID-19 and the shelter-in-place order caused major disruptions in VTA's operations, especially for Phase 2 deployment. VTA reduced its transit services from March to June. E-bus service did not resume until July 2020.

Bus Delays. COVID-19 delayed the new bus delivery timeline impacting the schedules for commissioning, installing the On-Board Clever Devices system, and testing varying bus-to-charger ratios. The team continued to experience delays due to bus maintenance issues.

Interface issues. It took several months to resolve problems with assigning block definitions assignments between Trapeze Ops and the EMP.

Data Collection Issues. Delays in Phase 1 compounded by delays in Phase 2 created challenges in creating and collecting enough data to generate a robust analysis of savings in cost and energy consumption. The team developed workarounds to ensure sufficient data to assess project benefits.

Work in Phase 2 led to Phase 3, which was outside the scope of this project but a critical part of the VTA path to fleet electrification. The VTA plans to develop a smart microgrid system to augment charging from the electric grid. It will include a second-life lithium-ion (Li-ion) battery system for energy storage, a PV system for energy generation, and a control system to manage the flow of energy between the PV system, the grid, and the energy-storage system. The system will also manage the split between the stored-energy and the grid-supplied energy to charge the e-buses. Once developed, the VTA will integrate this new system with the EMP developed in this VTA/VGI project to optimize charge plans for the e-buses.

CHAPTER 3:
Project Results

NREL performed measurement and verification (M&V) of e-bus operations for the VTA. The team used data from over 11,000 hours of in-use VTA bus operations to compare existing diesel-electric hybrid bus operations with the newly added Proterra BEBs to assess performance and emission reduction potentials. NREL also analyzed bus charging behavior and provided the VTA with a financial modeling tool to analyze e-bus operations.

Table 1 shows the data sources used in M&V activities. The first four items provide the primary data for the analyses. ChargePoint EMP data output is the fifth item, which is VTA electricity demand. The sixth item is indirectly considered a part of the site electricity demand.

Table 1: Summary of Data Sources for Measurement and Verification

Source	Description	Date Range
NREL logger data	Onboard logging of bus properties and GPS for 29 buses including 40-foot and 60-foot diesel and diesel-electric hybrid buses.	1/22/2018-2/12/2018
Proterra API data	74 data points with 1 Hz resolution	12/3/2019-1/3/2020 4/20/2020-5/20/2020 6/14/2020-8/6/2020
ChargePoint EMP data for its entire operation	Energy cost, optimizer, charging, alerts, load-smoothing and block reports	02/06/2020-11/1/2020
VTA Cerrone utility bills	15 billing properties with monthly resolution	6/28/2017-11/1/2020
VTA Cerrone electricity demand	Usage, temperature and peak demand with 15-minute resolution	7/23/2017-7/14/2020
VTA PV production for 3 years with 5-minute resolution	Average solar energy production with 5-minute resolution	1/1/2017-12/30/2019

Source: National Renewable Energy Laboratory

Bus Performance

The team analyzed fuel economy and found that VTA's e-buses averaged 23.1 MPGe while the hybrid buses averaged 5.8 MPG. The fuel efficiency analysis showed an average efficiency of 1.8 kWh/mi for the e-buses compared with 2.25 kWh/mi for the diesel-electric hybrid bus.

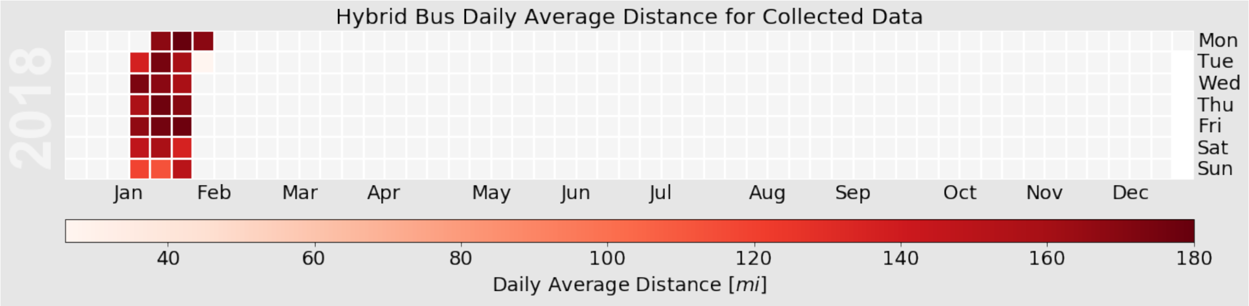
In analyzing fuel emissions, the team found that the hybrid-bus diesel engines produced 1.72 kg/mi CO_2, 2.08 g/mi NO_X, and 0.02 g/mi SO_X of tailpipe emissions; the e-buses, of course, had zero tailpipe emissions. The team also considered emissions from producing fuel. On average, the electric bus had 84.0 percent lower CO_2 emissions and 81. -percent lower NO_X emissions than the hybrid bus and eliminated SO_X emissions.

The following sections describe the methods and analyses that produced these results.

Fuel Economy

To compare the fuel economies of VTA's diesel-electric hybrid buses and the Proterra BEBs, the team first calculated daily miles traveled and determined miles per gallon (mpg) and miles per gallon of gasoline equivalent (MPGe).[12] Figure 11 summarizes the daily miles traveled by the baseline hybrid buses; the darker red indicates more miles. Table 2 summarizes these findings.

Figure 11: Daily Average Bus Distance of Diesel-Electric Hybrid Buses



Source: National Renewable Energy Laboratory.

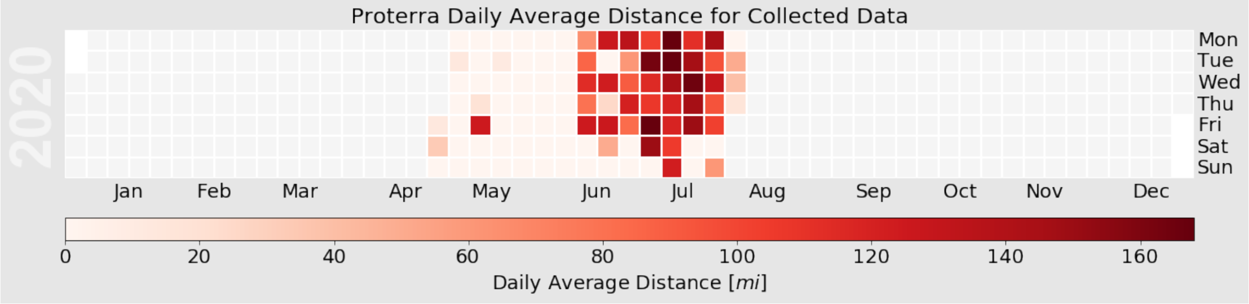
Table 2: Summary of 2018 Hybrid Bus Data Collection

Parameter	Miles	Gallons Used	Hours of Operation	Vehicle Days
Value	73,273	13,009	5,715	513

Source: National Renewable Energy Laboratory.

Figure 12 shows the daily miles driven by the e-buses, and Table 3 summarizes the data and illustrates the gallons of fuel using the diesel equivalent of MPGe.

Figure 12: Daily Average Bus Distance of E-buses



Source: National Renewable Energy Laboratory.

---

[12] The Environmental Protection Agency introduced MPGe as an energy-efficiency metric for comparing the amount of energy consumed by alternative fuel vehicles to traditional gas-powered cars.

Table 3: Summary of 2020 E-Bus Data Collection

Parameter	Miles	MPGe Gallons Used	Hours of Operation	Vehicle Days
Value	12,659	572	5,452	469

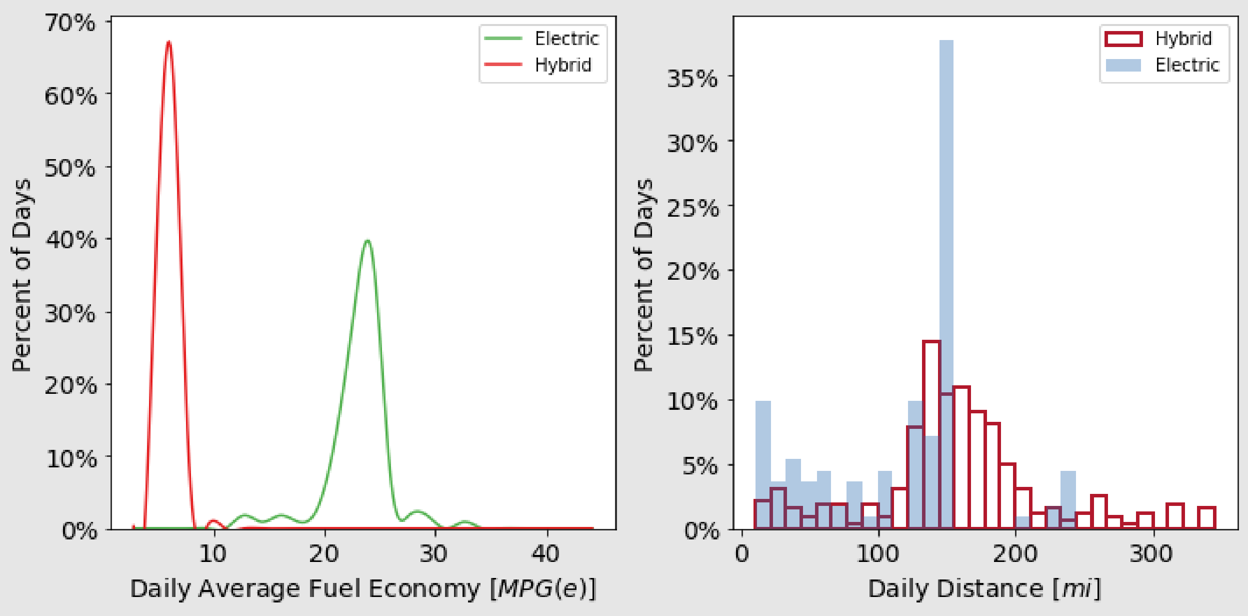
Source: National Renewable Energy Laboratory.

The e-buses used far less energy than the hybrid buses, reflecting the efficiency of electric power-train technology. To illustrate this advantage, the team compared the energy used per mile.

The MPGe is the equivalent fuel use, based on the fuel's energy content. Diesel contains approximately 37.6 kWh of energy per gallon. The team converted e-bus energy use to equivalent fuel use. As shown in the left plot of Figure 13, the BEBs averaged 23.1 MPGe, while the hybrid buses averaged 5.8 MPG.[13]

The team next compared distances traveled. The right plot in Figure 13 shows the distribution of daily distance by power-train type. While both power-train types have median daily distances of around 150 miles, the hybrid power train has a wider distribution with a maximum daily distance of 344 miles when compared with the e-bus maximum daily distance of 238 miles. This difference reflects the BEB range limitation of 350 kWh of usable battery.

Figure 13: Distribution of Fuel Economy (left) and Daily Distance Traveled (right)



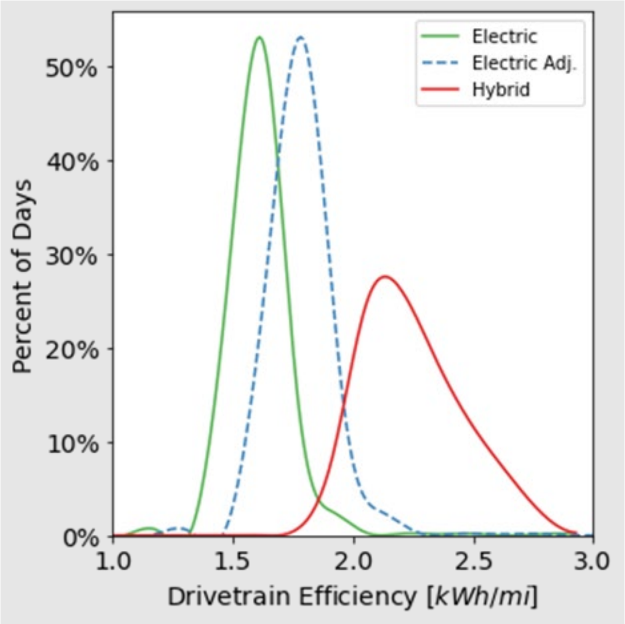
Source: National Renewable Energy Laboratory.

Next, the team estimated the energy use per mile. Figure 14 shows the distribution of day-averaged, e-bus energy use per mile (solid green line) with an average of 1.61 kWh/mi. Figure 14 shows the engine-energy production per mile after heat rejection averaging 2.25 kWh/mi for the hybrid bus; this compares drive-train efficiencies of the hybrid and fully electric technologies.

---

[13] This dramatic increase in efficiency reflects, in part, the lack of thermal losses that occur in combustion engines.

Figure 14: Distribution of Daily Average Driveline Efficiency



Source: National Renewable Energy Laboratory.

The green line in Figure 14 is energy use measured at the battery outlet. But if energy use is measured based on energy put into the battery from charging and incorporates a 95 percent conversion-charger efficiency, energy use per mile is higher. Based on these efficiency adjustments, the dashed blue line in Figure 14 shows an adjusted distribution of daily average efficiency with an average efficiency of 1.8 kWh/mi.

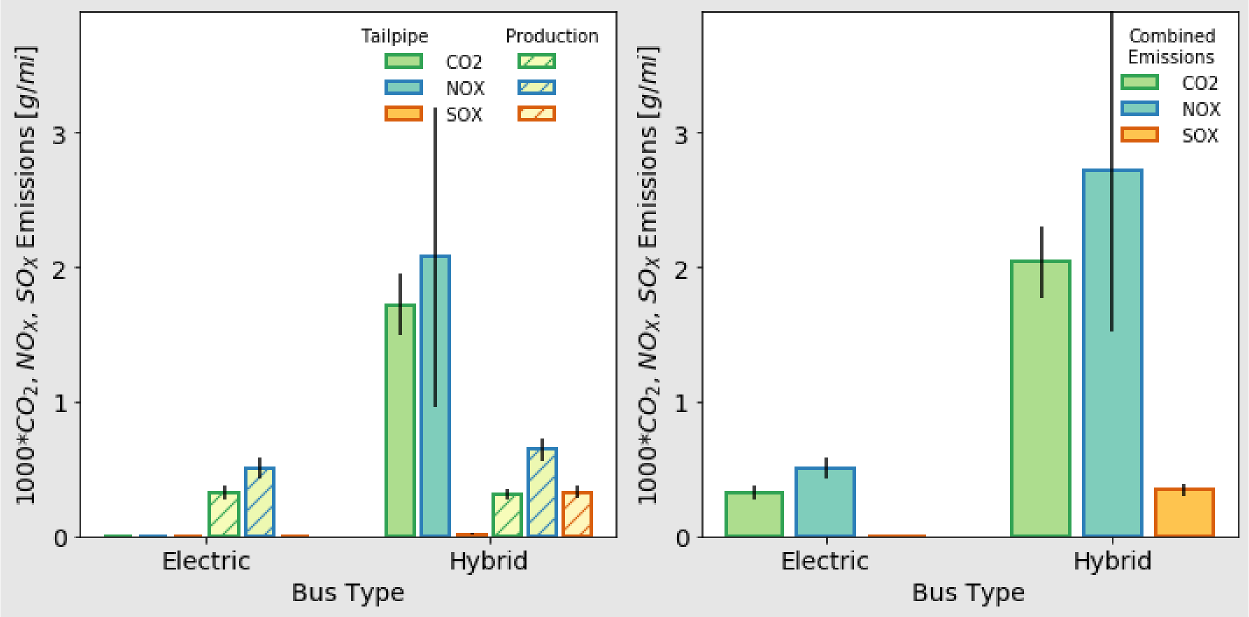
Bus Emissions

Emission reduction is another critical benefit of bus electrification. While CO_2 is a GHG and produces the greatest emissions by weight, NO_X and SO_X are criteria pollutants that both affect local air quality and contribute to smog.

The team calculated tailpipe emissions for the hybrid bus from the fuel rate for CO_2 and SO_X, and assumed that all carbon is converted to CO_2. Researchers measured the NO_X emissions from the after-treatment sensors, which detect particulate matter. As expected, the e-buses had zero tailpipe emissions while the hybrid’s diesel engines produced 1.72 kg/mi CO_2, 2.08 g/mi NO_X, and 0.02 g/mi SO_X of tai-pipe emissions.

It is also important to consider the emissions from producing the fuel. Figure 15 shows tail-pipe emissions and emissions from the production of the energy source used to power the bus for NO_X, SO_X, and CO_2 emissions.

Figure 15: Emissions from Tailpipe and Production Sources



The left plot compares tailpipe and production sources of emissions for electric and hybrid buses. The right plot compared the combined tailpipe and production emissions of both bus types.

Source: National Renewable Energy Laboratory.

Emission rates for the diesel-fuel production are from the Argonne National Laboratory *Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model* (GREET), and the electricity emissions are from the Energy Information Administration's *California Electricity Profile* report for 2019.[14] [15]

Considering production emissions, the e-bus produced on average 3.25 kg/mi CO_2, 0.51 g/mi NO_X, and 0.00 g/mi SO_X, while the hybrid diesel's emissions were 3.14 kg/mi CO_2, 0.65 g/mi NO_X, and 0.033 g/mi SO_X.

The right plot in Figure 15 combines these two types of emissions to show the overall emissions for each bus type. On average, the e-bus had 84.0 percent lower CO_2 emissions and 81.2 percent lower NO_X emissions than the hybrid bus and eliminated SO_X emissions. These substantial reductions are due to elimination of tailpipe emissions.

Since the California grid has a large percentage of renewable-energy sources, e-buses consume cleaner energy. As more renewable resources are added to the state's electric grid, emissions for electric transportation overall will continue to fall.

Bus Charging Behavior

Electric Bus Use

The team examined the ChargePoint EMP charging data to analyze when and how often the electric buses were used; this data was essential for planning and improving smart charging.

