Energy Research and Development Division

FINAL PROJECT REPORT

California E-Bus to Grid Integration Project

Gavin Newsom, Governor

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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 and advanced clean generation, energy-related environmental protection, energy transmission and 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 and include:

- 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.

California E-Bus to Grid Integration Project is the final report for Contract Number EPC-16-065 conducted by ZNE Alliance. 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@enegy.ca.gov.

ABSTRACT

The California E-Bus to Grid Integration Project engaged the Antelope Valley Transit Authority, based in Lancaster, California—the first transit authority in the nation to commit to a 100 percent all-electric bus fleet—to achieve developing an operator training model that demonstrates the impact of driver behavior on energy efficiency; and developing a Vehicle-to-Grid integration model that identifies cost savings opportunities from managed charging and electric fleet participation in wholesale energy markets. This report highlights the conclusions and recommendations of this multi-year effort funded by the California Energy Commission to develop best practices in electric fleet management.

The project developer and prime contractor on the California E-Bus to Grid Integration Project was the Zero Net Energy Alliance. Key partners included the Antelope Valley Transit Authority, Olivine, Energy Solutions, TAPTCO, SolutionLab, ASWB Engineering, Opinion Dynamics, and Prospect Silicon Valley.

Keywords: California Energy Commission, Antelope Valley Transit Authority, AVTA, Vehicle-Grid Integration, VGI, Vehicle-to-Grid, V2G, Vehicle-to-Building, V2B, use case, scenarios, case studies, measurement and verification, M&V, cost effectiveness, barriers, opportunities, E-Fleets, Olivine, baseline, evaluation.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Commercial-scale use of electric buses (E-Buses) and other medium- and heavy-duty electric vehicles is projected to accelerate significantly during this decade and beyond as electric vehicle product diversity, performance, and pricing becomes more attractive compared to fossil-fueled vehicles. In addition, California's Innovative Clean Transit Regulation, adopted by the California Air Resources Board (CARB) in 2018, progressively requires all transit agencies to shift to zero emissions bus fleets by 2040. With more than 10,000 full-size commercial transit buses in use in California, along with 24,000-plus school buses (based on CARB estimates), the total emissions impact of these vehicles is significant, and accelerating the transition to zero emission buses is a policy priority for California.

Fleet operators have significant concerns that are limiting E-Bus adoption, including: (1) high up-front electric vehicle and charging infrastructure costs; (2) range anxiety and other operating performance uncertainties; (3) limited data on total cost of ownership, including potentially significant variability in operations and maintenance costs; (4) uncertainty regarding charging-related energy costs, including demand charge issues, and offsetting grid services revenue potential; and (5) limited awareness of the overall E-Bus value proposition, taking into account life-cycle costs and benefits.

Project Purpose

The goals of this project were to demonstrate and disseminate knowledge of the potential value of E-Bus operator efficiency training and an E-Bus platform capable of smart charging and vehicle-grid-integration. By studying the interactions between fleet operations, electric vehicles, and the grid, the project team developed a comprehensive and holistic approach to overcome these complex challenges in transit fleet electrification.

Project Approach

In collaboration with Antelope Valley Transit Authority, the first major transit agency in the nation to commit to a fully electric fleet, the Zero Net Energy Alliance (the prime contractor) and its partners launched the California E-Bus-to-Grid Integration Project. Key project partners included Olivine, Energy Solutions, TAPTCO, SolutionLab, ASWB Engineering, Opinion Dynamics, and Prospect Silicon Valley.

At the start of the project, in 2017, Antelope Valley Transit Authority was using about 30 electric buses, produced by Build Your Dreams, a China-headquartered global manufacturer with a large assembly facility in Lancaster, California. By the project's end in 2020, 80 E-Buses were delivered, with the partners achieving the three major project goals:

1. Demonstrate technical, operational and behavior solutions to enhance E-Bus vehicle-grid-integration.
    - The project team used a statistical regression analysis to isolate the effects of operator behavior on the efficiency of E-Bus operation—measured in kilowatt hours per mile (kWh/mile). The results of this analysis were used to identify

factors that most influence E-Bus efficiency and to develop realistic operator efficiency improvement goals.

- Energy Solutions conducted operator and management interviews, ride-alongs, and surveys to inform the project team on E-Bus user experiences, as well as operator and management attitudes towards E-Buses. In addition, literature review revealed the state of the industry knowledge relating to: theoretical factors influencing efficiency (such as drag, rolling resistance, air conditioning load); effects of driving behavior on vehicle efficiency; and factors influencing behavior change (for example, feedback, training, and incentives).

2. Quantify the costs and benefits of diverse E-Bus vehicle-grid-integration use cases.
    - The project team used the Olivine E-Fleet Model to conduct quantitative analysis of a number of E-Bus use cases: smart charging, demand response, on-site solar photovoltaics with battery storage, and vehicle-to-building emergency energy.
3. Disseminate best practices in E-Bus planning, procurement, operations, training, maintenance, and grid-integration to accelerate E-Bus adoption throughout California.
    - The project team collaborated with CALSTART and a separate E-Bus vehicle-grid-integration project led by Prospect Silicon Valley and the Santa Clara Valley Transportation Authority known as the Advanced Transit Bus vehicle-grid-integration Project.
    - A joint technical advisory committee was formed with Prospect Silicon Valley to develop a comprehensive E-Bus Deployment Guide and to provide insight on the evolving E-Bus market. Committee members included subject matter experts from transit agencies, national labs, original equipment manufacturers, utilities, and technology companies.

Project Results

There were several hardware integration challenges limiting managed charging of the buses, including the inability to modulate charging current and automate charging schedules through software interfaces. The project team worked with equipment vendors but solutions that were both feasible and implementable within the project timeframe were not available. Therefore the project team determined that simulating vehicle-grid-integration use cases, with real-world E-Bus operational data from 30 telemetry-equipped E-Buses, would be the most effective and efficient means to advance project goals within the project timeframe. The E-Fleet vehicle-grid-integration simulation model, provided by the Olivine, and the operator training programs yielded important findings.

Key Results of Vehicle-Grid Integration Simulation Modeling

- Smart charging: Smart charging offers the most value to Antelope Valley Transit Authority relative to other vehicle-grid-integration strategies assessed, with models showing a 40 percent reduction in annual utility costs — equivalent to an estimated $11,460 per bus per year at current Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) rates..
- Demand response: Frequency regulation would have a comparatively smaller, but still positive value if policy and technology permitted its use.

- On-site solar photovoltaics: on-site solar with battery energy storage is not an economically feasible option for Antelope Valley Transit Authority because the E-buses are rarely connected to the charging stations during the time of day when solar is most available. The size of energy storage needed to shift solar to nighttime charging is cost prohibitive.
- Vehicle-to-grid: Antelope Valley Transit Authority fleet use rates and charging requirements were incompatible with vehicle-to-grid applications. The E-buses charge during nighttime hours when grid congestion is low and energy market bidding opportunities are scarce.

Operator Efficiency Program Results

- The E-Bus Operator Efficiency Program had a significant impact on operator efficiency. Operators used 0.084 fewer kWh/mile in a post-training and feedback period compared to trips driven before the training was offered. Operator incentives and an improved performance feedback mechanism may lead to additional successful behavior changes and improvements in fuel economy.
- Efficiency improvements from E-Bus operator training may not persist without subsequent interventions.

Technology Transfer and Market Adoption

Project team members attended and presented at 27 events including industry conferences, symposia, workshops, panels, webinars, and the technical advisory committee meetings. The project team presented summaries of project learnings, program concepts, and policy recommendations at the following events:

- Workshops: In collaboration with Prospect Silicon Valley, the project team hosted five workshops featuring speakers presenting on topics relevant to the project. Outreach for these workshops was conducted via contact lists curated by ProspectSV, as well as industry contacts curated by Zero Net Energy Alliance.
- Webinars: Project partners participated in four webinars to educate fleet operators on opportunities to implement vehicle-grid-integration systems in future projects and share lessons learned from both the Antelope Valley Transit Authority and Santa Clara Valley Transportation Authority projects.
- Industry Conferences: Project team members attended and presented at 11 industry conventions and meetings, largely in California, to network with industry professionals and share findings about the E-Bus Projects.
- California Energy Commission (CEC) Symposia: Project partners participated in two of the annual EPIC symposia and workshops as requested by the CEC.
- Prospect Silicon Valley Innovation and Impact Symposium: The ProspectSV Innovation and Impact Symposium was an annual event bringing together more than 250 innovators, industry leaders, and policymakers in transportation, energy, and the built environment. Members of the project team were included in panel discussions, had a booth to talk about the projects, and gained media visibility through the event. ProspectSV hosted three Symposiums that featured the E-Bus Projects.

- Technical Advisory Committee Meetings: ZNE Alliance and Prospect Silicon Valley used the joint TAC's domain experts to disseminate information from the project, provide input into final deliverables, and encourage industry-wide information sharing. The TAC included representation of more than 100 transit agencies, policy makers, utilities, and companies in the E-Bus vehicle, charging, and vehicle-grid-integration supply chain. During these events, team members provided specific and detailed knowledge to the targeted audience group and networked with other industry, technology, and policy professionals. In addition, the project team developed valuable findings from these events, including project learnings, program concepts, and policy recommendations. The TAC met twice from 2018-2019, and included key stakeholders, project team members, and solution providers, including Santa Clara Valley Transportation Authority, Antelope Valley Transit Authority, ChargePoint, National Renewable Energy Laboratory, PG&E, Proterra, Trapeze, Clever Devices, Electriphi, NOVA, ZNE Alliance, ProspectSV, Olivine, Energy Solutions, and the CEC.
- Private Sector Solution Provider Engagement: The project team engaged with third party E-Bus service provider AMPLY to identify charging solutions developed to address Build Your Dream bus vehicle-grid-integration challenges (currently being used at Tri-Delta Transit), and to explore retrofit opportunities to address the persistent charge control challenges at Antelope Valley Transit Authority. AMPLY is a cloud-software charge management system that ensures service level (every vehicle charged at the start of every shift) and energy cost optimization (smart charging at the cheapest energy rates).
- Policy Engagement: The project team participated in California's vehicle-grid-integration working group, providing feedback and comment to ongoing conversations on vehicle-to-grid policies in the commercial fleet segment. Additional information on policy recommendations is provided throughout this report.

Market Adoption

The project team determined that smart charging and operator efficiency programs provide the greatest potential benefits to Antelope Valley Transit Authority. For smart charging, additional research can further validate simulated results with a real-world controls use scenario. It is also important to note that EV charging services provider (Amply, Inc.) is developing a platform for remote control of Build Your Dream chargers, suggesting that other agencies with similar legacy chargers installed will be able to use smart charging.

Based on the research and demonstration findings, the California E-Bus to Grid project team recommends the following next steps for policy makers, transit agencies, and other stakeholders seeking to accelerate E-Bus adoption:

Operator Efficiency Program Improvement Recommendations

1. E-Bus operators should offer training opportunities for E-Bus drivers based on proven operator efficiency improvement resources and methods.
2. E-Bus operators should encourage drivers to use an efficiency feedback dashboard.