---

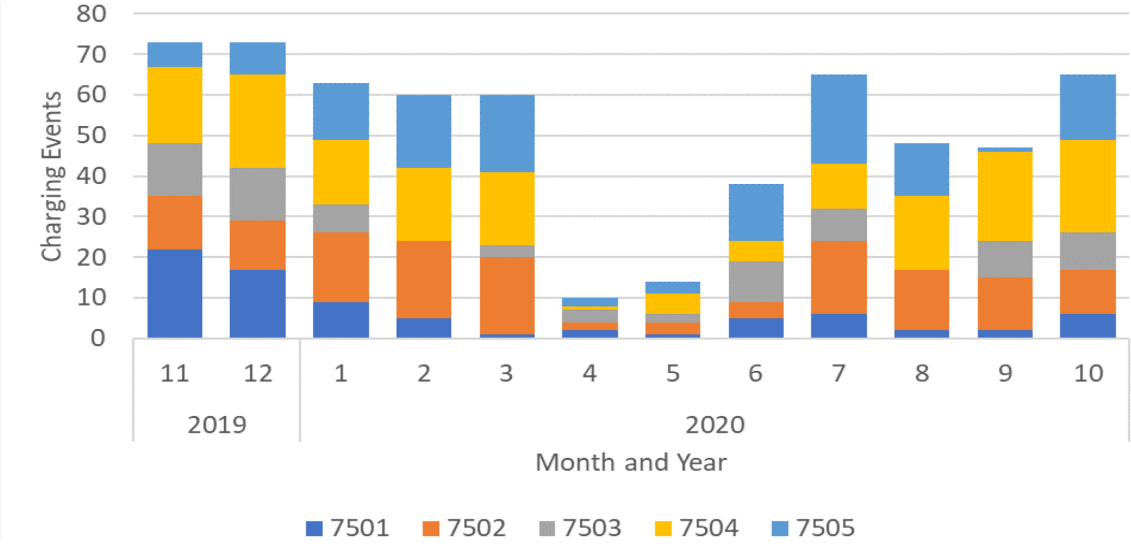
[14] The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model is an analytical tool that simulates the energy use and emissions of various vehicles and fuel combinations.

[15] EIA California Electricity Profile

Figure 16 shows the number of charge events each month over one year. In the last two months of 2019, the VTA used the e-buses around 43 percent of all days. Because of ridership reductions from COVID-19 restrictions, use fell dramatically during April of 2020 and later recovered; from July through October, use was 37 percent.

Figure 16: Monthly Charging Events for E-Buses

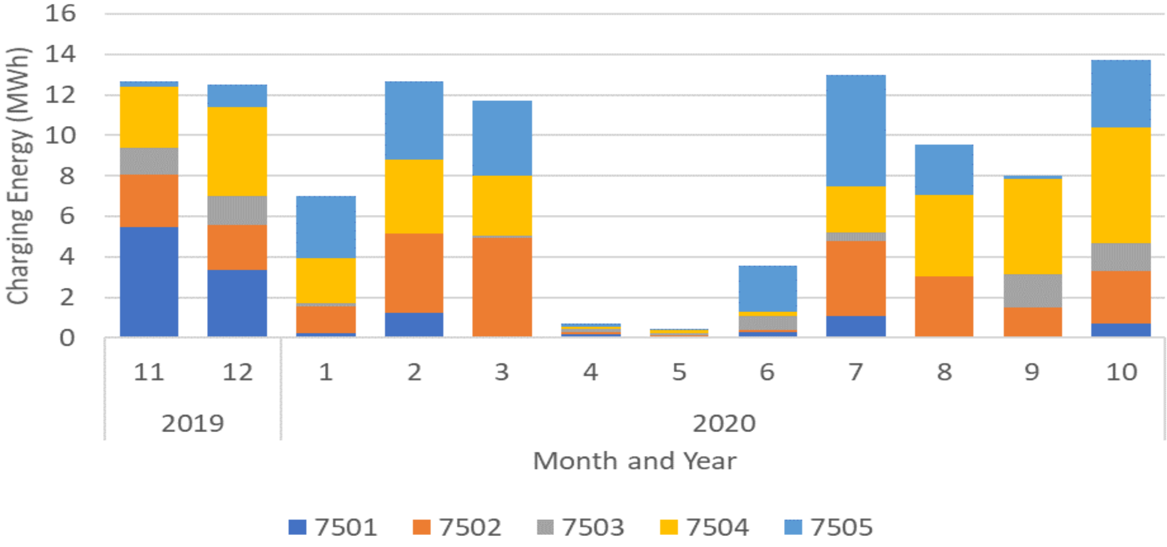
From 11/1/2019 to 10/31/2020



Source: National Renewable Energy Laboratory using ChargePoint EMP data.

The team also tracked the amount of energy delivered. Figure 17 shows total monthly charging energy delivered to each bus over one year. Assuming that the electric buses have a usable stored-energy level of 350 kWh, daily energy usage was about 16 percent of a full charge. Discounting April, May, and June, that value jumps to 21 percent; considering only weekdays, daily energy consumption climbed to 30 percent. Figure 17 shows a 5-day charging cluster followed by two days of reduced or zero charging, confirming that the buses are almost exclusively driven on weekdays.

Figure 17: Monthly Charging Energy From 11/1/2019 to 10/31/2020



Source: National Renewable Energy Laboratory with data from ChargePoint.

Timing and Extent of Bus Charging

Effective smart charging depends on coordinating the timing of bus charging with retail utility rates to minimize demand and energy charges. Throughout the project, VTA received services under PG&E's A-6 time-of-use rate (TOU). Figure 18 shows the timing of energy-cost periods for hours of the day by month and during weekdays and weekends. Table 4 shows energy-cost values of each time period. A-6 TOU does not have a demand-charge component.

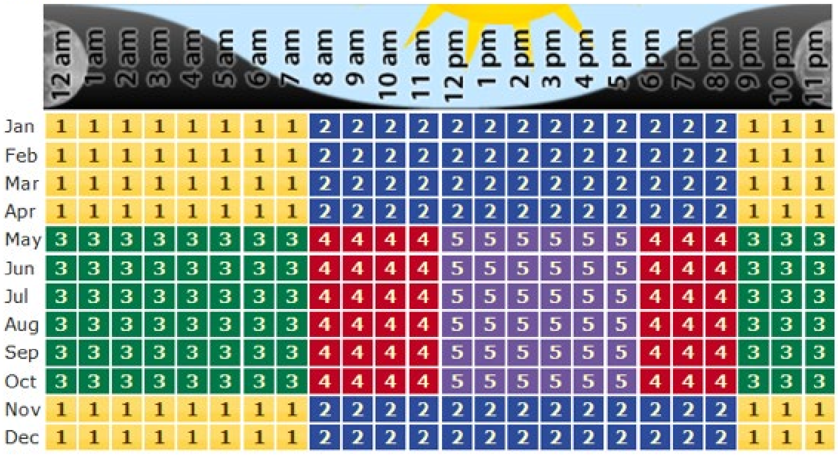
Table 4: Electricity Cost-Per-Unit Energy for A-6 TOU by Time Period

Period	Rate $/kWh
1	0.2184
2	0.2367
3	0.2216
4	0.2932
5	0.59

Source: National Renewable Energy Laboratory using the utility tariff sheet for A-6 TOU which sets peak, partial-peak and off-peak periods for weekdays, weekends, summer, and winter.

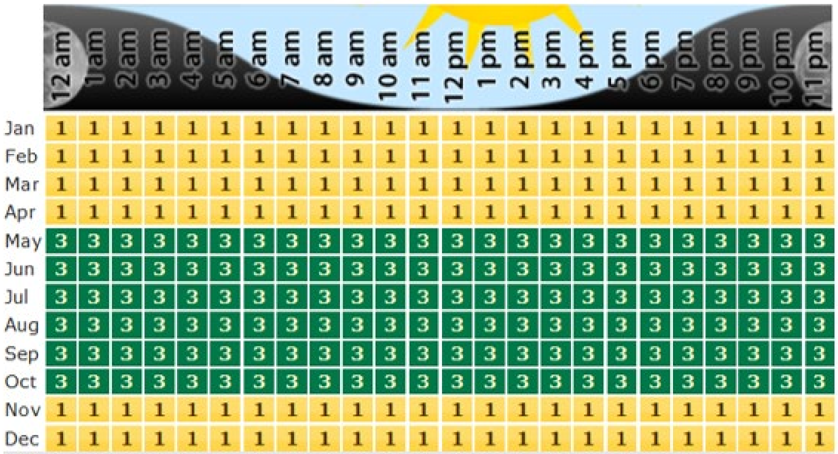
Figure 18: Pacific Gas and Electric Company A-6 TOU-Rate Timing

Weekday Schedule



	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Feb	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Mar	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Apr	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
May	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Jun	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Jul	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Aug	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Sep	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Oct	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Nov	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Dec	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1

Weekend Schedule



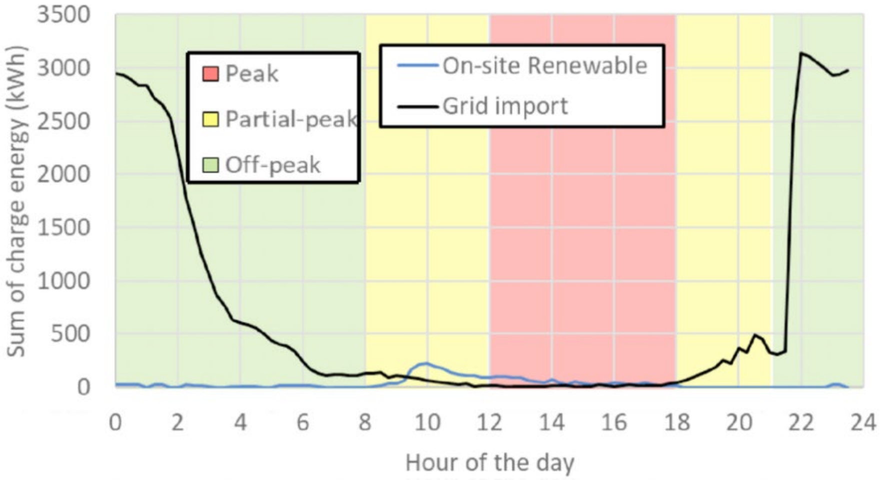
	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Feb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Apr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jun	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jul	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Aug	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Oct	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Nov	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dec	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: National Renewable Energy Laboratory Using Utility Rate Database.

The charging rate during summer peak (Period 5) is far higher than during other periods, and the charging rate during summer partial-peak (Period 4) is at least 30 percent higher than during periods 1, 2, and 3. Weekend days are off-peak, with no charging penalty. The ChargePoint controller nearly eliminates the consumption of grid energy during peak and partial-peak periods.

Figure 19 shows that most of the energy consumed by charging off the grid occurred during off-peak periods. Given the bus charging schedules, the e-buses consumed only a minimal amount of energy during peak periods.

Figure 19: Charging Energy of E-Buses on the Summer Schedule for A-6 TOU



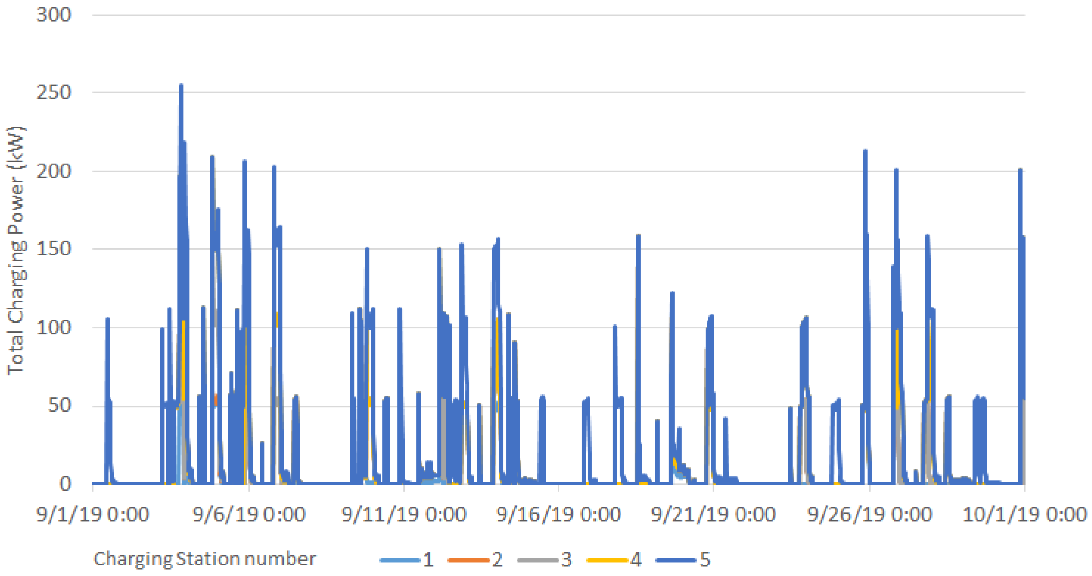
Hourly Weekday Charging Energy of E-buses from On-site Renewable and Grid Import Superimposed on the Summer Schedule for A-6 TOU

Source: National Renewable Energy Laboratory.

The evening charging typically begins at 9:45 p.m., though it could start as early as 9:00 p.m. without any cost penalty. Unavoidable daytime charging may occur if scheduling issues require that either the ChargePoint controller or the staff (manually) charge the bus during the day or charge a bus for a specific purpose.

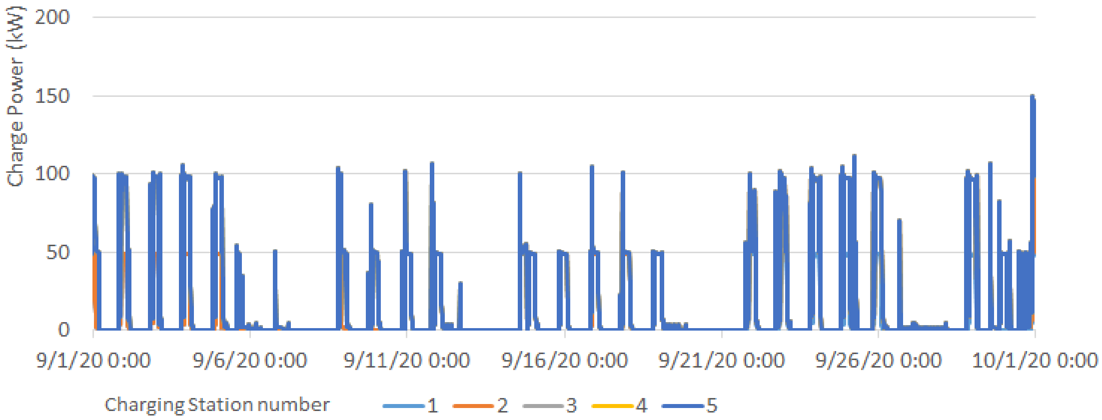
The team examined the differences in managed and unmanaged charging by comparing intervals of bus charging. Figure 20 shows unmanaged charging in September 2020, while Figure 21 shows managed charging in September 2020. Under unmanaged charging, peak-charging power fluctuates day to day; under managed charging, peak-charging power is typically the same value each day.

Figure 20: Intervals of Bus Charging During Unmanaged Charging



Source: National Renewable Energy Laboratory with data from VTA and ChargePoint.

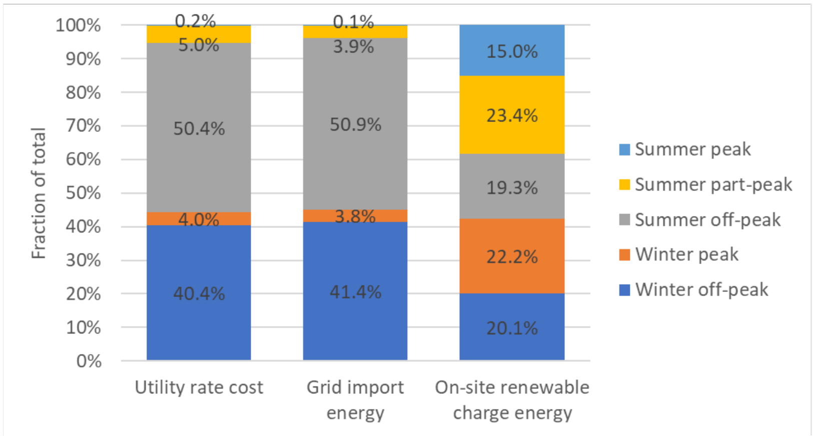
Figure 21: Intervals of Bus Charging During Managed Charging



Source: National Renewable Energy Laboratory with data from VTA and ChargePoint.

Figure 22 shows the percentage of peak uses of electricity cost, grid import, and on-site renewable generation for charging e-buses.

Figure 22: Breakdown of Utility Rate Cost for Charging E-Buses



Breakdown of Utility Rate Cost, Grid Import and On-site Renewable Energy used for Charging VTA E-buses.

Source: National Renewable Energy Laboratory with data from VTA, ChargePoint and PG&E A-6 TOU rate schedule.

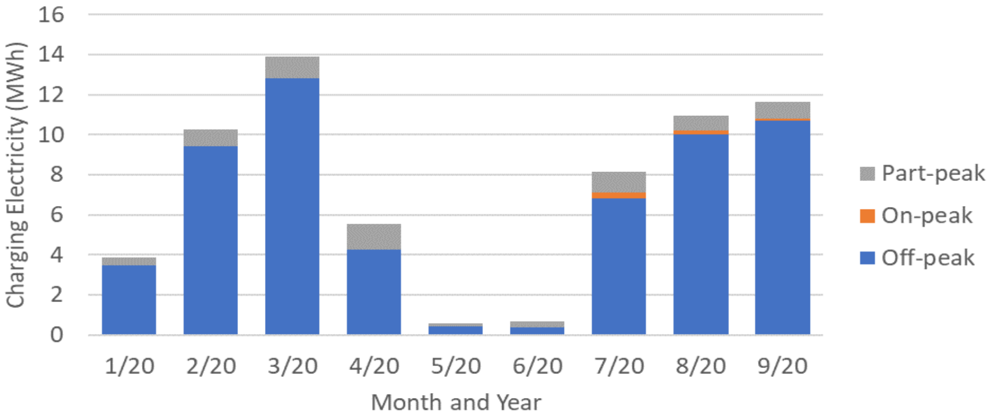
Energy purchased during the summer peak makes up less than one-tenth of one percent. The summer partial-peak is 3.9 percent of all energy consumed by the e-buses. On-site renewable-energy production is relatively evenly distributed across rate periods. Weekends and holidays are all off-peak, which helps direct more renewable generation to off-peak periods.

Financial Analysis

The team created a financial performance model for VTA staff to analyze several metrics of cost and performance for the e-buses. Researchers validated the model by comparing actual billed-electricity consumption with modeled data; this improved the model by integrating the net surplus electricity compensation (NSC) rate, [16] (which is part of the net energy metering utility rate [NEM]) to accurately account for on-site electricity generation.

Figures 23, 24, and 25 show some of the analyses the model performed for the VTA.