3. E-Bus operator training events should be held on a regularly recurring basis to sustain efficiency gains.
4. Transit agencies should institute incentive campaigns—with operator feedback on incentive design—to encourage improved efficiency outcomes.

Recommendations for Policy Makers

1. Require operational demonstration of vehicle-grid-integration and vehicle-to-grid functionality of buses and charging systems as a condition of CEC and CARB grant support for E-Bus equipment.
2. Continue to develop vehicle-to-grid specifications and building code requirements for heavy duty charging applications—including requirements and technology considerations for bidirectionality, especially for state funded projects.
3. Incorporate load profile analysis into time-of-use rate development for the medium- and heavy-duty use cases or consider subscription-based pricing structures to provide incentives for smart charging practices.
4. Reconsider the Self-Generation Incentive Program's current exclusion of mobile batteries. By enabling E-Buses to capture incentives, additional flexible capacity can be developed from E-Buses that operate as mobile batteries when not being used for transportation applications.
5. Encourage or mandate load-serving entities, in partnership with electric vehicle and charging system original equipment manufacturers and solution providers, to establish dedicated programs to scale uni- and bidirectional vehicle-to-grid programs.

Benefits to California

This project supported Antelope Valley Transit Authority and provided learning outcomes and program resources relevant to all bus operating agencies in California.

According to CARB, there are 10,231 full-size transit buses in operation in the state, and more than 24,000 school buses. Transit operator benefits highlighted by the project include: lower costs, increased reliability, and reduction of harmful emissions. The project team identified a 40 percent reduction in annual utility bills resulting from smart charging through the E-Bus Platform. In Southern California Edison and Pacific Gas and Electric Company territories, it is estimated that savings of $11,460 per bus per year are possible based on current rates. At Antelope Valley Transit Authority this represents a net present value of $1 million–$5 million over 10 years from load balancing and demand charge mitigation. When scaled statewide, these savings represent $50 million–$70 million assuming deployment of 6,112 E-buses by 2030 (CARB estimates).

For California ratepayers, scaled use of these strategies will further improve the return on investment by electrifying the state's bus fleet, as well as medium- and heavy-duty vehicles. These strategies will also provide long-term benefits as more affordable access to transit, and improved air quality from reduction in fossil fuel combustion and associated climate pollution. According to CARB, full implementation of the Innovative Clean Transit Rule requiring 100 percent zero-emission bus deployment by 2040 is expected to reduce greenhouse gas emissions by 19 million metric tons from 2020 to 2050 — the equivalent of taking 4 million cars off the road. Also, it will reduce harmful tailpipe emissions (nitrogen oxides and particulate matter) by about 7,000 tons and 40 tons respectively during that same 30-year period. In addition, the deployment of E-buses in conjunction with smart charging will enable utilities and grid operators to leverage opportunities for energy procurement cost savings and for infrastructure cost avoidance through deferral of transmission and distribution system upgrades.

CHAPTER 1: Introduction

Commercial-scale use of electric buses (E-Buses) and other medium- and heavy-duty electric vehicles (EVs) is projected to accelerate significantly in 2020 and beyond as EV product diversity, performance, and pricing becomes increasingly attractive in comparison with fossil-fueled vehicles. However, transit operators still have significant concerns that are limiting E-Bus adoption. These include: (1) high up-front electric vehicle and charging infrastructure costs; (2) range anxiety and other operating performance uncertainties; (3) limited data on total cost of ownership, including potentially significant variability in operations and maintenance costs; (4) uncertainty regarding charging-related energy costs, including demand charge issues, and offsetting grid services revenue potential; and (5) limited awareness of the overall E-Bus value proposition, taking into account life-cycle costs and benefits.

Among the first transit agencies in the state to navigate these challenges is the Antelope Valley Transit Authority (AVTA), headquartered in Lancaster, California. AVTA serves Northern Los Angeles County—and was the first transit agency in the nation to make a commitment to a 100 percent all-electric fleet. Between 2017 and 2020, AVTA has used 80 E-Buses in its fleet, covering 100 percent of its routes. In its pioneering role, AVTA has also been one of the first transit agencies in the country to confront the many dimensions of the electrification challenges on a fleet-wide scale. These challenges include:

- Operator driving behavior and resulting fuel efficiency: Fuel economy among the initial operator cohort ranged from 1.2 kWh/mile to 5kWh/mile between the most efficient and least efficient operators. This presented significant uncertainty and risk regarding E-Bus operating range and costs.
- Charging operations and route matching: The normal schedule of operator breaks and route schedules needed to be significantly revised to enable in-route charging. At the same time, new charging and load management strategies needed to be devised to mitigate future demand charges that could occur due to the 250kW high-power in-route chargers. The project used an innovative simulation approach to model cost-effective technical solutions to enable transit operators to leverage Smart Charging (SC) and other vehicle-grid-integration value streams.
- Cumulative effects of disruptive change: The electrification of an entire fleet is disruptive—for the transit agency, its workforce, and the local electric utility. Transit agencies will be operationally challenged to simultaneously: (1) "shake down" and integrate a new generation of technologically sophisticated buses; (2) train operators and mechanics on the new technology; (3) design and deploy large-scale new charging systems; and, (4) optimize the integration of vehicle fleets and the grid. Project findings and lessons learned will help other transit agencies anticipate and mitigate these challenges before they create significant problems in service delivery.