Figure 23: E-Bus Peak Charging by Billing Period

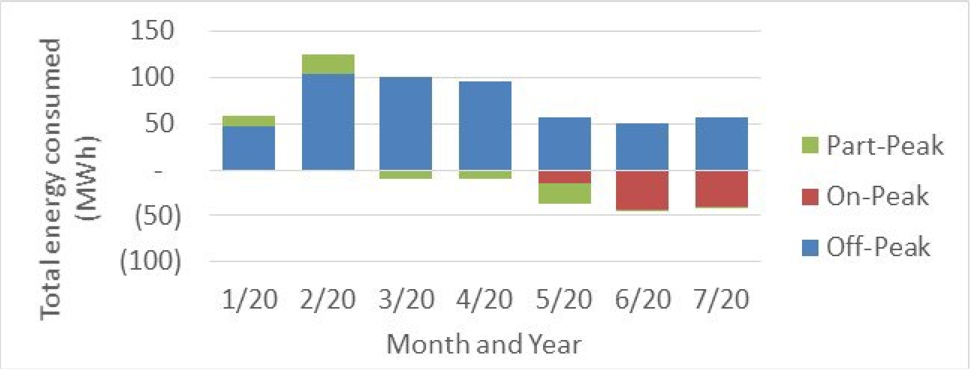


Source: National Renewable Energy Laboratory with data from VTA using the National Renewable Energy Laboratory performance model.

---

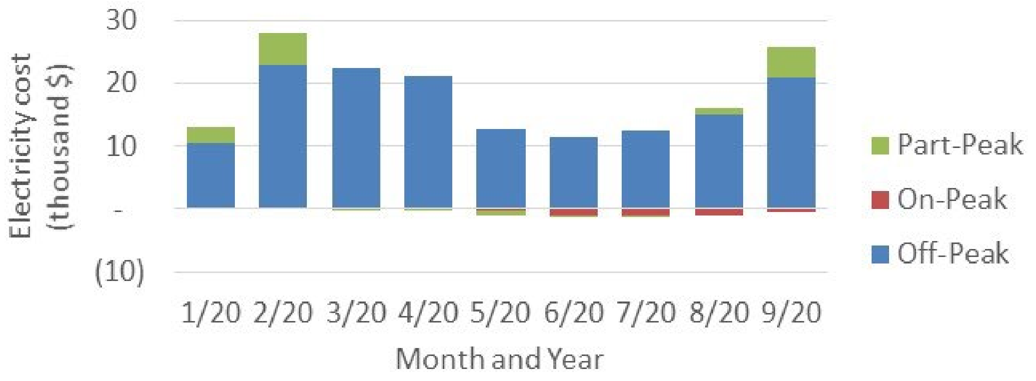
[16] PG&E NSC rate list.

Figure 24: Energy Consumed by Billing Period



Source: National Renewable Energy Laboratory with data from VTA using the performance model.

Figure 25: Energy Cost by Billing Period



Source: National Renewable Energy Laboratory with data from VTA using the performance model.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

The knowledge transfer activities for this project had two broad objectives. The first was to demonstrate the benefits of including an integrated energy management platform in the agency's long-term electrification strategies. The second was to create programs that address California EV labor-market-readiness issues. The knowledge transfer teams worked to:

- Increase understanding of opportunities for expanding e-bus energy management systems in the state
- Educate and engage a diverse set of stakeholders: transit agencies, vehicle OEMs and suppliers, utilities and energy-service professionals, and policymakers at the local, regional, state, and federal level
- Inform and engage stakeholders with presentations on the overall project framework, economic and energy outcomes, challenges and approaches, and policy considerations for e-bus deployment
- Conduct outreach and education primarily through events and dissemination of technical resources

The team undertook two key strategies to disseminate project findings, products, and services for diverse stakeholders. First, researchers created strategic-knowledge-transfer partnerships with three not-for-profit organizations to leverage their specific technical expertise, community knowledge, and relationships. Second, the team amplified knowledge-transfer activities by engaging both ProspectSV networks and project partners with established communications channels.

Knowledge Transfer Partnerships

ProspectSV partnered with ZNE Alliance, CALSTART, and NOVAworks to leverage their collective expertise, share resources, and publicize project results. Each partnership had specific knowledge-transfer goals.

ZNE Alliance: Amplifying Initiatives and Results

ZNE Alliance managed the Energy Commission's *California E-Bus to Grid Integration Project*, working with the AVTA in Southern California. The project demonstrates critical VGI technical solutions for the operational and behavioral challenges of large-scale deployment of e-buses and its impact on the state's electric grid.

With CEC support, ProspectSV and ZNE Alliance together developed knowledge-technology plans and knowledge-transfer initiatives. The two teams combined efforts to publicize project results and best practices with transit agencies and other stakeholders throughout California.

ProspectSV coordinated with AVTA and ZNE Alliance on joint knowledge-transfer activities: technical advisory committee (TAC) meetings, conferences, and webinars. ZNE Alliance's knowledge-transfer team coordinated transit-agency outreach, education, and programs and consolidated lessons learned and best practices.

ProspectSV and ZNE Alliance established a joint TAC to provide oversight for this project and the *California E-Bus to Grid Integration Project*. They additionally worked with CALSTART to produce a standard best-practices guide, and contributed vital information resources, technical information, and case studies to CALSTART's editorial team.

CALSTART: Establishing and Disseminating Best Practices

CALSTART led development of *Best Practices on E-Bus and Grid Integration: A Guide for California Transit Fleets*, a guide that is available on CALSTART's website. The guide summarizes the VTA and AVTA projects and reviews other projects and literature. It addresses technical, operational, and workforce issues that arise during integration of e-buses with a traditional transit fleet. Throughout the VTA project, the team accumulated valuable lessons about technologies and strategic approaches for scaling e-bus energy management systems. The guide combines knowledge gained from design strategies, technology choices, and impact on operations. CALSTART also joined NOVAworks to create educational materials including a PowerPoint presentation for high school, college, and university students and their instructors.

NOVAworks: Preparing a Workforce

The project team engaged NOVAworks to leverage its relationships with high school, college, adult school, and university institutions to create curriculum enhancement materials. NOVAworks tapped several curriculum-development resources, including Pam Gutman, regional director, Advanced Transportation and Logistics, Bay Area California community colleges; Nick Rothman, chairman of the automotive, motorcycle, construction, custodial, and building-maintenance departments at City College of San Francisco; Sorin Neagu, automotive technology instructor at Independence High School in San Jose; and Fred Barez, professor of mechanical engineering at San Jose State University. These educators joined CALSTART to design materials for careers in the e-bus and vehicle-grid integration ecosystems. Rothman incorporated VGI findings into his curriculum to reflect changing automotive-industry technical skill requirements. Gutman introduced VGI concepts and project results to community college faculty throughout California. Neagu led his students on a tour of the VGI operation at the VTA Cerrone Yard and created a unique mentoring program that paired high school automotive technology students with San Jose State University mechanical-engineering students.

Curriculum enhancements introduced students to the theory and practice of VGI and systems concepts, with the long-term goal of creating pathways to employment and graduate engineering programs at San Jose State University and other universities.

Target Audiences

The project team engaged more than 100 organizations and individuals to communicate about the project and the unique challenges of fleet electrification. Target audiences for these knowledge-transfer activities were transit agencies, vehicle OEMs and suppliers, utilities and energy-service professionals, policymakers and ecosystem partners, and workforce-development professionals and educators.

Transit Agencies

Working with VTA, NREL, CALSTART, and ZNE Alliance, ProspectSV shared VGI e-bus benefits, challenges, and strategies with transit agencies across California, especially those actively exploring e-bus procurement. These promotional communications efforts targeted chief innovation officers, fleet engineers, fleet-operations managers, and marketing professionals, among others.

Vehicle Original Equipment Manufacturers and Suppliers

These companies played a critical role in VGI systems integration, fleet operator education, and training. Working with CALSTART, ProspectSV engaged automotive OEMs including General Motors, bus manufacturers including New Flyer, and tier-one vehicle suppliers like Denso.

Utilities and Energy-Service Professionals

Partners from both the VTA and AVTA projects generated VGI data important to electric utilities, including IOUs like PG&E and Community Choice Aggregations (CCAs) like Silicon Valley Clean Energy.

Policymakers and Ecosystem Partners

ProspectSV engaged local, regional, state, and federal policymakers and policy and regulatory experts through sustainability networks such as Urban Sustainability Directors Network and Green Cities California. These communications focused on policy strategies for advancing e-bus deployment with energy services.

Workforce Development Professionals and Educators

Working with NOVAworks, San Jose State University, and their partners, ProspectSV engaged this audience to develop a future e-bus workforce. Communication channels included the Nova Workforce Board listserv, the San Jose State University listserv, City College of San Francisco, and California community colleges.

Outreach Materials and Vehicles

To support e-bus market expansion, knowledge-transfer teams summarized project findings from both the VTA and AVTA projects for key stakeholders at events and conferences.

The two project teams collaborated with CALSTART to develop a key resource for transit agencies. *Best Practices on E-Bus and Grid Integration: A Guide for California Transit Fleets* incorporates research and recommendations from both projects. Its purpose is to educate transit agencies and prospective e-bus operators about the most cost-effective technical, operational, and behavioral solutions for transitioning to an all-electric bus fleet.

Core materials for multiple audiences and broad distribution channels included:

- **VTA VGI Video.** Produced by the VTA and uploaded to YouTube, this video describes the project to a broad audience. The team presented it at two events: an Independence High School tour at the VTA, and the Energy Commission’s e-bus workshop. The VTA and Prospect SV included the video’s URL in other VGI marketing materials.

- **News Releases.** Initial news releases describing the project's scope were released to a broad audience.
- **Fact Sheet.** The team distributed a concise summary of key facts to the project's TAC and educators involved in the project.
- **Project Overviews.** The team created single-paragraph descriptions for easy reference.
- **Presentation Slides.** Team members developed slides for presentations, network meetings, the *Prospect SV Innovation and Impact Symposium*, and other external meetings.
- **Newsletters.** The team routinely shared project updates through ProspectSV and ZNE Alliance channels, including ProspectSV's monthly newsletter.
- **Websites.** ProspectSV posted a description of the VTA project on its website, and ZNEA posted a description of the AVTA project on its website.
- **Blogs and Articles.** Both ProspectSV and ZNE Alliance developed and pitched posts about both e-bus projects including project milestones, lessons learned, new data, partner information, and invitations to engage in events, requests for information (RFIs), the TAC, and other avenues.
- **Social Media.** ProspectSV posted updates for both projects on its Twitter, LinkedIn, Facebook, and Instagram accounts including photographs of e-buses and installations. Partners were copied and encouraged to share these updates on their own social media platforms and in their respective publications.

Outreach Activities

Throughout the project, team members attended and presented summaries of findings, program concepts, and policy recommendations at 27 events including industry conferences, symposia, workshops, panels, webinars, and TAC meetings. Appendix D contains a detailed calendar of knowledge-transfer events.

- **TAC Meetings**. ProspectSV and ZNE Alliance engaged with TAC domain experts to share project information, provide input into final deliverables, and encourage industry-wide information collaboration. The TAC included representatives from over 100 transit agencies, policymakers, utilities, and companies in the e-bus, charging, and VGI supply chain. The TAC met twice between 2018 and 2019. During these meetings team members presented specific and detailed project updates and networked with other industry, technology, and policy professionals. The project team also gleaned valuable information from these events including project findings, program concepts, and policy recommendations. A final TAC meeting was held in January of 2020 to present Phase 2 results and review achievements and challenges for the project as a whole. Appendix C presents a list of TAC members.
- **Innovation and Impact Symposium**. This annual event, hosted by ProspectSV, brings together over 250 innovators, industry leaders, and policymakers in transportation, energy, and the current environment. In the 2017, 2018, and 2019 symposia, project team members participated in panel discussions, met attendees at the project booth, and attracted media attention. The events included panels on the

challenges, trends, and emerging innovations that are driving the EV infrastructure market including fast-charging and integration with the electric grid. Panels also highlighted the two California e-bus projects and featured speakers from project partners CALSTART, NREL, Olivine, and ChargePoint. Attendees also viewed the electric Proterra bus during the 2019 event.

- **Cerrone Yard News Event**. In 2018, the San Francisco Bay Area's print and broadcast media covered the Cerrone Yard news event hosted by the VTA to showcase both e-bus projects. Reporters, speakers, and more than 60 attendees received a guided tour of the Cerrone Bus Yard, buses, and charging stations. Figure 26 shows speakers and attendees at the event.
- **Independence High School VTA VGI Tour**. Prospect SV and NOVAworks collaborated with the VTA to provide a tour of the Cerrone Yard e-bus charging station and explain the VTA VGI project to 28 students from the automotive program at San Jose's Independence High School.

Figure 27: Independence High School Students Tour the Cerrone Yard

Source: ProspectSV

- **Workshops.** The project team hosted five workshops featuring technical and policy issues. ProspectSV promoted these events using its targeted industry-contact lists.
- **Webinars.** Project partners participated in four webinars to educate fleet operators on implementation of VGI systems and share findings from the VTA and AVTA projects. These included a webinar with over 100 attendees, which highlighted Phase 1 findings from the VTA VGI project and progress-to-date on the AVTA project. Project partners, including NREL, VTA, ChargePoint, and Olivine, participated in the school e-bus webinar hosted by the Energy Commission.
- **Industry Conferences**. Project team members attended and presented at 11 industry conventions and meetings, mainly in California, to network with industry professionals and share the e-bus project findings.

- **Energy Commission Symposia.** Project partners participated in two of the annual Electric Program Investment Charge (EPIC) program symposia and workshops hosted by the Energy Commission, in addition to the Energy Commission's school e-bus workshop.
- **Policy Engagement**. The project team participated in the state's VGI working group (Gridworks VGI Working Group), engaging in discussions on V2G policies for the commercial-fleet industry.

CHAPTER 5: Conclusions and Recommendations

The *VTA Advanced Transit Bus VGI Project* successfully transferred VGI advancements to a commercial e-bus fleet, implemented V1G, and explored retail and wholesale energy services. While grid energy services are primarily available when buses are operating, the research prepared the VTA for future V2G implementation. The team designed an energy services and management system integrating leading commercial-fleet management tools with key Energy Commission-funded VGI platforms, implemented cybersecurity protocols, and created an architecture to support the entire fleet's transition to ZEV. The team provided the VTA with simulation and analytical tools for further planning and improvements and developed curricula for training workforces that support California's transition to ZEV transit vehicles.

This project, a small-scale deployment of VGI, laid the foundation for the agency's complete fleet electrification by incorporating time for testing, training, and calibrating existing operations. The project team has identified opportunities and challenges that could be applied to public and private fleet electrification efforts across the State of California. These findings are focused on the VTA's fleet electrification initiative and are not scaled to reflect agency-wide or statewide impacts.

Drivers of Key Results

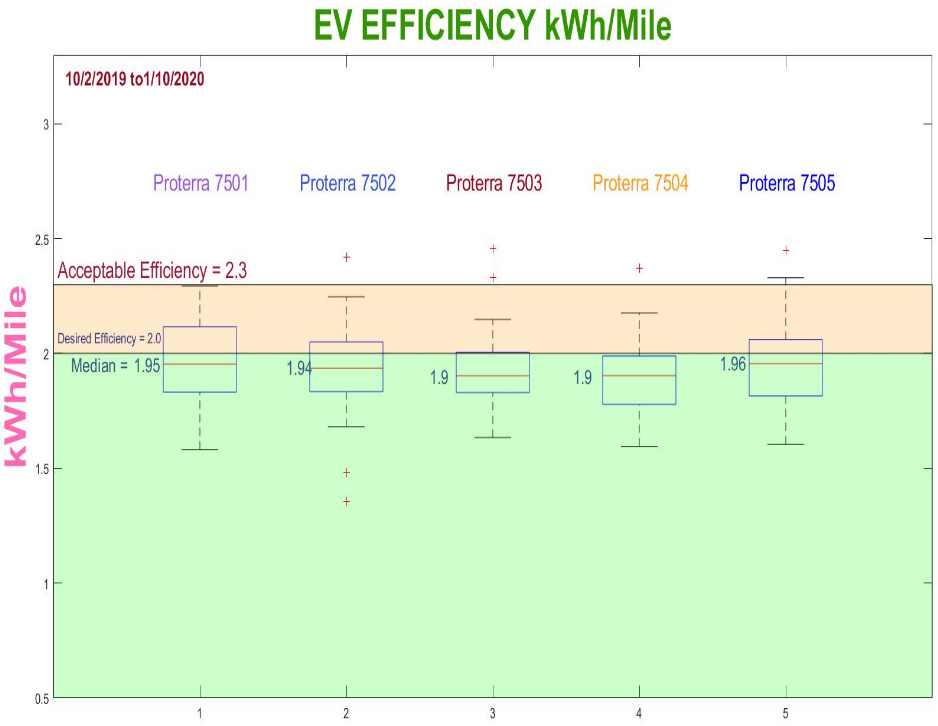
Efficiency

The agency achieved an average of 1.8 kWh/mi, significantly besting Proterra's promise of 2.1 kWh/mi. These outstanding results are due to the driver-training program, which decreased battery use by 15 to 25 percent. Even in winter, the agency achieved 1.9 kWh/mi, a 30 percent improvement over the manufacturer's predicted 2.7 kWh/mi. Higher efficiency also lowered costs by reducing the amount of power needed to charge the buses. Figure 28 summarizes the annual efficiency for each of the five Proterra e-buses.

Costs

Despite increased energy use, the agency successfully managed the cost/kWh by decreasing battery use. Smart charging (through full integration of the EMP with the charging controller, scheduling, and telematics software) effectively managed energy usage and nearly eliminated grid electricity use during peak and partial-peak periods. Software integration also automated e-bus management, ensuring that EVs were cleaned, charged, repaired, and ready for use.

Figure 28: Annual E-Bus Efficiency in kWh/Mile

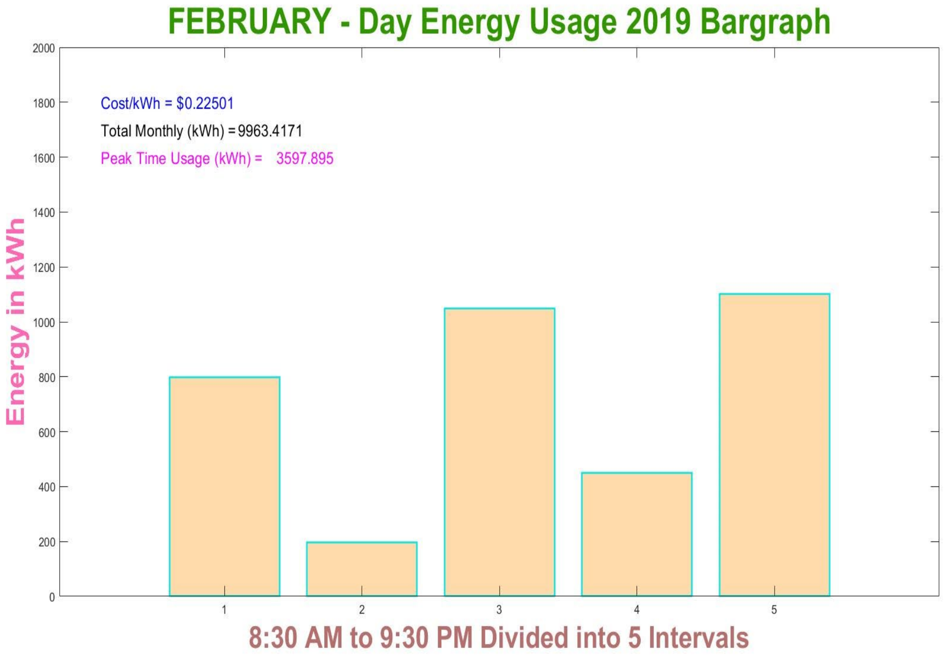


The chart shows the efficiency of each of the Proterra e-buses over a year ranging from a median of 1.9 to 1.96 kWh/mile.

Source: Valley Transportation Authority.

Figure 29 shows energy use in February 2019, without smart charging.

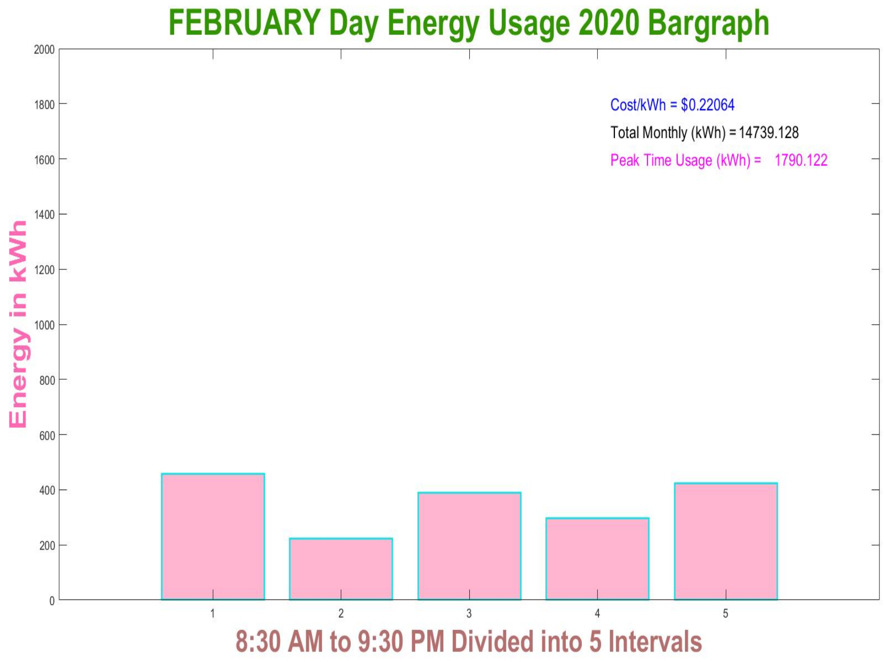
Figure 29: Energy Usage Without Smart Charging



Source: Valley Transportation Authority.

Figure 30 shows energy use in February 2020 with smart charging. Comparing the graphs shows that peak use dropped by 50 percent while total use increased by only 47 percent. Thus, EMP played a significant role in reducing overall cost/kWh.

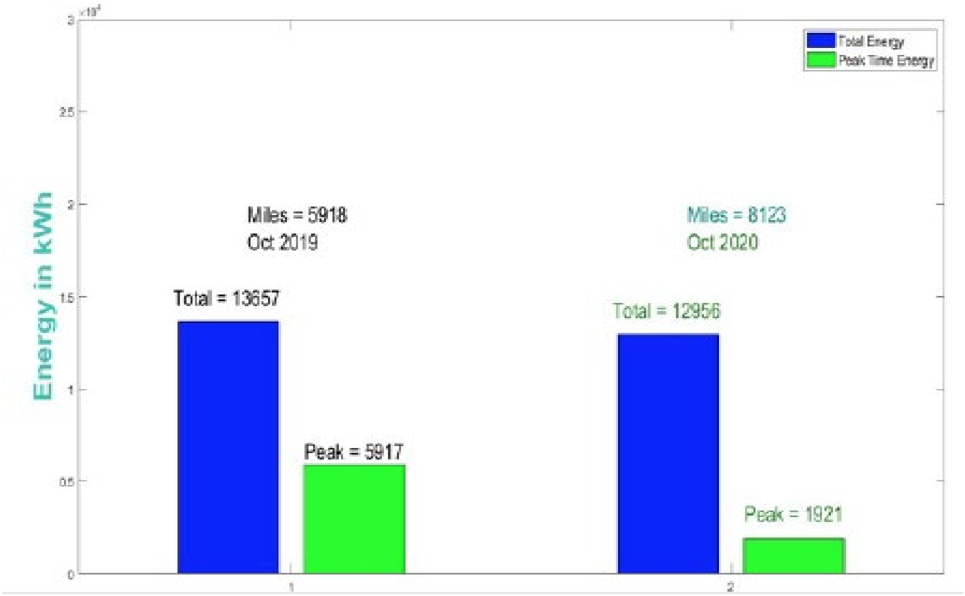
Figure 30: Energy Use with Smart Charging



Source: Valley Transportation Authority.

Figure 31 compares energy consumption for October 2019 and October 2020. While total energy consumption did not significantly change, peak usage decreased by 67 percent, demonstrating the efficiency of smart charging and the integrated system.

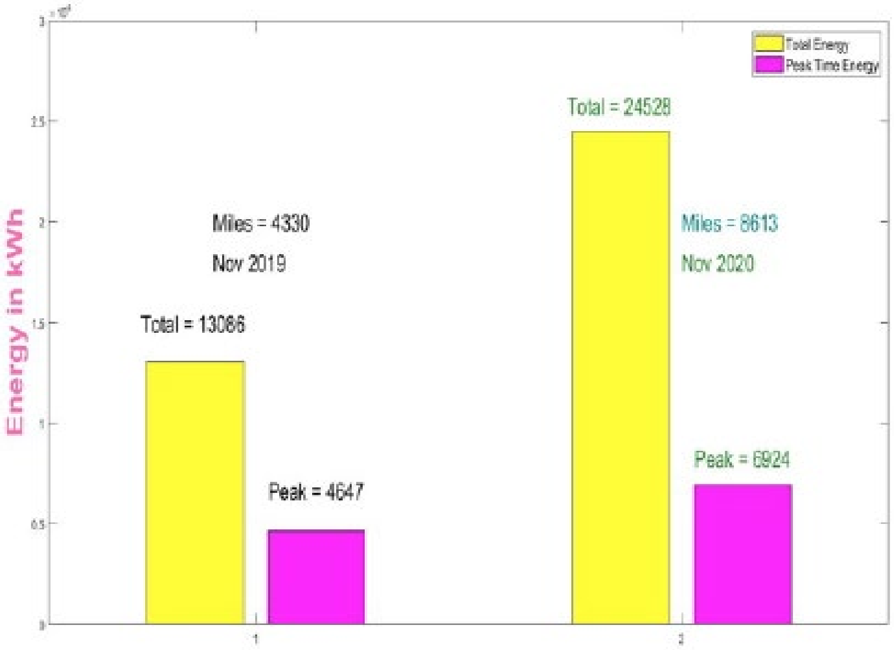
Figure 31: Comparing Energy Consumption for October 2019 and 2020



Source: Valley Transportation Authority.

Figure 32 shows that while total energy consumed in November 2019 increased by 88 percent in November 2020, peak energy use increased by only 49 percent.

Figure 32: Comparing Energy Consumption for November 2019 and 2020



Source: Valley Transportation Authority.

The team also compared the cost of energy consumed by the hybrid and e-buses in 2020. As Table 5 shows, there was no significant difference in energy costs for operating the new electric buses. As a result, expected savings in maintenance costs over the life of the e-buses will not be offset by increased energy costs to operate the buses. These savings will be calculated once the e-buses are no longer under warranty and the VTA performs maintenance in-house.

Table 5: Comparing Cost of Energy

	Diesel-Electric Hybrid	Electric Bus
Total miles travelled in 2020	2,251,247	56,778
Number of buses	56	5
Distance/bus	40,201	56,778
Average miles/fuel	5.9 MPG	1.85 kWh/mile
Quantity of energy used	380,249 gallons	105,039.3 kWh
Energy cost	$2.33/gallon	0.221/kWh
Cost/mile/bus	0.3935	0.4088

Source: Valley Transportation Authority.

Key Challenges and Lessons Learned

Delays

The project team experienced several issues that delayed deployment. These delays were exacerbated by the COVID 19 shelter-in-place and business restrictions in the spring, summer, and fall of 2020.

- Proterra bus deliveries were delayed due to extremely high demand for the vehicles.
- There were delays from Proterra due to manufacturing issues. The buses did not arrive with the right parts including Clipper card-payment booths, which then took six months to install. There were also minor design issues that took several months to resolve. These manufacturing issues required troubleshooting between VTA and Proterra, extending commissioning beyond the scheduled timeline
- There were delays with the delivery and installation of ChargePoint chargers.
- Delays in contracting between VTA and two key fleet-management and operations subcontractors, Clever Devices and Trapeze, led to significant delays in both developing and deploying the EMP.

Future projects should note that deploying new technologies impacts the commissioning process and scheduling. Agencies also need to allow ample time for engineering, purchasing, and contracting when developing timelines for e-bus electrification projects.

New Technology

The VTA needs to continually review new technologies to identify best-available options for 100-percent e-bus electrification. With 350 kWh of usable energy, the current bus technology does not support distances required for all existing blocks. For example, a newer 440 kWh e-bus runs 220 miles, compared with VTA's current buses at 170 miles; the next generation of e-buses promises a 1 MW battery without increasing bus weight. A transit agency may also consider hydrogen buses to replace the last 20 percent of fossil fuel buses used for longer-distance routes Simulation tools created by NREL will help predict the impacts of these e-bus-purchasing decisions.

Charger technology has dramatically changed just since this project's inception. If the project was starting today, for example, the team would likely install only 1 or 2 of the latest chargers (equipped with multiple dispensers) instead of 5 62.5 kW chargers. In the latest designs, a 1.5 MW charger can dispense electricity to 20 vehicles, increasing operational flexibility and lowering charger installation costs. Like buses, chargers are capital investments. (The VTA spent $1.5 million for the 5 chargers.)

The VTA did not support some aspects of the scope and complexity of enabling grid services. The VTA learned that, in addition to the problem of bus availability for grid services, the VTA learned that neither the vehicles nor the chargers supported bidirectional energy flow. The manufacturer can convert the latest generation of buses for bidirectional flow, but customers must specify this requirement. The latest 1.5 MW chargers are also capable of bidirectional flow. However, at the beginning of the project, this technology was unavailable for grid services.

The new e-buses had unforeseen maintenance issues that became reliability issues. The VTA improved e-bus availability by purchasing spare parts to reduce repair down times. The VTA also shared common operator issues across the team by increasing communication and knowledge among operators, maintenance staff, and Proterra technicians.

The complexity of integration increased with the need to develop interfaces to multiple vendor products and troubleshoot communications with both new hardware and software. While the team did adopt existing industry standards, there were no communications standards for an energy management platform application, which did not exist before this project. For example, when Trapeze developed an API for the EMP, the Trapeze data was in an incorrect format so, ultimately, ChargePoint re-engineered the EMP to match the Trapeze system.

Integration of Players

The challenges of integration were not confined to the development team. Some vendors were unaccustomed to the level of integration required for the software and hardware, the degree of disclosure needed between partners, or, most importantly, the extent of investment required for the project. For successful electrification projects, it's critical to align and incentivize all project participants to avoid future conflicts.

Missed Opportunities

The VTA, Mission College, and the Amalgamated Transit Union, Local 265, run an apprenticeship training program for bus drivers, mechanics, and overhead linemen. Early in the project, there were discussions with the union about expansion to include VGI training. It is important for the VTA and its partners to promote this opportunity again, particularly if and when VTA decides to bring additional VGI-related work in-house.

COVID-19 in-person limitations eliminated workforce development activities planned by the project team. However, one idea triggered by the necessity of online learning was to create a module where students would learn the importance of the energy management system, the impact of environmental conditions on energy use, and the role of hardware and software components.

The initial project scope included developing and demonstrating controlled, bidirectional energy transfer between e-bus batteries, end loads, and grid-connected facilities. Transit buses purchased in 2018 and the charging platforms installed in 2019 did not support bidirectional energy transfer, and the cost of modifications required to support it were prohibitive. It wasn't until late 2020 that bus and charging infrastructure manufacturers addressed bidirectional energy transfer. The second problem with bidirectional energy transfer was the business case. When the grid needed stored energy to supplement electric load, transit buses are not available. Up to 80 to 90 percent of the fleet operates between 4:00 a.m. and 6:00 a.m.; the buses return after 6:00 p.m. Returning transit buses have only a 15 percent to 25 percent state of charge. The majority of the fleet is charged from 9:00 p.m. to 4:00 a.m. Because of this timing, both NREL and VTA assessments showed that bidirectional energy transfer would deliver a poor return on investment (ROI) for transit agencies.

Importance of Training

Driver training was a critical component of VTA's e-bus performance efficiency. Drivers learned regenerative braking, controlled acceleration, and efficient HVAC practice. Training was part of a feedback loop; data collection and bus-performance analyses created new insights that were in turn integrated into the training. Driver results were also benchmarked.

Training was expanded to other members of the VTA staff. For example, training the yard staff on using the EMP dashboard helped synchronize EMP charging plans with actual charging.

Recommendations

Recommendations for Policymakers

In the San Francisco Bay Area, transit buses have an emergency response role in evacuating and transporting residents after earthquakes, fires, and other disasters. Another potential use case is that e-buses can also generate back-up power for hospitals. But given transit e-buses' primary transportation role in emergencies, policymakers should consider enlisting electric school buses to generate emergency power. School buses run just 20 to 25 percent of the miles run by transit buses, so school buses may have more availability to provide backup power. If electric school buses were equipped with mobile chargers that could convert voltage for hospitals, they could perform this back-up power role.

The current market for grid services is not well developed for transit agency participation. Buses are unavailable during key hours of grid service needs, and the grid services that are needed when buses are available pay too little to make this a viable option.

Policymakers should consider the importance of developing a talent pipeline that supports the new clean transportation industry. The required workforce will offer employers a hybrid skill set that includes highly technical knowledge and an understanding of systems integration. Educational disciplines generally operate in silos; future industries will need workers skilled across separate domains.

Recommendations for Transit Agencies

Best Practices on E-Bus and Grid Integration: A Guide for California Transit Fleets provides a full set of recommendations for transit agencies. A few highlights from the VTA experience follow:

- Transit agencies need to identify collaborators willing to invest in electrification projects because they believe establishing a new clean transportation industry will deliver long-term benefits.
- An agency must train all its staff on each facet of the fleet's VGI system. Drivers, dispatchers, maintenance staff, and management need to know how the VGI system works, how to operate it, and how it may have changed standard operating procedures. As the VTA experience shows, training is an ongoing process reflecting the dynamics of a complex, scaling-up system. Training directly impacts bus performance, smart charging, efficiency, and costs.
- Deploying and integrating new technology impacted nearly every aspect of the project. While agencies need to build in extra time for commissioning, their teams must also be flexible, willing to troubleshoot, solve problems collaboratively, and create workarounds.

Recommendations for Technology Providers

Given the importance of driver training, technology providers should consider including automated system feedback to drivers, trainers, and operations management on individual drivers' performance and impact on energy efficiency.

Technology companies also have a role in helping vocational training and higher education institutions develop a workforce to support the industry. Companies can transfer critical knowledge about designing and using the technologies they create through internships and collaborations with educators.

CHAPTER 6:
Benefits to Ratepayers

Electrifying transit fleets benefits transit agencies and the communities they serve. This chapter summarizes how the VGI project benefited the VTA and the larger community.

The e-bus VGI system, integrated with smart charging, provided several specific benefits.

Reduced Peak Charging. Smart charging nearly eliminated the use of grid energy in peak and partial-peak periods. The energy purchased during the summer peak made up less than one-tenth of one percent, the summer partial-peak was 3.9 percent of all energy consumed by the e-buses, and the winter peak was 3.8 percent of all energy consumed by the e-buses. The system saved thousands of dollars for the VTA and will be especially important when it scales to full electrification.

- **Increased Energy Efficiency**. Driver training programs, informed by system data, dramatically improved driver performance. The VTA's e-buses rate an average of 1.8 kWh/mi, beating the manufacturer's prediction of 2.1 kWh/mi and besting the rate of VTA's diesel-electric hybrids of 2.25 kWh/mi.
- **Increased Fuel Efficiency**. VTA e-buses average 23.1 MPGe while the hybrid buses averaged 5.8 MPG.
- **Decreased Fuel Consumption**. For two and a half years, the five e-buses traveled 144,506 miles, saving more than 25,500 gallons of diesel fuel. Reducing diesel fuel consumption also reduces related health hazards for bus maintenance staff and increases safety by reducing the need to produce, deliver, and store diesel fuel.
- **Reduced Range Anxiety**. Extensive driver training ensures that buses complete 85 percent of VTA's existing blocks; these blocks average 170 miles. With highly trained drivers, the buses can go over 200 miles on a single charge.
- **Reduced Maintenance Costs**. In the future, the VTA expects lower operating costs since e-buses have fewer maintenance issues than diesel-hybrid bus engines. These reductions will not be offset by higher energy costs since the cost/mile is roughly equivalent.
- **Reduced Infrastructure Costs**. The VTA is reducing the electrical infrastructure required for 100 percent fleet electrification by taking advantage of PG&E's EV Fleet program, which helps the VTA manage the load needed to charge its e-buses. This will result in savings in the capital costs for electrical infrastructure at each of VTA's three bus yards. The VGI project lowers the cost for VTA to participate in the EV Fleet program, thus enabling greater savings for the VTA.
- **Reduced Operating Costs**. The VTA is reducing operating costs by adopting PG&E's Business EV2 rate program, which encourages charging outside of the peak hours of 4 pm to 9 pm through its time-of-use rate differentials. Since the VGI project significantly minimized charging during the highest cost hours, it helps the VTA maximize the new rate plan benefits.