The California E-Bus to Grid Integration Project was launched by the Zero Net Energy Alliance (the prime contractor), AVTA (the transit agency host), and their partners to address these complex challenges in a comprehensive and holistic manner. Key project partners included

Olivine, Energy Solutions, TAPTCO, SolutionLab, ASWB Engineering, Opinion Dynamics, and Prospect Silicon Valley. The key project goals and objectives are:

Project Goals and Objectives

1. Demonstrate technical, operational and behavioral solutions to enable E-Bus Vehicle-Grid Integration (VGI).
2. Quantify the costs and benefits of diverse E-Bus VGI use cases.
3. Disseminate best practices in E-Bus planning, procurement, operations, training, maintenance, and grid-integration to accelerate E-Bus adoption throughout California.

To accomplish these goals, the project pursued these key objectives:

- Demonstrate and use a VGI-enabled E-Bus platform that optimizes charging and enables grid services by integrating real-time data feeds from onboard telematics, route tracking software, charging interfaces, and the energy systems of local utilities and the California Independent System Operator (California ISO).
- Demonstrate a state-of-the-art E-Bus operator training and engagement program to encourage efficient operator behaviors that maximize fuel economy and close the performance gap between the least and most efficient operators.
- Develop and disseminate E-Bus and E-Truck technical, policy, and program recommendations to accelerate adoption of E-Buses.
- Develop and disseminate an *E-Bus Deployment Guide* that educates transit agencies and prospective E-Bus operators on the most cost-effective technical, operational and behavioral solutions, policies and programs for transitioning to 100 percent E-Buses.

In addition to these formally scoped goals and objectives, the Project team was able to address two additional challenges, including: (1) assessing the integration of onsite renewable generation assets to further optimize E-Bus charging economics; and (2) modeling the synchronization of local energy supply with demand to ease grid congestion.

Ratepayer Benefits[1]

Transit operator benefits highlighted by the project include: lower costs, increased reliability, and reduction of harmful emissions. These benefits have been supported by the following project activities: (1) modeling the value of load balancing and demand charge mitigation for E-Buses; (2) quantifying the value of VGI strategies to mitigate costly transmission or distribution upgrades needed to serve these new loads by matching electrical supply and demand to ease local grid congestion; (3) evaluating additional revenue streams for E-Bus fleets and additional value to ratepayers and the community; and (4) improving real-world operator efficiency through training programs.

[1] California Public Resources Code, Section 25711.5(a) requires projects funded by the Electric Program Investment Charge (EPIC) to result in ratepayer benefits. The California Public Utilities Commission, which established the EPIC in 2011, defines ratepayer benefits as greater reliability, lower costs, and increased safety (See CPUC "Phase 2" Decision 12-05-037 at page 19, May 24, 2012, http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF).

For California ratepayers, scaled deployment of these strategies will further improve the return on investment in the electrification of the state's bus fleet, as well as medium- and heavy-duty vehicles more broadly. These strategies will also provide long-term benefits as more affordable access to transit, and improved air quality from reduction in fossil fuel combustion and associated climate pollution. In addition, the smart charging benefits identified by the project team's e-fleet model will support Load Serving Entities (LSEs) and grid operators to leverage opportunities for procurement cost savings and for cost avoidance through deferral of transmission and distribution system upgrades.

The VGI use case scenarios analyzed in Chapter 3 showed that load balancing and demand charge mitigation results in a Net Present Value (NPV) of between $1 and $5 million over 10 years. However, technical, customer, and policy barriers must be overcome before these benefits are fully realized at AVTA, as discussed in Chapter 2. Results from the operator efficiency program discussed in Chapter 4 showed that AVTA saved approximately $28,000 in electricity costs. This exceeded the team's initial estimates of $5,900 annually. Operator training was shown to be effective at reducing average kWh per mile driven. As discussed in Chapter 4, additional improvements in operator feedback may further increase electric fuel efficiency for AVTA and other fleets that adopt behavioral training programs.

Technological Advancement and Breakthroughs

This project has helped overcome barriers to the achievement of California's statutory energy goals by unlocking greater value for E-Fleet operators by integrating onboard E-Bus telematics with analytics and distributed energy resource (DER) management platforms.[2] Specific technological advancements demonstrated in this project include:

- The E-Fleet energy analytics platform and simulation model to estimate the economic benefit of smart charging—including minimization of demand spikes and demand charges for in-route and depot charging.
- Advanced E-Bus operational analytics that address operating behaviors (such as acceleration, deceleration.) and environmental conditions (for example passenger loading, HVAC operations) to identify and encourage efficient operator behaviors.
- Quantification of the value of E-Bus related grid services that provide grid operators with increased flexibility to address renewable intermittency, excess generation, and DER portfolio management.

[2] California Public Resources Code, Section 25711.5(a) requires EPIC-funded projects to lead to technological advancement and breakthroughs to overcome barriers that prevent the achievement of the state's statutory and energy goals.

CHAPTER 2: Challenges and Opportunities

Charging Control and Bus Telemetry Systems

Over the course of the E-Bus to Grid Integration Project, AVTA acquired multiple charging control and bus telemetry systems that functioned at varying degrees of effectiveness. Many of the challenges faced by these systems led to project alterations but also revealed potential opportunities. This section will first summarize AVTA's existing charging control and bus telemetry systems and then discuss challenges faced due to limitations on those systems.