- **Sustainability Benefits**. The VGI project also supported VTA's sustainability objectives.
    - Greenhouse gas emissions:
        - VTA targets: Reduce GHG emissions by 60 percent by FY 2025; 90 percent by 2040 over the baseline of 2009
        - VGI project: Based on the diesel fuel saved over the two and a half year project, the VTA saved 261 MT of GHG
    - Criteria air pollutant emissions:
    - VTA targets: Reduce criteria air-pollutant emissions by 80 percent by FY 2025 and 95 percent by FY 2040
    - The VGI project: The e-buses generated 84 percent lower CO_2 emissions and 81.2 percent lower NO_X emissions than the hybrid bus; the e-buses eliminated SO_X emissions.
- **Data, Tools, and Analysis**. The system delivers rich data on driver, vehicle, and charger performance and the VTA is learning how to use that data to make improvements and extract even more savings. The system reports include:
    - Load Smoothing: Shows 15-minute charging data for tariff rules and to determine costs
    - Charging: Reports details of each charging session
    - Optimizer: Reports the details of each schedule-optimization run
    - Block: Captures the block details for each EV charging event
    - Trip: Reports the details of each trip including energy consumed and miles driven
    - Alerts: Reports the details of each alert issued by the system and when the alert was cleared
    - Energy Cost: Estimates depot TOU usage and maximum demand for billing cycles to support bill estimates
    - Energy Consumption: Predicts energy consumption by route and block
- NREL created a simulation tool that helps predict miles and energy for various route and bus technology configurations, which in turn helps the VTA plan for its full fleet electrification. A financial performance model additionally helps analyze several metrics for e-bus cost and performance as well as overall site performance.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AC	Alternating current
AVTA	Antelope Valley Transit Authority
BEB	Battery electric bus
CAD/AVL	Computer-aided dispatch/automated vehicle location
CAISO	California Independent System Operator
CARB	California Air Resources Board
DC	Direct current
DER	Distributed energy resource: DER includes distribution connected-generation resources (such as solar, wind), energy efficiency, energy storage, electric vehicles, and demand response (DR) technologies.
DR	Demand response (Demand response is a change in the power consumption of an electric utility customer to better match the demand for power with the supply. Wikipedia)
EMP	Energy management platform
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FC	Fast charging
GLONASS	Global Navigation Satellite System
GREET	Greenhouse gases, regulated emissions, and energy use in technologies
ISO	Independent System Operator
LTE	Long-term evolution
MW	Megawatt
MPGe	Miles per gallon of gasoline equivalent
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PG&E	Pacific Gas and Electric
PV	Photovoltaic
RODeO	Revenue operation and device optimization model
RTO	Regional transmission organization
SOC	State-of-charge
TOU	Time of use
Utility-scale	The solar power generated is sold directly into the grid. NREL considers a solar project utility-scale if it generates at least 5 MW.
V1G	Smart charging, or managed charging
V2B	Vehicle-to building
V2G	Vehicle-to-grid
VGI	Vehicle-grid integration
VTA	Santa Clara Valley Transportation Authority
ZEB	Zero-emission bus
ZEV	Zero emission vehicle

REFERENCES

Argonne National Laboratory (website). Energy Systems: GREET Model. Accessed January 5, 2021. https://greet.es.anl.gov/

California Air Resources Board (website). Innovative Clean Transit. Accessed November 19, 2020. https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/about

California Air Resources Board (website). California transitioning to all-electric public bus fleet by 2040. Accessed March 19, 2021. https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040

California Energy Commission (website). Clean Energy and Pollution Reduction Act SB 350. Accessed November 27, 2020. https://www.energy.ca.gov/rules-and-regulations/energy-suppliers-reporting/clean-energy-and-pollution-reduction-act-sb-350

California ISO. 2014 California Vehicle-Grid Integration (VGI) Roadmap. Accessed November 19, 2020. https://www.caiso.com/Documents/Vehicle-GridIntegrationRoadmap.pdf

California Public Utilities Commission (website). DR Provided by Utilities. Accessed January 5, 2021. https://www.cpuc.ca.gov/General.aspx?id=5926

California Public Utilities Commission (website). Drive OIR Vehicle-Grid Integration Working Group. Accessed January 5, 2021. https://www.cpuc.ca.gov/vgi/

Denholm, Paul and Josh Eichman, Robert Margolis. 2017. Evaluating the Technical and Economic Performance of PV Plus Storage Power Plants. Technical Report. National Renewable Energy Laboratory. Accessed January 5, 2021. https://www.nrel.gov/docs/fy17osti/68737.pdf

Eichman, Joshua and Aaron Townsend, Marc Melaina. 2016. Economic assessment of hydrogen technologies participating in California electricity markets. Technical Report. National Renewable Energy Laboratory. Accessed January 5, 2021. https://www.nrel.gov/docs/fy16osti/65856.pdf

Eichman, Joshua and Francisco Flores-Espino. 2016. California Power-to-Gas and Power-to-Hydrogen Near-Term Business Case Evaluation. Technical Report. National Renewable Energy Laboratory. Accessed January 5, 2021. https://www.nrel.gov/docs/fy17osti/67384.pdf

Horrox, James and Mathew Casale. 2019. Electric Buses in America: Lessons from Cities Pioneering Clean Transportation. Environment Research, and Policy Center, Frontier Group. October 2019. p.11. https://uspirg.org/sites/pirg/files/reports/ElectricBusesInAmerica/US_Electric_bus_scrn.pdf

Institute for Local Government (website). The Basics of SB 375. Accessed November 27, 2020. https://www.ca-ilg.org/post/basics-sb-375

IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. Accessed February 5, 2021. www.ipcc.ch/report/ar5/wg1.

National Renewable Energy Laboratory. January 2016. Foothill Transit Battery Electric Bus Demonstration Results. Accessed November 16, 2020. https://www.nrel.gov/docs/fy16osti/65274.pdf

National Transit Database. California Transit Agencies. Accessed November 18, 2020. https://www.nationaltransitdatabase.org/california/

Pacific Gas and Electric Company (PG&E) (website). Electric Schedule A-6: Small General Time-of-Use Service. Accessed January 5, 2021. https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_A-6.pdf

Pacific Gas and Electric Company (PG&E) (website). Net Surplus Compensation Rates for Energy. Accessed January 5, 2021. https://www.pge.com/pge_global/common/pdfs/solar-and-vehicles/green-energy-incentives/AB920_RateTable.pdf

Santa Clara Valley Transit Authority. 2019. Santa Clara Valley Transit Authority Relies on ChargePoint to Power its Fleet of Zero Emission Buses. YouTube video. Accessed January 5, 2021. https://www.youtube.com/watch?v=l2XdkItkj-0&feature=youtu.be

U.S. Energy Information Administration (EIA) (website). California Electricity Profile 2019. Accessed January 5, 2021. https://www.eia.gov/electricity/state/california/index.php

U.S. Utility Rate Database (USURDB). OpenEI. Accessed January 5, 2021. https://openei.org/apps/USURDB/

Valley Transportation Authority. Zero Emission Bus (ZEB) Microgrid, Energy Storage and Solar Infrastructure. (YouTube video). Accessed January 12, 2021. https://www.youtube.com/watch?v=b300RdkcMVQ).

APPENDIX A:
Grid Services Options and Analysis

Prepared by NREL

August 15, 2018

Deliverable Task

Analyze duty cycle requirements and energy services (wholesale and retail) potential to optimize fleet operations and energy services software algorithms.

Deliverable Summary

The opportunity for VTA's electric buses to provide grid services is explored. The following list of programs was evaluated: Base Interruptible Program (BIP), Capacity Bidding Program (CBP), Peak Day Pricing (PDP), Excess Supply Pilot (XSP), Supply Side II DR Pilot (SSP II) and participation using the Proxy Demand Resource (PDR) and Reliability Demand Response Resource (RDRR) CAISO market enhancements.

While there are many programs the main challenge for buses is availability. Buses are not typically being charged when you want grid services and when they are being charged the value for grid services is lower. As a result, most of the programs will produce little to no value unless bus driving patterns are shifted.

BIP, CBP and PDP programs are only valuable if buses are charging between 14:00 and 21:00. XSP and SSP have flexible timing windows and should be considered for bus participation. Based on charging availability, buses are not likely to meet the DRAM requirements since load reductions will be required during the peak demand periods when buses are not charging. PDR and RDRR are used by several DR programs to access wholesale markets. Participation in energy markets may prove challenging because of the competition between reducing retail rates and increasing revenue by bidding into wholesale energy markets. Participation in spinning and non-spinning reserve markets could provide as much as $315/kW-year for a typical VTA bus traveling on average, 130 miles a day. While not currently allowed in PDR, if DR could provide regulation the potential value would increase to $659/kW-year.[17]

Electric Bus Duty Cycle Requirements

Battery electric buses offer a unique opportunity to reduce fuel consumption, emissions and potentially reduce operating costs.[18] The extent to which electric buses affect emissions and costs is dependent on when and where they charge. A disaggregation of spatial and temporal emissions factors for California is presented in Figure A-1. This estimate is for a California grid

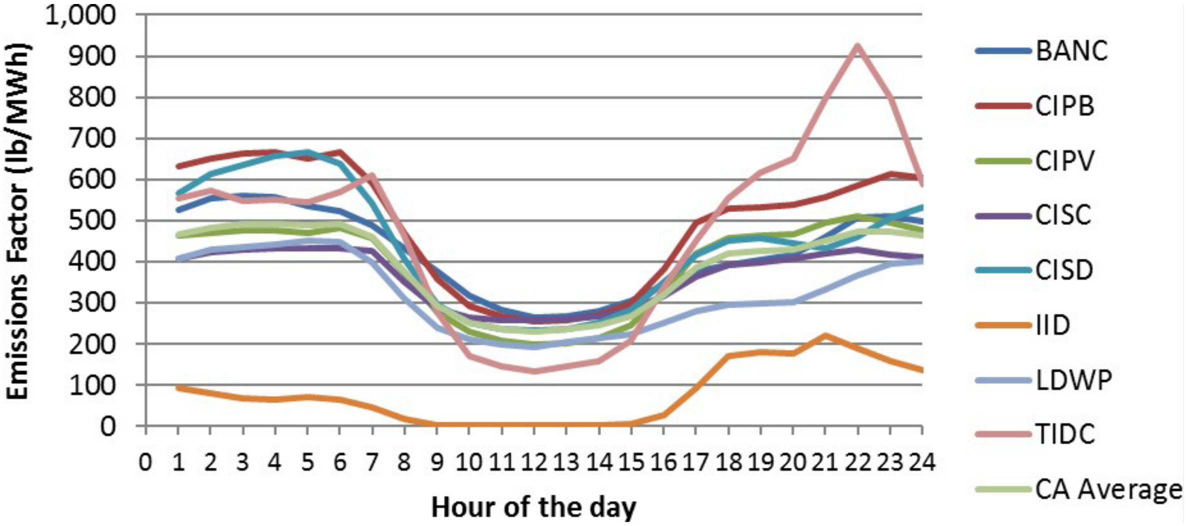
---

[17] Does not include the additional costs and charging impacts when regulation or other reserve services are called.

[18] Chandler, S., Espino, J., O'Dea, J., 2016. Delivering Opportunity. Union of Concerned Scientists

with 23 percent renewable penetration. Notice that consuming electricity during certain times of the day and in certain regions can dramatically affect the carbon dioxide emissions.

Figure A-1: Carbon Dioxide Emissions Factors in California

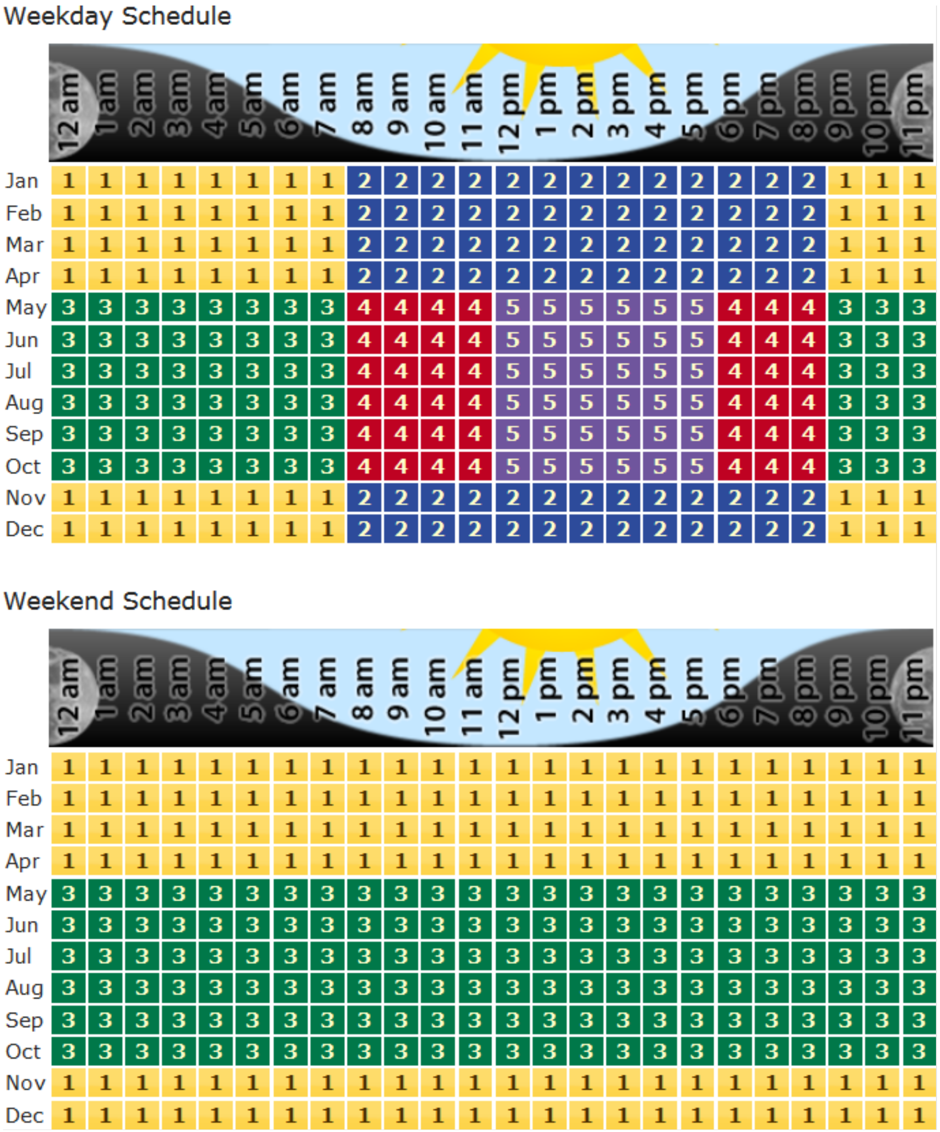


Spatial and Temporal disaggregation of Carbon Dioxide Emissions Factors in California

Source: National Renewable Energy Laboratory

Similarly, the cost of electricity on retail tariffs can vary by the time of day the electricity is consumed. Figure A-2 shows an example of a time-of-use utility rates that changes for each hour of the day, between weekdays and weekends and seasonally. In addition to energy charges which are based on the total energy consumption (kWh) during each period, there are demand charges, which are based on the maximum electricity demand during a given period (MW) (Figure A-3).

Figure A-2: PG&E E19 Utility Rate Shape for Energy Charges



Weekday Schedule

	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Feb	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Mar	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Apr	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
May	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Jun	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Jul	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Aug	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Sep	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Oct	3	3	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5	4	4	4	3	3	3
Nov	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Dec	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1

Weekend Schedule

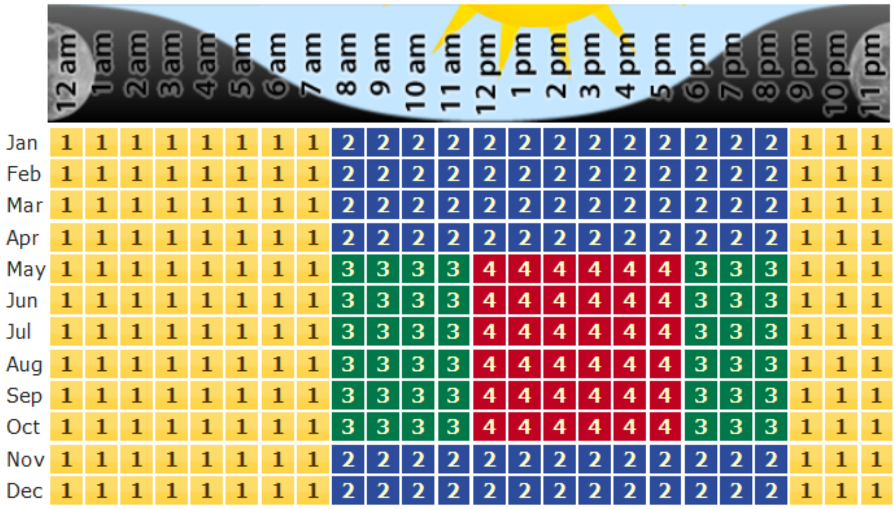
	12 am	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm
Jan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Feb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Apr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jun	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jul	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Aug	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Oct	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Nov	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dec	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Period	Rate ($/kWh)
1	0.09401
2	0.11004
3	0.08671
4	0.11613
5	0.16055

Source: National Renewable Energy Laboratory Using Utility Rate Database

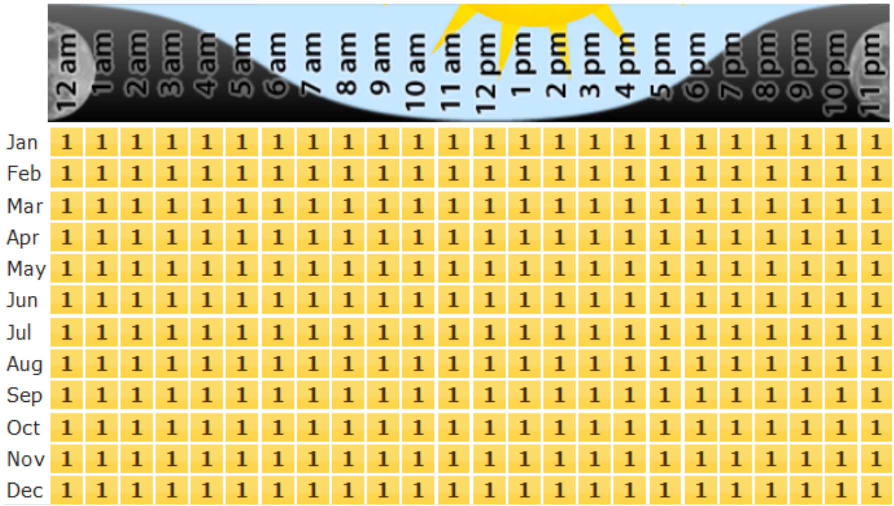
Figure A-3: PG&E E19 Utility Rate Shape for Demand Charges

Weekday Schedule



	12 am	1am	2am	3am	4am	5am	6am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2pm	3 pm	4 pm	5 pm	6pm	7pm	8pm	9pm	10pm	11 pm
Jan	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Feb	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Mar	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Apr	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
May	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Jun	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Jul	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Aug	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Sep	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Oct	1	1	1	1	1	1	1	1	3	3	3	3	4	4	4	4	4	4	3	3	3	1	1	1
Nov	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
Dec	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1

Weekend Schedule



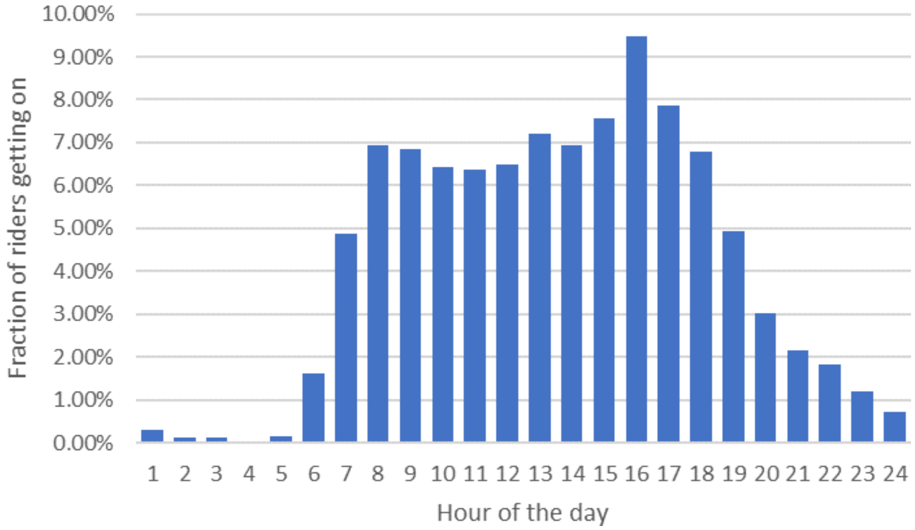
	12 am	1am	2am	3am	4am	5am	6am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2pm	3 pm	4 pm	5 pm	6pm	7pm	8pm	9pm	10pm	11 pm
Jan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Feb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Apr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jul	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sep	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Oct	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nov	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dec	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Period	Rate ($/kWh)
1	0
2	0.12
3	5.4
4	19.65

Source: National Renewable Energy Laboratory Using Utility Rate Database

Understanding how the Valley Transit Authority (VTA) currently operates their buses is essential to determining how best to operate the buses to reduce costs, emissions, and grid impacts. VTA ridership grows rapidly in the morning around 6 AM, stays relatively flat until 6 PM and then slowly falls (Figure A-4). The routes that buses run, and the frequency of those runs, has a similar pattern to the shape in Figure A-4.

Figure A-4: Popular Travel Times for Part of the VTA Bus Fleet



Source: National Renewable Energy Laboratory with Data Supplied by VTA

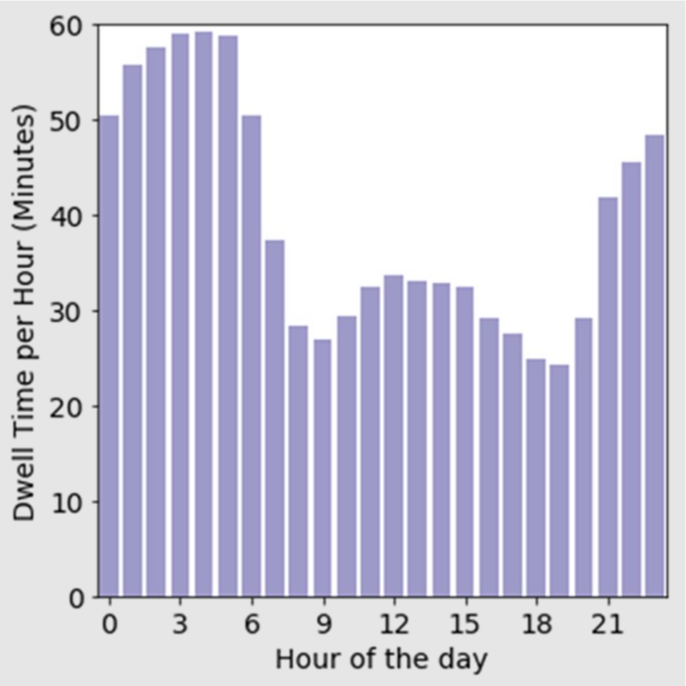
VTA has a collection of bus stops that are used to construct routes. These routes are combined to create blocks and a single bus can complete multiple blocks in one day. Figure A-5 shows the daily operating times for part of the VTA bus fleet. Identifying these periods of inactivity or dwell periods (green) is essential for understanding when the vehicle can be charged and at what rate it must be charged. From the snapshot of data, buses did not start driving before 6AM and some ended after midnight.

In addition to inactivity due to scheduling, there are periods throughout the scheduled day where the buses stop for longer durations at a layover or between changing directions on a route. These stops may be able to provide additional periods of charging and could coincide with the daytime solar potential allowing the buses to charge for cheaper, produce lower emissions during charging, and extend the range of the vehicle. Figure A-6 provides the average minutes of dwell time per hour of the day for 28 vehicles. Like Figure A-5, we see nearly all the vehicles are idle at night, but unlike Figure A-5, Figure A-6 shows an average of 30 minutes of engine-off activity during the mid-day which could provide opportunities for day-time charging. However, further analysis is needed to differentiate how long these vehicles are off for since these vehicles use engine start-stop technology and could be shutting off at a stop light were charging the vehicle is not feasible.

Figure A-5: Typical Operating Times for VTA Buses by Block

Source: National Renewable Energy Laboratory with Data Supplied by VTA

Figure A-6: Average Dwell Time per Hour (in minutes) of all Collected Buses



Source: National Renewable Energy Laboratory with Data Supplied by VTA

Energy Services Available

Battery electric buses can provide support to utilities and grid operators by changing the time and rate that the buses charge. This allows for load shedding, load shifting and provision of other gird services.

For this report, energy services will be separated into two broad categories. 1) retail programs and services, which includes pilot programs that, depending on success, can be migrated into the retail space, and 2) wholesale programs and markets. More details can be found on the California Public Utility Commission's Demand Response website.[19]

In addition to the purchase of electricity, providing energy services offers an opportunity to provide support to the grid and get some revenue. Provision of these services could result in a relatively low impact on operation (in the case of some demand response (DR) programs and for some ancillary service markets), while providing other services might strongly impact customer operations.

Retail Programs and Services

There are many different demand response programs that are applicable for PG&E's territory.[20] Current retail programs include Base Interruptible Program (BIP), Capacity Bidding Program (CBP), and the Peak Day Pricing (PDP). Pilot programs include the Excess Supply DR Pilot (XSP), and Supply Side II DR Pilot (SSP II).

Determining the value of each can be challenging for a number of reasons including 1) determining the likely number of events called during a year, 2) determining how to

---

[19] CPUC Demand Response

[20] PG&E Business energy incentive programs

appropriately value each event, and 3) potential for participating in multiple programs and possible exclusions or penalties that may result.

Wholesale market products

Customers can also participate in wholesale markets using a variety of mechanisms. Participation can be completely wholesale in the case of Rule 24 participants, where they work with a scheduling coordinator to schedule their services. Participation can also be hybrid between retail and wholesale where customers are on a retail rate but have access to wholesale markets. Some of those programs include the Demand Response Auction Mechanism (DRAM), non-generator resource (NGR), proxy demand resource (PDR) and reliability demand response resource models (RDRR). CAISO administers the NGR, PDR, and RDRR programs.[21] [22]

DRAM is a pay-as- bid program that is being piloted in California. It explores the role that demand response devices can play in providing grid services. In 2019 PG&E will be accepting system, local, and flexible capacity products.[23]

NGR is designed for energy constrained resources (i.e., largely for storage) and includes consumption and discharge of energy. NGR resources can participate in energy or ancillary service markets including regulation up and down, spinning, and non-spinning reserve.

PDR and RDRR are more focused on responsive loads and changing the time of electricity consumption. Currently PDR devices can participate in ancillary service markets (only spinning and non-spinning reserve) as well as energy markets by comparing to a difference from the baseline device operation.

The collection of products to access wholesale markets allows for participation in the energy and ancillary markets in California including regulation up and down, spinning and non-spinning reserve; however, similar to the retail programs there are complications with ensuring that your device or site meets the requirements along with starting the process sufficiently early to meet project needs or winning in the DRAM auction.

Description of Services

An illustrative example is provided in Figure A-7. The example considers adding one bus to an existing facility load. The bus is on route from 8AM to 7PM and in the depot and available for charging all the remaining time. The bus is assumed to charge at up to 50kW and requires 350kWh of charging every day. The bus can provide support to the grid by shedding load at times when the grid is stressed and shifting that load to another time. Without any management (i.e., Load + Immediate Charging line in the figure), the maximum demand increases to 137 kW, but by shifting the charging from 7PM – 10PM to 5AM – 8AM (Load + Shifted Charging) reduces the peak to 107 kW. This could, for example, reduce demand charge and time-of-use on- peak energy charges. The shifting is shown more clearly in Figure A-8.

---

[21] CAISO Storage technology overview

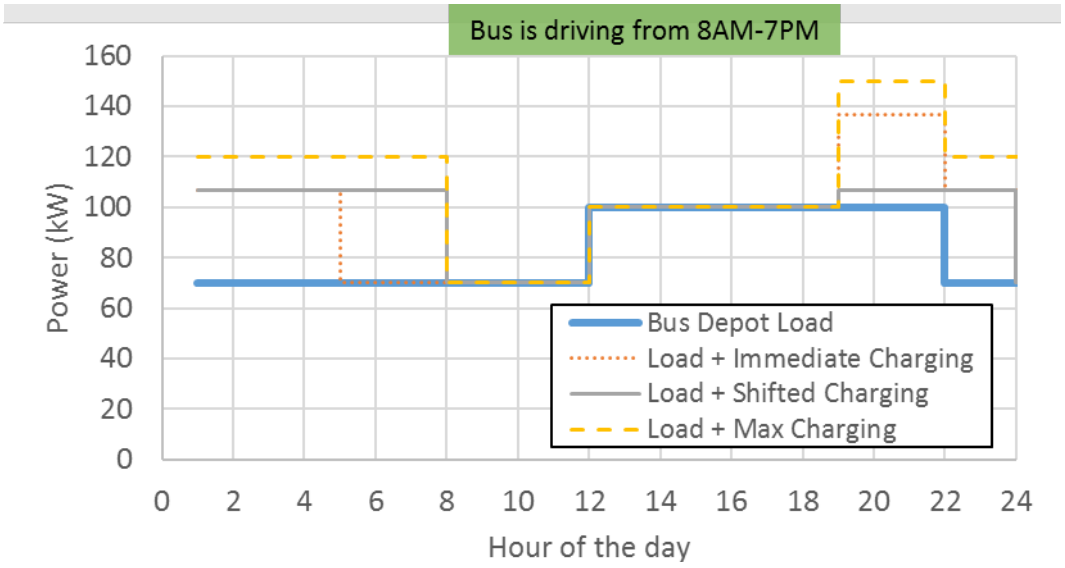
[22] CAISO Demand response and load participation

[23] PG&E 2019 DRAM protocol

In addition, to shifting and shedding, the charger can be controlled to provide ramping capacity to the grid by steadily increasing or decreasing the amount of charging.

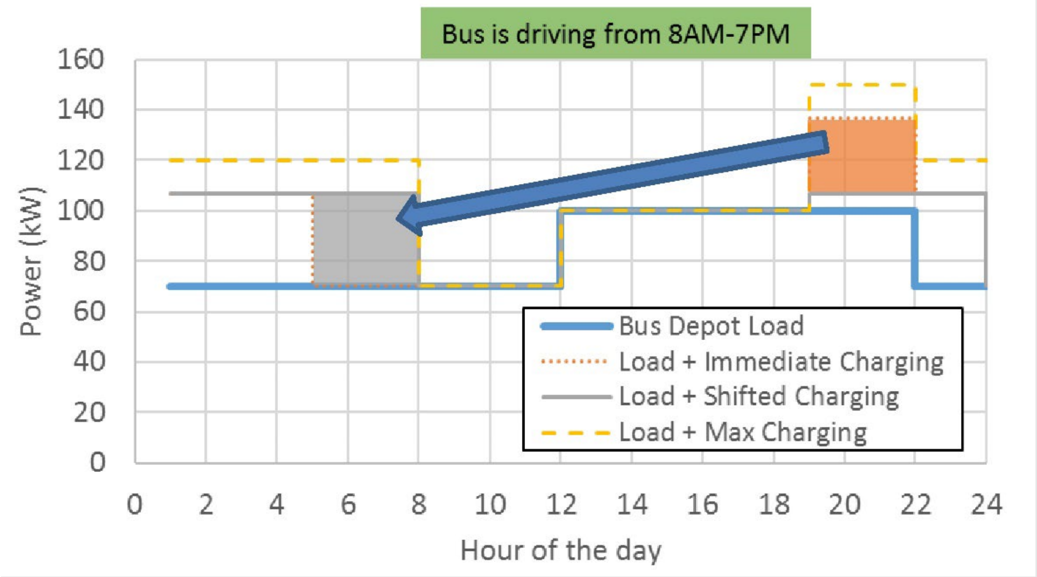
To keep the grid electricity supply matched to the demand, grid operators must also procure ancillary services including reserve services. In this report we will explore spinning and non-spinning reserves and regulation. Spinning reserves and non-spinning reserves are provided by resources that can increase generation or shed load to offset changes on the grid (e.g., power plant outage). Regulation is an ancillary service that is used to provide rapid grid balancing and is the most lucrative market in California. Regulation can be provided in two directions – Regulation up and regulation down. Regulation up is provided by an increase in generation or a reduction in electricity demand from flexible load. Conversely, regulation down is provided by a reduction in generation or an increase in flexible load.

Figure A-7: Illustrative Example of Charging Patterns and Opportunities



Source: National Renewable Energy Laboratory

Figure A-8: Illustrative Example of Charging Patterns and Opportunities (Highlighting Shifting)

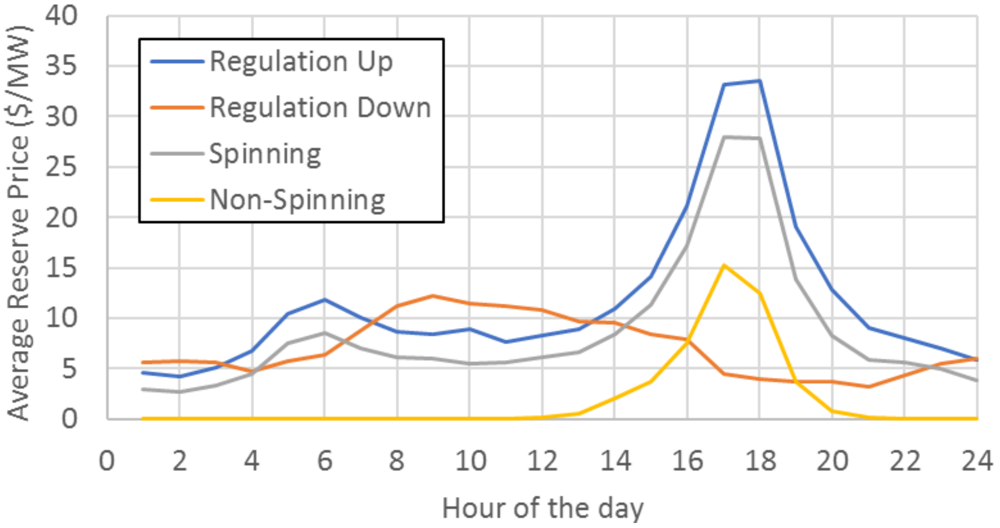


Source: National Renewable Energy Laboratory

Ancillary Services Value

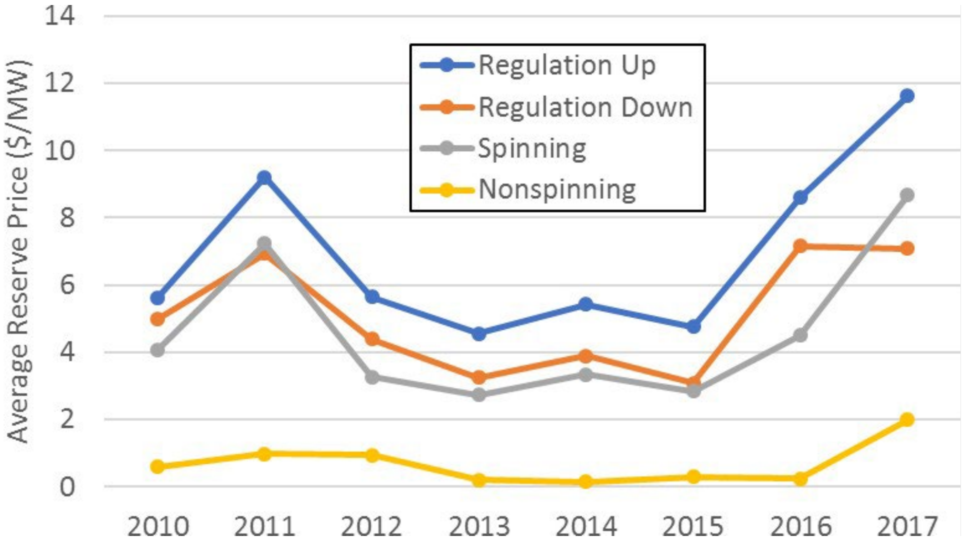
Ancillary services vary from year to year and hour to hour. Hourly variations for CAISO are shown in Figure A-9. Regulation up and spinning reserve are the highest value followed by regulation down and then non-spinning reserve. Annual variation for CAISO from 2010 to 2017 is shown in Figure A-10.