Details of Key Antelope Valley Transportation Authority Original Equipment Manufacturer Systems Relevant to Vehicle-Grid Integration

Build Your Dream Buses and Vehicle-to-Grid Power Flow

Antelope Valley Transportation Authority (AVTA) currently has a fully electric fleet composed of 80 electric BYD buses. This fleet contains transit buses and long-distance commuter buses. An important characteristic of BYD buses is that the AC to DC power conversion occurs on board the vehicle as opposed to in the off-board charging appliance. Given this arrangement, any vehicle-to-grid power flow must be supported by the power conditioning equipment on the bus, and any power flow control equipment must also be supported on the bus. While AVTA had initially expected that BYD buses would have V2G capability, they do not currently support two-way power flow and are not likely to do so in the near future. This issue is discussed further in the "Hardware and Software Control Challenges" section.

Depot Chargers

The BYD-supplied charging hardware used at the AVTA depot includes high-power AC pedestal chargers capable of delivering three-phase 480 VAC power directly to the buses. As noted above, the AC/DC inverters and power conditioning equipment are on the busses themselves. AVTA used these chargers at a 1:1 ratio with their bus fleet. They were able to do so because they had available space at their depot and multiple redundant electrical service points capable of supporting the additional load. Each charger was equipped with two charging guns or connectors to enable faster charging.

Wireless Chargers

AVTA has also installed underground, high power (250 kW) wireless charging stations at in-route locations. These chargers were developed by WAVE, a Utah-based company. The project team was not able to gain detailed technical and control specifications for the wireless chargers due to the desire of WAVE to keep this information confidential. Software control and telemetry for these high-power chargers will be crucial for extending VGI optimization opportunities to large-scale wireless charging networks in the future.

I/O Controls Electrical Load Management System

The I/O Controls Electrical Load Management System (ELMS) manages the charging and electrical system on the bus. The product is intended to enable flexible control of charging through cloud-connected software, including full modulation of charging, setting of charging parameters for each vehicle, and information display on the vehicle's state of charge, range, total mileage, and charging energy (kWh). I/O Systems devices of various kinds are deployed on 100,000 transit buses nationally. However, the initial generation of BYD E-Buses and the I/O Controls system were not sufficiently integrated to enable the Electrical Load Management System (ELMS) to provide direct software control of bus charging on site or through third party application programming interfaces (APIs) and cloud systems. Despite significant efforts by Olivine, including offering to build a new API to enable cloud control of the chargers, the challenges with integrating the I/O Controls system and BYD charging appliances were not resolvable within the project period. A new version of the system, which will require BYD-funded and supervised retrofits across the AVTA fleet, was made available in late 2019, but BYD had not yet committed to performing the necessary upgrades as of early 2020.

I/O Controls Health Alert Management System

The I/O Controls Health Alert Management System (HAMS) provides bus telemetry information at the end of each day that includes data on mileage, state of charge, energy consumption, and emissions. This bus telematics is sufficiently rich to support VGI services, but the data are not available in real time. The daily data are retrieved upon return of buses to the depot. The interval of data recording is one minute or three minutes, depending on the configuration of the vehicle.

Hardware and Software Control Challenges at Antelope Valley Transportation Authority

This project incurred multiple hardware and software challenges that impeded implementation of the original plan for smart charging and VGI services. The difficulty in overcoming challenges with charger control at AVTA came to light in stages through persistent engagement with the transit district and third-party system manufacturers and service providers. As I/O Controls and BYD engaged in the early stages of project implementation, it became clear that the software and hardware systems deployed at AVTA would not achieve their expected functionalities—and therefore would not be able to support the VGI and V2G use cases originally envisioned. The shortcomings and challenges in these systems are described in Table 1.

Uncontrollable Depot Chargers

As noted, once the project team determined that the BYD depot chargers deployed at AVTA would not support the capability to remotely initiate or throttle power delivery, a variety of alternatives were assessed. These included full hardware replacement and the installation of additional ancillary systems on the circuits that feed the depot chargers. However, it was determined that even if the depot chargers were controllable, the software systems at the depot were not capable of communicating dispatch schedules or telematics in real-time via machine-to-machine interfaces, as detailed below. This finding further pushed the team to pursue a simulation approach to advance project goals. As of early 2020, a new charging services company, Amply, Inc., has entered into a partnership with BYD to provide more flexible software control of the chargers. The results of this partnership are expected to provide the enhanced charging system control that was previously lacking, and to enable the optimized smart charging schedules developed through this project to be broadly implemented at transit agencies served either by BYD or other electric transit bus OEMs.

Table 1: Vehicle-Grid Integration Hardware and Software Control Challenges at Antelope Valley Transportation Authority

Challenge	Brief Description	Steps Taken to Address Challenge	Solution
Uncontrolled Depot Chargers	AVTA's depot chargers were unable to have their power throttled or to be toggled on/off at the charger.	Technical trouble-shooting and discussions with BYD and I/O Controls to enable charge control	I/O Controls piloted a solution on-board the BYD bus through the ELMS hardware on the bus. However, this system only functioned inconsistently on-site; i.e. locally, and did not enable remote control.
Lack of Machine-to-Machine (M2M) Control Interfaces	The local software systems at the depot were not capable of communicating directly with third parties due to lack of an API.	Technical discussions with I/O Controls to enable control via an API. Olivine proposed to develop an interface spec that could be implemented by I/O Controls, but this option was not pursued by I/O.	No new control solution was arrived at during the available project timeline at AVTA. Therefore, Olivine and project partners decided to utilize Olivine's e-fleet simulator and valuation model to assess VGI use cases using real-world data from the AVTA bus fleet, and time-synchronized data on energy markets from actual California ISO grid data.