Figure A-9: Hourly Average Reserve Price for California Independent System Operator in 2017



Source: National Renewable Energy Laboratory

Figure A-10: Annual Average Reserve Price for California Independent System Operator



Source: National Renewable Energy Laboratory

Energy Services Potential

Previous sections explored the types of market products, and the bus availability. This section brings those together to determine what potential value exists for buses providing grid services.

Retail Programs and Services Value

Previous sections explored the types of market products, and the bus availability. This section brings those together to determine what potential value exists for buses providing grid services.

Most retail DR programs provide a flat dollar per kilowatt charge for providing services all month or year. This capacity payment ranges in value for each program.

Table A-1: Pacific Gas and Electric Company Demand Response Programs

Demand Response Program	Value	Notes
Base Interruptible Program (BIP)	1-500 kW reduction receives $8/kW-month 500-1000 kW reduction receives $8.5/kW-month >1000 kW reduction receives $9/kW-month	Penalty for not responding is $6/kW- month Must provide ≥100kW 10 events/month or 180 hours a year Max bid is 85% of the fixed stable level
Capacity Bidding Program (CBP)	$2.27 to $22.54/kW/month[a] Energy payment is based on difference between Day-ahead payment and real-time settlement	Program Season: May 1 - October 23 Includes capacity and energy payment The program provides day-ahead notice of events
Peak Day Pricing (PDP)	PG&E A-6: Peak and part-peak summer energy charge reduction PG&E A-10, E19 and E20: Summer demand and energy charge reduction	All rates have an energy penalty if demand occurs during event Does combine with PG&E Excess supply pilot or Supply side II DR pilot
Excess Supply Pilot (XSP)	$5-10/kW-month (depending on number of elected days per month, 2-7)[b] plus an additional amount to offset demand charges	30kW increase for 2 hours over a 4-hour block Blocks may not overlap 7-9AM or 6-8PM There is no penalty for not reducing Day-of and Day-ahead event notification
Supply Side II DR Pilot (SSP II)	Up to $10/kW from PG&E and wholesale energy and ancillary service payments from CAISO	Uses the CAISO Proxy Demand Resource (PDR) product Must achieve ≥100kW of load shed Day-ahead notification for events

Notes in Table: a) The value depends on the duration provided (1–4, 2–6, 1–8 or 1–24 hours). b) For more detail, see PG&E Excess Supply Pilot.

Source: National Renewable Energy Laboratory using: PG&E tariff sheets

By looking at historical data for demand response events we can develop an understanding for when the programs are most likely called and the potential availability of electric buses to participate. BIP, CBP and PDP programs are included in the table but not for the pilot programs (XSP and SSP). More data is needed to understand the event timing for XSP. SmartAC and SmartRate programs were included for comparison. Notice that all events in 2017 started between 14:00 and 19:00 with a low standard deviation. Events ended between 18:00 and 21:00.

Table A-2: 2017 Pacific Gas and Electric Company Demand Response Program Events Statistics

Demand Response Programs	Program Type	Average Start Time (PDT)	Averag e End Time (PDT)	StdDev of Start Time (hours)	StdDev of End Time (hours)	Tolled Hours
Base Interruptible Program (BIP)	Day Of	19:00	21:00	1.41	1.00	3
Capacity Bidding Program (CBP)	Day Ahead	16:00	19:00	1.16	-	68
Capacity Bidding Program (CBP)	Day Of	16:00	19:00	1.27	-	76
Peak Day Pricing (PDP)	Day Ahead	14:00	18:00	-	-	60
SmartAC	Day Of	15:00	20:00	4.34	1.22	66
SmartRate	Day Ahead	14:00	19:00	-	-	70

Source: National Renewable Energy Laboratory with Data from CPUC Collection of DR Events

Given the vehicle travel patterns shown in Figure A-5 and Figure A-6 and comparing to the program event timings in Table A-2, we can establish the availability of buses to participate. Buses start in the morning and then travel most of the day. From Figure A-6 there are some buses that have dwell time during the day, but the buses arrive back to the depot around 21:00. That means there is a limited opportunity for participation in the BIP, CBP and PDP programs. XSP and SSP allow you to set your own time blocks for participation so timing is not an issue but for XSP a device will still need to be called for an event, which may not happen if the time block is set at times when no events are called. For example, the time block for XSP and SSP could be set from 01:00 to 05:00, which would allow for full participation of the charger; however, maybe there are never any XSP events called and for SSP the ancillary service prices are very low between 01:00 and 05:00 (Figure A-9). This presents a challenge for XSP and SSP programs.

Wholesale Market Products Value

Wholesale and hybrid retail/wholesale products present another opportunity to provide grid services and receive payment. These programs use wholesale markets to set the value of the resources and require the device owner or an aggregator to determine when and how to bid each resource.

The Federal Energy Regulatory Commission, Regional Transmission Operators (RTO) and Independent System Operators (ISO) over the past several years have been improving the mechanisms by which demand response can participate in wholesale electricity markets. The process for direct participation in wholesale markets can require substantial time and funds; however, the CAISO market has introduced several market enhancements to enable DR to participate in the wholesale markets more quickly and at a lower cost. Most relevant for the buses is the PDR and RDRR enhancements. Many of the pilot programs and the DRAM require that the DR resources be a PDR or RDRR. A description PDR and RDRR is provided in Table A-3.

Table A-3: Description of Proxy Demand Response and Reliability Demand Response Resource Resources

Market Enhancement	Service	Market	Description
Proxy Demand Resource	Energy, spinning reserve, non-spinning reserve, residual unit commitment	Economic day-ahead and real-time	Bid into market as supply resource Minimum 100kW load curtailment for energy markets and 500kW for reserve markets (can be aggregated) Requires telemetry metering
Reliability Demand Response Resource	Energy	Economic day-ahead, reliability real-time	Used for providing reliability Minimum 500kW load curtailment (can be aggregated) Must be able to curtail for up to 4 hours Does not require telemetry metering

Source:

To determine the revenue potential for BEBs the following properties are assumed (Table A-4). The maximum charging power for VTA will increase more in the future but is currently at 50kW, limited by the charger.

Table A-4: Electric Bus and Charging Assumptions

Property	Value
Max charging power (kW)	50
Battery max capacity (kWh)	440
Battery usable capacity (kWh)	350

Source:

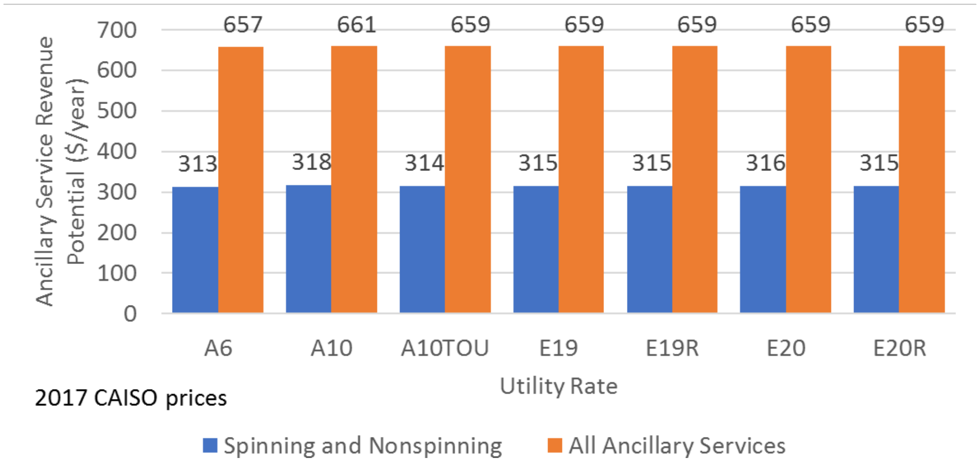
Two ancillary service scenarios are explored. The first, only includes spinning and non-spinning reserve provision. The second, includes regulation, spinning and non-spinning reserves (Figure A-11). While the PDR and RDRR do not currently allow for DR to provide regulation services, this provides an estimate of the value if that changes in the future. Historical prices are for 2017 CAISO markets. For a bus that travels around 130 miles per day on average, the total value for spinning and non-spinning reserves is between $313 and $318 per year. All the revenue for this scenario comes from spinning reserve markets. The utility rates, which are mostly time-of-use, have little impact on the ancillary service value. For the "All Ancillary Services" scenario all the revenue comes from regulation (54 percent from regulation up and 46 percent from regulation down).

The value for regulation and spinning reserves does not include the costs of when reserves are called. That is particularly impactful for regulation which is called more often than spinning reserve.

To meet the size requirement of 500kW would require an aggregation of 10 buses with 50kW chargers. VTA's plan is to increase the capacity for the chargers to above 100kW in the future as well as purchase additional electric buses, either of which would alleviate the capacity limitation.

Additionally, there are costs for participating in the wholesale markets. First, participation requires a meter that can provide telemetry data to the CAISO. There are some costs associated with application to become a PDR or RDRR. These costs should be considered when determining the value of market participation.

Figure A-11: Ancillary Service Value Per Bus When Driving Around 130 Miles/Day



Source:

PDR and RDRR both enable energy market integration. The buses could receive revenue by reducing their charging during a time of the day when they are typically charging (based on the 10-in-10 baseline or select alternative methods). The challenge with participating in energy markets is the mismatch between retail rates and wholesale energy prices. For retail rate optimization, the goal is to minimize demand and energy charges. However, the most likely times to experience price spikes in wholesale markets are the times of high demand and rapid changes. Also, predicting price spikes to advise energy market bids for the DR device is challenging. That means a device must risk guaranteed price reductions through rate optimization against uncertain value in energy markets.

In addition to those programs for accessing wholesale energy and reserve markets, the DRAM market allows for DR resources to access capacity value. For the 2017 DRAM request for offer (RFO), PG&E sought to acquire 10MW of product. Participating resources can provide system capacity (bid into day-ahead market), local capacity (bid as PDR or RDRR), or flexible capacity (bid as PDR and requires ability to participate in day-ahead and real-time markets). DRAM markets require a change (reduction or increase) in energy and is provided compensation based on the resources bid in the DRAM.

There is no publicly available data on the resulting contract between PG&E and the DRAM participants, but based on PG&E's request in 2017, a maximum value can be determined. PG&E asked for 10MW of capacity and has a price cap of 6 million dollars. That means the value could be as high as $50/kW-month. Given that the program is pay-as-bid and that utilities have not hit the price allowance in the past, the revenue is certainly lower than the maximum, but it is unclear by how much.

Capacity is typically needed during periods of high demand (e.g., late afternoon or early evening). Unless buses are already charging during those periods of high demand, they will not be able to reduce load. Presently, most of the VTA bus blocks do not allow for afternoon charging which complicates the opportunity for electric buses to participate in the DRAM.

Conclusions

This report explores the availability of VTA electric buses to provide both wholesale and retail gird services. Grid services explored include Base Interruptible Program (BIP), Capacity Bidding Program (CBP), Peak Day Pricing (PDP), Excess Supply Pilot (XSP), Supply Side II DR Pilot (SSP II) and participation using the Proxy Demand Resource (PDR) and Reliability Demand Response Resource (RDRR) CAISO market enhancements.

The biggest challenge facing market participation of electric buses is the timing of the bus charging. Charging typically occurs in the evening. For VTA that would start at around 21:00 and end by 06:00 the following day. Most of the DR events for retail programs (BIP, CBP, PDP) occur between 14:00 and 21:00 so without changing bus scheduling, the buses are not even in the depot to provide load reduction. XSP and SSP have flexible scheduling for participation so buses could schedule to provide services from 21:00 to 01:00 or from 01:00 to 05:00. In this way timing is not an issue, but the question is how much value do markets provide during those times? For XSP, that depends on when events are called. There isn't enough data to determine this timing yet, so event calls for XSP should be considered in the future. Value for SSP participation depends on the ancillary service market values at that time. Participating directly as a PDR resource is likely more valuable but participating in SSP may be easier and lower cost, so costs for SSP should be explored.

Participation in the DRAM is likely not possible based on the availability of electric buses. The value of the DRAM is not publicly available but will likely be less than $50/kW-month.

Participation in PDR and RDRR programs was explored. The value for participation in energy markets is uncertain and difficult to achieve. For a bus that travels on average 130 miles per day, the value for ancillary service markets is estimated to be around $315/kW-year for spinning reserve and around $659/kW-year (excluding impacts when reserves are called). In addition, the application cost and infrastructure cost should be considered when evaluating the PDR and RDRR programs.

Changing the driving patterns for electric buses could substantially change the opportunity for providing grid services. If the buses returned to the depot or transit hub to charge during the day for two to four hours, then there would be greater potential for using more low-cost solar power, while also enabling greater value from retail DR program and wholesale market participation.

Also, as ridership goes down in the evening, the ancillary service prices increase. That is a potential area where ancillary service revenue could be increased if electric buses arrive at 17:00 or 18:00 and are connected to chargers immediately, enabling them to provide support to the grid as the load falls after the evening peak electricity load. The potential value must be balanced with the utility rate, particularly looking at the time-of-use bins to avoid on-peak costs.

APPENDIX B:
Hardware Specifications

Table B-1: Specifications for E-Buses
(Proterra Catalyst E2 Buses, Battery 440 kWh, 352 kWh usable, Li-ion NiMnCo)

Specification	Description
Dimensions	
Length	42’6” ft
Wheelbase	11’2” ft
Approach Angle	24’8” degrees
Breakover Angle	7° degrees
Departure Angle	9°degrees
Turning Radius	41.9’ ft
Curb Weight	29,849 lbs
Gross Weight	39,050 lbs
Performance	
Projected Altoona Efficiency	1.75 kWh/mile; w/full passenger load
Top Speed	65 mph
Acceleration	6.8 from 0-20 mph
Total Energy	440 kWh
Nominal Range	251 Miles; Total energy/projected Altoona efficiency
Standard Charge Time	<3.5 hrs
Charging In Depot	120 kW; Utilizes standard J1772-CCS plug-in chargers
Charging On Route	Option; Configured for Proterra overhead fast-charger
Interior	
Seating Capacity	40
Door Width – Front	43.2”
Door Width – Rear	49.1”
Brakes & Suspension	
Braking System	Front & rear air disk brakes
Traction	4-wheel ABS with optional traction control
Suspension	Multi-Link Air Ride rear suspension

Specification	Description
Drivetrain	
Motor	220 kW peak permanent magnet drive motor
Gearbox	Proterra 2-speed auto-shift EV gearbox
Cooling System	Roof-mounted cooling system

Source:

Table B-2: Specifications for Smart Chargers (ChargePoint Express CPE 250)

Specification	Description
Station Electrical Input	
Input Rating	400V AC, 3-phase, 96A, 50 Hz 480V AC, 3-phase, 80A, 60Hz
Wiring	L1, L2, L3, Neutral & Earth
Station Electrical Output	
Max Output Power	62.5 kW
Output Voltage, Charging	200-1,000 DC
Max Output Current	156A
Max Modules per Station	2
Paired Station Electrical Output	
Paired Max Output Power	125 kW
Paired Max Output Current	CCS1: 174A or 200A CCS2: 200A CHAdeMO; US: 140A, EU: 125A
Power Module	
Max Output Power	31.25 kW
Max Output Current	78 A
Power conversion Efficiency	>95%
Power Factor	0.99 at full load
Harmonics	iTHD < 5% (Complies with IEEE 519 Requirements)
Power Module Cooling	Liquid Cooling Technology
Functional Interfaces	
Max Connector Types per Station	Up to two different connector types per station
Supported Connector Types	CHAdeMO, CCS1 (SAE J1772^{TM} Combo), CCS2 (IEC 61851-23)

Specification	Description
Cable Length with Swing Arm*	Full Horizontal Reach: 4.27m (14’)
LCD Display	Full-color 254 mm (10”) display for driver interaction
Top Display	Full-color 508 mm (20”) LED display for notifications
Authentication	RFID: ISO 15693, ISO 14443, NEMA EVSE 1.2-2015 (UR) Tap to Charge (NFC on Apple & Android): 15118-1 (EIM) Remote: Mobile and in vehicle (if supported by vehicle)
Connectivity Features	
Vehicle Safety Communications	CHAdeMO – JEVS G104 over CAN, CCS1 – SAE J1772 over PLC and CCS2 – IEC 61851-23
Plug-Out Detection	Power terminated per JEVS G104 (CHAdeMO), SAE J2931 (CCS1) and IEC 61851-23 (CCS2)
Local Area Network	2.4 GHz and 5 GHz Wi-Fi (802.11 b/g/n)
Wide Area Network	4G LTE (fall back to 3G GSM)
Supported Communication Protocols	OCPP
Service and Maintenance	Remote system monitoring, diagnostic, and proactive maintenance
Safety and Operational Ratings	
Station Enclosure Rating	Type 3R, IP54
Station Impact Rating	1K10
Safety and Compliance	UL and cUL listed: complies with UL 2202, UL 2231-1, UL 2231-2, CSA 107.1 CE marking: complies with IEC 62196, IEC 61851
Station Surge Protection	Tested to IEC 6100-4-5, Level 5 (6kV @ 3,000A). In geographic areas subject to frequent thunderstorms, supplemental surge protection service panel is recommended.
EMC Compliance	U.S.: FCC part 15 Class A; EU: EN55011, EN55022 and IEC6 1000-4
Cooling	Liquid Cooling Technology
Storage Temperature	-40°C to 50°C (-40°F to 122°F)

Specification	Description
Operating Temperature	-30°C to 50°C (-22°F to 122° F)
Operational Altitude	<3,000 m (<9,800 ft)
Operating Humidity	Up to 95% @ 50°C (122°F) non-condensing
Generic Specifications	
Station Enclosure Dimensions	2,230 mm x 712 mm x 420 mm (7’4” x 2’4” x 1’4”)
Power Module Dimensions	760 mm x 430 mm x 130 mm (2’6” x 1’5” x 5”)
Station Weight (without Power Modules)	250 kg (551 lbs)
Power Module Weight	45kg (98.5 lbs)
Energy Management Features	
Dynamic Power Management	Allows a fixed maximum power output per station or lets the system dynamically manage the power distribution per station
Remote Energy Management	Manage output power via the ChargePoint Admin Portal, API, and Open ADR 2.0v VEN

***Horizontal reach to typical vehicle charging port: 3.76 (12’4”)**

Source:

Table B-3: Specifications for Communications Device (Clever Devices IVN4)