Source: ZNE Alliance

Lack of Machine-to-Machine Control Interfaces

The charge management systems used at AVTA did not deliver on the functionalities expected by the transit agency or the project team for local control of charging. However, it is also the case that the BYD and I/O systems were never designed to support cloud based or third-party control. This type of control, typically enabled through APIs, has been the industry standard means by which DERs—including EV charging systems—can be controlled by DER management platforms like Olivine and participate in energy markets. However, after engaging in technical discussions on various options for API controls through mid-2018, I/O Controls finally made clear that a machine-to-machine interface to control charging would not be available during the project period. I/O controls indicated that their own web-resident User Interface (UI) might be made available, at additional, but unknown cost. However, the web UI would not meet the needs of an energy management system participating in California ISO markets.

As summarized, Olivine pursued multiple pathways to resolve or work around the API challenges. These pathways included:

- In early 2018, Olivine recommended that I/O Controls develop an API to support remote charging and Olivine DER Platform integration. I/O Controls made it clear that an API was not on their product roadmap at that time. As a result, Olivine focused on data collection and analysis to simulate individual buses and whole-fleet charging. This simulation was conducted using Olivine's E-Fleet Simulator.
- In late 2018, Olivine pushed for VGI support again by offering funding and engineering support (in the form of a high-level technical specification) for a fleet charge management API to I/O Controls. I/O Controls once again chose not to proceed with API development.
- In early 2019, Olivine pursued an alternative approach to demonstrate VGI in the field. Olivine engaged with AC Transit to propose a small VGI demonstration with a 5-bus pilot. After working with California Energy Commission (CEC) and laying out a project proposal, AC Transit indicated that they did not have the bandwidth to support a demonstration.
- In parallel, Olivine also engaged with ViriCiti—another leading bus charging control and telematics system—to propose software and hardware development to support a VGI demonstration at AVTA. Due to resource constraints combined with personnel turnover at ViriCiti, they were unable to commit to the demonstration at AVTA within the project timeline.
- With no API solution available, the project team moved forward—with CEC management approval—to using Olivine's E-Fleet Simulator and E-Bus VGI Valuation Framework Model to evaluate VGI use case scenarios for AVTA.

Operational and System Design Challenges at Antelope Valley Transportation Authority

Along with the technical charging control issues that were surfaced over the course of the project, there were also several operational challenges related to E-Bus deployment, fleet operations, and VGI. These challenges are highlighted in Table 2 and detailed further.

Table 2: Vehicle-Grid Integration Operational and System Design Challenges at Antelope Valley Transportation Authority

Challenge	Brief Description
Slow Bus Delivery to AVTA	The delivery of busses to AVTA was far slower than originally promised and did not allow sufficient time to capture all the fleet performance data required to meet all the original project goals.
AVTA Range Anxiety	AVTA was concerned about letting third parties control their bus charging schedules due to concerns over range anxiety, even though proposed charging schedules were designed to enable full completion of assigned routes with adequate reserve capacity. This concern is expected to abate with further operational experience with the full complement of buses being delivered by mid-2020.

Source: ZNE Alliance

Slow E-Bus Delivery to Antelope Valley Transportation Authority

One challenge encountered early is that delivery of the buses was far slower than originally promised due to challenges at the then new Lancaster BYD E-Bus assembly plant. At the time the original VGI project proposal was developed, the fleet of 80 buses was supposed to be delivered very near the beginning of the three-year project period. As of Quarter 1, 2020, final delivery of the last of the 80-vehicle order was still underway.

Antelope Valley Transportation Authority Range Anxiety: Concerns for Battery Life in VGI Applications

The AVTA fleet manager was understandably cautious about taking any actions that could interfere with the mandate to provide reliable public transit. Specifically, fleet management was concerned that allowing a third party to control their bus charging schedule could leave the buses undercharged in the morning and limit their overall driving range. They were not completely averse to any form of VGI-focused charge scheduling, however. AVTA leadership recognized the value of smart charging and perceived it as less risky than the other VGI use cases. However, the fleet management initially did not view smart charging as a high priority relative to other pressing E-Bus roll-out priorities because they believed that the amount of money that AVTA could save with smart charging—given the initially small electric fleet size—would not be significant. Going forward, it is expected that smart charging will be introduced at AVTA shortly due to the confluence of these factors: 1) availability of full data on Smart Charging savings; 2) imminent delivery of the full 80 bus E-fleet and completion of the shakedown and testing of bus systems; 3) significantly increased energy costs associated with operation of the fully electric fleet; 4) availability of new options for automated control of smart charging (via Amply and/or upgraded I/O Controls systems); and, 5) hiring of a new Fleet Manager at AVTA who will be under pressure to manage the AVTA system at greatly reduced operating cost due to fiscal stresses on the system.

Opportunities for Vehicle-Grid Integration Ecosystem: Technology and Market Readiness

Lessons Learned for Transit Agencies

While the California E-Bus to Grid Integration project encountered challenges in implementing VGI use cases in the field, the smart charging and VGI analytics developed in the Project, along with the operator training program designs, provide significant resources for transit agencies seeking to electrify their fleets. In addition, these high-level lessons for transit agencies are important to keep in mind. A more comprehensive *E-Bus Deployment Guide* based on the AVTA and Santa Clara Valley Transportation Authority project—led by Prospect Silicon Valley—will be published in late 2020 in a collaboration of ZNE Alliance, Prospect Silicon Valley, and CALSTART.

Conduct a Thorough Energy Needs Assessment Based on Smart Charging Analytics

Many transit agencies are in the process of specifying power infrastructure for their depot charging that reflects an overly simplistic approach to charging management (for example, based on the expectation that all buses may require full power draw as soon as they enter the depot.) Poorly estimated energy and power needs can easily result in unnecessary electricity infrastructure costs. Energy needs assessments conducted with utility and charging partners should account for (and require) the implementation of managed charging, using proven analytical approaches.

Integrate the Vehicle and Charging Technology Teams at Project Start

Effective vehicle grid integration is complicated. Enabling a VGI-capable E-Fleet requires multiple systems to operate together seamlessly, relying on multiple hardware and software providers. Engaging all system partners early can mitigate potential complications and reduce overall system costs. System choices can have long-lasting implications, and sub-optimal choices can lock transit districts into technologies that are not capable of basic functionality such as optimized smart charging, let alone full VGI and market participation.

Understand Your Fleet Duty Cycle

To effectively integrate VGI systems, transit authorities need to know what their fleet's duty cycle will be. It is necessary to know how much energy will be needed for fleet operations and when and when the busses will be plugged in and if those times align with grid service and support opportunities. With that information, transit authorities can define the necessary parameters for VGI participation, including the energy available for VGI services. Using available energy market information and effective off-the-shelf VGI technology, transit authorities can now determine which VGI services in which they can and should participate.

Gaps and Opportunities in Vehicle-Grid Integration Offerings

A key non-technical challenge became apparent in the early days of VGI implementation discussions with AVTA. Generally, AVTA and transit districts are extremely sensitive to any activities that might jeopardize their ability—or their perceived ability—to provide reliable service. In the case of AVTA, any use of the battery in a managed charging configuration that could create even a theoretical risk of leaving the fleet dispatcher with a bus battery at less than a 100 percent state of charge created a perceived risk that was unacceptable to the fleet manager.

This is an understandable concern for transit districts today. E-Buses are new, and their ranges are often widely variable based on constraints such as ambient temperature, traffic, passenger loading, and individual operator behavior. Moreover, transit districts are at the earliest stage of the adoption curve—meaning that E-Buses are still in the "shakedown" stage of operational deployment. As a higher proportion of fleet vehicles are electric, operators will: (1) discover the actual extra capacity available in their batteries under the full range of operating conditions; and (2) focus on lowering the significant aggregate cost of electricity to run their fleets. Thus, focus will soon shift from debugging the buses and charging systems to ensure basic reliability, to maximizing cost savings through effective managed charging, VGI, and optimized driver efficiency.

Opportunity for Entrepreneurship

The project team envisions an opportunity for hardware and software providers to innovate further in the E-Bus VGI space, developing vehicles, charging equipment, and cloud services that are vertically integrated "out of the box" to provide comprehensive fleet management, charge management, and VGI. The team also envisioned an opportunity for providers to retrofit or upgrade existing E-Bus deployments to add charge management and VGI functionality. This functionality can help transit districts reduce their energy costs, improve service, reduce grid stress, and better track their systems to enable important services such as LCFS credit management.

Policy Recommendations

Recommendation #1

Require operational demonstration of VGI and V2G functionality of buses and charging systems as a condition of CEC and CARB grant support for E-Bus equipment.

The systems originally specified by AVTA were expected to support or enable most or all of the VGI use cases, including potential V2G programs. Further, these systems are not significantly more capital intensive when designed from the start for VGI/V2G functionality. It is the project team's view that all E-Fleet deployments include systems that are fully capable of VGI functionality and that CEC and CARB should, as a condition of grant support for capital equipment, require that manufacturers demonstrate that functionality in operational demonstrations.

Currently, BYD and other bus original equipment manufacturers (OEM), including Proterra, claim to have equipped their buses for V2G, but the end-to-end software and systems required to connect these vehicles to the grid has been lagging. The same is true for the new generation of electric school buses now being delivered in California as of 2020. In the case of electric school buses, the state mandated V2G capability as a condition for Prop 39 funding to school districts, but reportedly the pathway to V2G remains problematic for some OEM products. Effective testing of VGI and V2G capability could potentially be enabled by the CEC's existing CalTestBed initiative or other appropriate state resource.

Many of the barriers encountered by the AVTA project team and other VGI initiatives could be addressed by some of the new policies being considered by the state's Vehicle-Grid Integration Working Group, which is preparing a set of recommendations for release later in 2020. The following policies are among the most important under consideration for accelerating VGI and V2G progress:

Recommendation #2

Continue to develop V2G specifications and building code requirements for heavy duty charging applications—including requirements and technology considerations for bidirectionality, especially for state funded projects. This may include OEM requirements to standardize charging protocols in open ADR 2.0 or other protocols to enable remote monitoring, controls, and dispatch signaling.

Recommendation #3

Incorporate load profile analysis into TOU rate development for the MD/HD use case or consider subscription-based pricing structures to incentivize smart charging practices. Load serving entities should be encouraged to develop custom rate designs that align with local energy portfolio needs while recognizing the flexible load management and grid services that smart charging and V2G enabled vehicles can provide.

Recommendation #4

Reconsider SGIP's current exclusion of mobile batteries. By enabling E-Buses to capture SGIP incentives additional flexible capacity will be enabled from these EVs when otherwise parked and grid-connected. Electric school buses would be an ideal market segment to begin this expansion of SGIP, as these vehicles are idle a substantial portion of the work day, nearly all weekends, and for several months in the summer and on school holidays. The payment of the SGIP incentive could potentially be provided in a manner proportionate to the availability of batteries for provision of grid services.