Specification	Description
Electrical	
Voltage	24 V DC nominal, 18–48 V DC range
Power Draw	24 W nominal
Electrical Environment	SAE J145 (load dump, inductive switching, mutual coupling)
Switched Power Supply	Via Run switch: 8 A capacity Via power hold parameter: 4 A capability
Computing	
CPU	Intel Atom 1.6 GHz
RAM	2 GB
Mass Storage	4, 8, or 32 GB industrial SSD, depending on configuration
Operating System	Windows 7 Embedded
Additional Computing	Integrated I/O coprocessor

Specification	Description
Networking	
Ethernet	4x 10/100 Ethernet ports w/internal switch
Wi-Fi	Optional 802.11b/g/n
Cellular	Optional internal modem
Connectivity	
Control Head	1x DVI to Transit Control Head (TCH)
USB	4x ports
Serial Ports	3x RS232, 3x, RS485, 1x switchable
J1708	2x
J1939 CAN	2x
Digital I/O	12x inputs, 4x outputs
Emergency Alarm	Monitored circuit input
Positioning	
Receiver	32 channels
Constellations	GPS and GLONASS
Time to First Fix	35 second cold start, <1 second hot start
Dead Reckoning	Via odometer and internal gyroscope
Audio	
Audio output	4x channels of 25W into 8 Ohm 1x channel of 10W into 8 Ohm
Automatic volume control	Included
Additional interfaces	PA microphone and volume adjust Handset
Mechanical	
Dimensions	3.9”H x 8.4 W x 8.5” D
Weight	7.0 lbs 3.2 kg
Environmental	
Operating Temperature	-30º – 60º
Humidity	SAE J1455
Vibration	SAE J1455
Shock	SAE J1455
EMC	SAE J1113/J1455
Compliance	FCC Part 15 Class A

APPENDIX C:
Technical Advisory Committee Participants

Table C-1: Technical Advisory Committee Participants

Name	Organization	Title
Chris Durant	AC Transit	
Ka'Ryn Holder-Jackson	ACCEL Adult School Consortium	
Phillip Kobernick	Alameda County	Transportation Operations, AlCo GSA
Sam Hil-Cristol	Alameda County	Climate Corps Fellow
Ahsan Baig	Alameda-Contra Costa Transit District	Chief Information Officer
Salvador Llamas	Alameda-Contra Costa Transit District	Chief Operating Officer
David Lu	ASWB	
Therese Fisher	ASWB	
Macy Neshati	AVTA	
Mark Perry	AVTA	
Alex Munster	Black & Veatch	
Maryline Lewett	Black & Veatch	
Paul Stith	Black & Veatch	
Randal Kaufman	Black & Veatch	
James Holtz	BYD	
Justin Scalzi	BYD	
Bryan Lee	California Energy Commission	
David Erne	California Energy Commission	Supervisor
Edward Ortiz	California Energy Commission	Media Office
Fernando Pina	California Energy Commission	Office Manager
Jeffrey Sunquist	California Energy Commission	CAM
Qing Tian	California Energy Commission	
Robin Goodhand	California Energy Commission	
Peter Klauer	California ISO	Expert in grid stability, VGI
Jasna Tomic	CALSTART	Research Director

Name	Organization	Title
Jonathan Norris	CALSTART	Project Manager
Robin Goodhand	California Energy Commission	CAM
Benjamin Waxler	ChargePoint	Applications Engineer
Darryll Harrison	ChargePoint	Director, Global Communications
Michael Jones	ChargePoint	VP, Sales
Clay Collier	ChargePoint Energy Solutions	Co-Founder
Paul Lipkin	ChargePoint Energy Solutions	Project Manager
Rajiv Singhal	ChargePoint Energy Solutions	
Rob Calvert	ChargePoint Energy Solutions	
Shana Patadia	ChargePoint Energy Solutions	
Nick Rothman	City College of San Francisco	
Pam Gutman	City College of San Francisco	Bay Area Regional Director for Advanced Transportation
Lori Mitchell	City of San Jose	Director of Community Energy
Ramses Madou	City of San Jose	Transportation Planner
Dean Roussinos	Clever Devices	Software Engineer
Sandra Graman	Clever Devices	
Steve Damozonio	Clever Devices	
Steve Halberstadt	Clever Devices	
Betty Seto	DNV-GL	Head of Department
Arnaud Souille	EDF Innovation Lab	
Paul Breslow	EDF Innovation Lab	
Muffi Ghadiali	Electriphi	
Sanjay Dayal	Electriphi	
Drew Bohan	California Energy Commission	
Andrea Vas	Energy Solutions	
Daniela Urigwe	Energy Solutions	
Emily Kehmeier	Energy Solutions	
Kitty Wang	Energy Solutions	
Tamara Perry	Energy Solutions	Quality Analysis
Tim O'Keefe	Energy Solutions	

Name	Organization	Title
Dan Bowermaster	EPRI	Program Manager, Electric Transportation
Mark Kosowski	EPRI	
Mark Goody	FleetCarma	Manager, EV Programs
Lori Riehl	Fremont HSD Adult School	
Raji Visvanathan	Fremont HSD Adult School	
Sorin Neagu	Independence High School	
Michael Kilpatrick	Intueor	
Mike Kilpatrick	Intueor	Principal Consultant and Leader for the Asset Management Practice
Mike Ferry	KnGrid	COO
Kathy Wells	Lancaster Choice Energy	
Doug Black	Lawrence Berkeley National Lab	
John Welty	Lehigh University	
Wendy Fong	Lehigh University	
Luther Jackson	NOVAworks	Program Manager
Andrew Kotz	NREL	
Joshua Eichman	NREL	Analyst/Engineer
Ken Kelly	NREL	Sr. Engineer
Kenneth Kelly	NREL	
Bjor Christiansen	NUVVE	Chief Strategy Officer
Beth Reid	Olivine	CEO
Beth Reid	Olivine	
Hitesh Soneji	Olivine	Senior Solutions Design Engineer
Joe Bourg	Olivine	
Valerie Nibler	Olivine	
Elizabeth Focella	Opinion Dynamics	
Mersiha McClaren	Opinion Dynamics	
Sam Hill-Cristol	Optony	
John Matranga	OSIsoft	
Peter Ambiel	Peninsula Clean Energy	
Rafael Reyes	Peninsula Clean Energy	Director of Energy Programs

Name	Organization	Title
Cal Silcox	PG&E	Program Manager, Electric Vehicles
Dean Kunesh	PG&E	Account Manager
Jonathan Burroughs	PG&E	Expert Program Manager Demand Response Policy and Pilots
Christian Hosler	Prospect Silicon Valley	Former Project Manager
Doug Davenport	Prospect Silicon Valley	CEO
Gary Hsueh	Prospect Silicon Valley	Former Director of Mobility Programs
Hilary Davidson	Prospect Silicon Valley	Former Communications Director
Melissa Benn	Prospect Silicon Valley	Program Associate
Mike Harrigan	Prospect Silicon Valley	Senior Program Manager
Rajiv Mathur	Prospect Silicon Valley	
Ruth Cox	Prospect Silicon Valley	
Tina Hu	Prospect Silicon Valley	Project Manager
Venkatesh Nadamuni	Prospect Silicon Valley	Former Project Manager
Kent Leacock	Proterra	Director Gov’t Relations & Public Policy
Rajiv Singhal	Proterra	
Ryan Popple	Proterra	CEO
Sam Sperling	Proterra	
Seamus McGrath	Proterra	Manager, Charging Systems
Roger Thorn	Sacramento Regional Transit	
Nigel Daniels	SAIC	
Michael Wygant	San Diego Metropolitan Transit System	Director of Fleet & Facilities
Fred Barez	San Jose State University	
Fred Barez PhD.	San Jose State University	Professor of Mechanical Engineering
Antonio Castillo	Santa Cruz Metro	Maintenance Supervisor
Eddie Benson	Santa Cruz Metro	Maintenance Manager
Greg Nolen	Santa Cruz Metro	Maintenance Supervisor

Name	Organization	Title
Lionel DeMaine	Sequoia Adult School	
Bhavin Khatri	SF MTA	
Marley Miller	SF MTA	
Timothy Doherty	SF MTA	Senior Planner
Aimee Bailey	Silicon Valley Clean Energy	
Alan Suleiman	Silicon Valley Clean Energy	Director of Marketing and Public Affairs
Don Bray	Silicon Valley Clean Energy	Manager of Account Services
Girish Balachandran	Silicon Valley Clean Energy	
Justin Zagunis	Silicon Valley Clean Energy	
Tim McRae	Silicon Valley Leadership Group	Director of Energy Policy
Julia Thompson	SJSU EPICS	
Emre Kara	SLAC National Accelerator Lab	Associate Staff Scientist
Sila Kiliccote	SLAC National Accelerator Laboratory	Staff Scientist
Len Engel	solutionLab	Executive Director (formerly CEO, AVTA)
Brian Shaw	Stanford University	Director, Stanford Parking & Transportation
Kyle Yamaguchi	Sumitomo	Business Development Manager
Seth Nishida	Sumitomo	
Bill Boston	Trapeze Group	Project Manager/Sales Engineer
Chris Ramirez	Trapeze Group	
Scott Moura	UC Berkeley	Professor
Tim Lipman	UC Berkeley Transportation Sustainability Research Center	Co-Director
Rajit Ghadh	UCLA	Professor, UCLA, Smart Grid/EV/AV
Ani Peralai	VTA	Mechanical Engineer
Gary Miskell	VTA	CIO/CTO
James Wilhelm	VTA	Engineering
Joonie Tolosa	VTA	Analyst

Name	Organization	Title
Manjit Chopra	VTA	Program Manager
Larry Carr	VTA	Board Member
Richard Schorske	ZNE Alliance	Executive Director
Sam Irvine	ZNE Alliance	Senior Program Manager

APPENDIX D:
Knowledge Transfer Calendar

Table D-1: Knowledge Transfer Calendar

Event	Type	Location	Date	Description
Prospect Silicon Valley Innovation and Impact Symposium	Conference	Microsoft, Sunnyvale	06/14/17	The 2017 Innovation and Impact Symposium focuses on emerging technologies in Mobility, Energy and the Built Environment. Gary Miskell, CTO at VTA, participated in the Electric Vehicles panel at the Symposium. Many of the region’s leaders from the startup, corporate, public and research communities participated in the event.
CARB Zero Emission Bus Rule Making	Workshop		12/01/17	ZNE Alliance participated in this event.
TAC Meeting #1 and Press Event	TAC Meeting	Nor-Cal	04/19/18	The Press event was a major media event (print and TV) included Mayor Sam Liccardo of San Jose, the CEO of Proterra, the CEO of the AVTA, the Board President of the VTA, and the Executive Director of the CEC, among other notables. Both the AVTA and VTA projects were highlighted along with a ride on VTA electric buses. The Technical Advisory Committee Meeting for Joint E-Bus Project was held afterwards.
RICAPS Webinar	Webinar	Online	05/22/18	Regionally Integrated Climate Action Planning Suite (RICAPS) Multi-City Working Group. Prospect Silicon Valley presented on the E-bus projects.
Prospect Silicon Valley Innovation and Impact Symposium	Conference	City Hall, San Jose	05/31/18	The 2018 Innovation and Impact Symposium focuses on emerging technologies in mobility, energy and the built environment. Kisensum participated on a Vehicle Charging Panel highlighting the VTA VGI project, and Richard Schorske and Hitesh Soneji presented on the AVTA project.

Event	Type	Location	Date	Description
Roadmap 11 Conference	Conference		06/01/18	Discussed with Research into Action Energy Solution's acceptance to present at the Roadmap 11 Conference in Portland, OR in June 2018. The proposal Moving the Needle to Improve Electric Bus Fuel Economy will be a featured segment of the Scaling Electric Transit session.
EPRI Electrification Conference	Conference		08/01/18	Attended EPRI Electrification Conference mobility track in Long Beach to monitor progress on fleet electrification and grid integration, and to outreach to new fleet charging providers, including new startups Amply and InCharge. These firms provide "charging as a service" via pay per kwh and pay per mile approaches that include demand charge management and stationary storage integration. AVTA will evaluate the Amply solution, informed by project analytics from Olivine and Energy Solutions.
SPUR (leading the Charge on EV Buses)	Presentation	San Jose	10/24/18	Focused on how public transportation agencies around the Bay Area are taking bold new steps to electrify their fleets, create new systems to manage electric vehicle (EV) charging and make sure that the bus is at the center of our mobility options. Presentation on the E-Bus Project by ProspectSV and TAC team.
CTA conference	Conference		11/01/18	(CTA) as host for the solutionLAB E-Bus Workshop at the November CTA conference in Long Beach
EUCI Utility-EV conference	Conference		12/10/18	ZNE Alliance attended to learn about best practices in utility program design related to E-fleet transition programs and to share information and resources on E-Bus and E-Fleet program design opportunities & needs.

Event	Type	Location	Date	Description
CARB ZEB Tech Symposium	Conference		01/01/19	CARB’s ZEB Technology Showcase & Symposium: Interfaced with AVTA and CARB to enable participation by Olivine and Energy Solutions and participated in a preparation session for Panel 2.1.
solutionLAB conference	Conference		01/24/19	Discussed plans to engage the California Transit Association (CTA) regarding co-hosting of the solutionLAB conference in November 2018. Len Engel reached out to engage with host, Long Beach Transit.
VGI Working Group Meetings	Workshop		02/01/19	Olivine participated in VGI Working Group Meetings hosted by Gridworks on behalf of the CPUC: “VGI Value Initiative Framing Document by Gridworks”.
CARB, AVTA & CTA Zero Emission Bus Technology Showcase and Symposium	Conference	Sacramento	02/06/19	The Symposium provides stakeholders with updated technical information on zero-emission technologies, associated infrastructure and scale up options, operating costs and fuels, deployment planning, and funding sources. Presentation by Hitesh Soneji of Olivine.
EPIC Symposium	Conference	Sacramento	02/19/19	The EPIC Symposium highlights cutting-edge emerging energy solutions that enhance safety, reliability and affordability, and bringing clean energy ideas to the marketplace. Presentation by Hitesh Soneji of Olivine and ProspectSV team leads.
Behavior, Energy and Climate Change conference	Abstract for Conference		03/01/19	ZNE Alliance submitted an abstract for the Behavior, Energy and Climate Change conference in partnership with Energy Solutions.
VGI Working Group Meeting	Workshop		03/15/19	ZNE Alliance participated in the VGI Working Group Meeting on March 15 hosted by Gridworks on behalf of the CPUC in support of the development of a VGI Road Map for California.

Event	Type	Location	Date	Description
Produced VGI Project Video	Video	Online	05/01/19	VTA produced project video. Watch the Video here: https://www.youtube.com/watch?v=b300RdkcMVQ
NOVAworks: Independence High School Tour of Cerrone Yard	Workshop	VTA	05/10/19	ProspectSV and NOVAworks coordinated a site visit to VTA Cerrone Yard with Independence High School Students. Blog post: http://www.vta.org/News-and-Media/Connect-with-VTA/High-School-Automotive-Students-Learning-that-the-Future-is-Now#.XOQoLFNKgWq
TAC Meeting #2	TAC Meeting	VTA	05/28/19	Technical Advisory Committee Meeting #2 hosted at VTA. Partners from both Projects gave presentations on updates and progress thus far.
Business of Local Energy Conference	Conference	Sacramento	06/01/19	Presentation provided to the Business of Local Energy Conference on E-bus VGI and other EV fleet issues.
Prospect Silicon Valley Innovation and Impact Symposium	Conference	ZNE Center, San Leandro	06/19/19	The 2019 Innovation and Impact Symposium focused on transforming California with Clean Technology. Project partners participated in panels on the “Mobility Track”. VTA displayed a Proterra bus at this event.
School E-Bus Workshop #1	Workshop	CEC HQ	08/30/19	This workshop (organized by Robin Goodhand) focused on the importance of smart charging, and operator training to optimize energy efficiency, and VGI. ChargePoint, NREL, and Olivine presented.

Event	Type	Location	Date	Description
EVs & the Grid conference	Conference	LA	10/1/19 - 10/3/19	Infocast's 5th edition of EVs & the Grid convenes major players from the energy, transportation, and real estate sectors. Ruth Cox (ProspectSV) moderated & Gary Miskell (VTA) presented on panel: Owning & Optimizing Your Electric Fleet Charging Depot. Description: Electric fleet owners who own and operate their own charging stations can customize their infrastructure to their specific needs, providing more control over their operations and costs. How else can fleet owners benefit from electrification? How do transportation network companies (TNC) plan on supporting their fleets?
Community Choice Energy EV Program Design Webinar	Webinar	Online	10/23/19	Presentation to ~60 Community Choice Energy staff and consultants on EV-related program design, with a focus on incentives for electric fleet transitions and VGI. Richard Schorske presented with Justin Zagunis of Silicon Valley Clean Energy.
California Transit Association (CTA) Conference & Expo	Conference	Monterey, CA	11/13/19	AVTA project team participated in the Fall Conference and Expo. The event featured dynamic presentations from industry experts on today's pressing transit challenges and the novel solutions being implemented by innovative transit leaders.
Phase 1 findings webinar/workshop	Webinar	Online	02/26/20	CALSTART facilitated and coordinated this webinar on the findings thus far for both projects. Panelists: ProspectSV, VTA, ChargePoint, Olivine, ZNEA. ProspectSV providing outreach and logistics.
Climate Smart Transportation	Webinar	SPUR San Jose (Online)	03/10/20	ProspectSV hosted this webinar with SPUR. Gary Miskell, VTA presented on the Advanced Bus VGI Project.
EPIC Symposium	Conference	Sacramento	Cancelled	Originally planning to present or attend the Symposium, but was cancelled due to COVID-19.

Event	Type	Location	Date	Description
Webinar on Diverse Approaches to Charging Technology	Webinar	Online	Cancelled	Originally planning to host a webinar on charging technologies, include WAVE wireless charger and highlight the VGI project, but was cancelled due to COVID-19.
Zero Emission Bus Conference	Conference	Online	9/15 - 9/17/20	Planning to attend (online) the Zero Emission Bus Conference, a premier event for electric bus knowledge and industry collaboration sponsored by Center for Transportation and the Environment.
NOVAworks	Webinar/	online	11/12/20	Hosted a webinar with NOVA, bringing together educators to review VGI findings and to elicit thoughts about how best to apply VGI lessons in the classroom.
Final Project Webinar	Webinar	Online	Jan 28 2021	Hosted a Final Project Webinar to highlight Phase 2 Integration and overall project findings.
Press Release on Phase 2/Project completion	Press Release	Online	TBD	Planning to produce a Press Release on Phase 2 completion and the end of the project.