Recommendation #5

Encourage or mandate Load Serving Entities, in partnership with EV and charging system OEMs and solution providers, to establish dedicated programs to scale V1G and V2G programs. Consider use of targets similar to the current mandate for behind-the-meter storage deployment.

Technology Vision for Vehicle-Grid Integration Ecosystem

In addition to the policy recommendations, a more comprehensive vision for the VGI ecosystem is needed to support the adoption and scale-up of VGI and smart charging capabilities, while motiving additional private sector innovation (Table 3). Developing enhanced VGI capabilities is especially urgent and timely in light of the increasingly robust market for E-Bus adoption. Market acceleration factors include the CARB Innovative Clean Transit (ICT) Rule, which will substantially increase demand for future E-Buses in California. Various state and federal grant programs and funding from the CARB HVIP program is also helping to grow the E-Bus fleet, including school buses. As battery costs continue their steady descent on the cost curve, E-Bus uptake will also grow rapidly due to the increasingly clear economic advantage of E-Bus operation when compared with fossil fueled alternatives on a total cost of ownership (TCO) basis.

Table 3: Vision for a Vehicle-Grid Integration Ecosystem

System	Software Control Needs	Hardware Control Needs
Transit Fleet Schedule / Dispatch	Fleet management data: 1. Bus schedules 2. Routes 3. Charging schedules 4. Maintenance schedules 5. Aggregated meter usage data*	Dispatch control for route optimization 1. Bus route schedules 2. Charging schedules 3. Maintenance schedules
Electric Vehicle / Bus	Onboard cellular modem providing real-time data on key E-Bus operational elements: 1. Battery State of Charge (SOC) (kWh) 2. Charge and discharge power (kW)	Smart charging control requires either the bus or the charger to support turning charge power on and off. Two-way power flow: 1. Supported by vehicle power conditioning or DCFC charger hardware. 2. Power flow and direction must be controllable. 3. Enables vehicle to building or vehicle to grid use cases
Chargers	Real-time telemetry providing data on charger state including: 1. Active / Engaged 2. Connected vehicle info 3. Real time Charge and discharge power	Chargers support turning power flow on and off. Advanced capabilities would include support of throttling power either at the vehicle itself or at the bus.
Charge Management System	A complete charge management solution provides vehicle-based control of charge power as well as aggregation of data streams to provide inputs for managed charging algorithms.	N/A
Electricity Market Interface	VGI requires interfacing charge management systems with platforms capable of electricity markets participation via a scheduling coordinator with expertise in VGI.	N/A

Source: ZNE Alliance

Unfortunately, a countervailing threat to robust fleet EV uptake is the demand charge situation. While many California utilities are providing some form of accommodation to mitigate demand charges, there is no guarantee that these accommodations will continue after the "demand charge pause" that some utilities have implemented. In light of the demand charge variable—and the significant cost of electric fueling for larger fleets—it is anticipated that transit bus operators will progressively demand VGI ready technologies for their electrification efforts. In light of this need, the following table presents key components of a holistic E-Bus to Grid technology environment in which E-Buses, EV charging equipment, and related systems are truly factory-enabled for Vehicle-Grid Integration and (where desirable) for V2G operation.

CHAPTER 3: Vehicle-Grid Integration Use Case Evaluation—E-Fleet Model

Background

This chapter defines the criteria used to select use cases for VGI valuations for AVTA, the results of those valuations, and recommendations based on those results developed by Olivine, the team lead for VGI. To select the use cases most applicable to AVTA, Olivine followed a careful section process where all potential use cases were run through a screening matrix to determine which were most practical, feasible, and effective. For E-Fleets in the early adoption stages, such as AVTA, three categories of VGI services were assessed to determine which would provide the greatest value to the transit operator, the grid, and the surrounding community. These VGI categories included:

- V1G – Smart Charging: In a V1G configuration, the charging of the vehicle is optimized via the E-Bus EVSE (charging station), to reduce retail electricity costs or potentially to generate revenue through the supply of grid services to wholesale markets.
- V2G – Vehicle-to-Grid: In this configuration, the E-Fleet vehicles and charging units can provide two-way energy flows, (specifically charging/discharging vehicle batteries) to reduce facility demand or supply grid services. V2G operations require V2G-enabled vehicles.
- V2B – Vehicle-to-Building: V2B strategies are designed to take advantage of the mobility of E-Fleet vehicles and use vehicle batteries to discharge their energy storage capacity to power buildings or other critical loads. This strategy would only be deployed during grid emergency events or disaster-related events to maintain power for facilities that provide emergency or other mission critical services.

After these VGI categories were identified, all possible use cases using them were run through a screening matrix. This screening matrix can be found in the AVTA E-Bus Use Cases report. Unless otherwise noted, each of the use cases selected through this method contained the same set of assumptions. These assumptions are displayed in Table 4.

Table 4: Vehicle-Grid Integration Parameter Assumptions

Parameter	Assumed Value
Energy Price Escalation Rate	2.71%
Spinning Reserves Price Escalation Rate	-4.80%
Frequency Regulation Up Price Escalation Rate	-3.04%
Frequency Regulation Down Price Escalation Rate	-6.02%
Discount Rate	5.00%
Real Inflation	2.20%
Utility Rate Schedule	LCE+SCE TOU-EV-9 & TOU-EV-8
E-Buses Used	All BYD

Source: ZNE Alliance

Use Cases Selected for his Project

1. V1G E-Bus Smart Charging: Optimizing the E-Bus charging schedule to take advantage of the lowest utility time-of-use (TOU) rates and minimize demand charges. This report assesses the value of this use case to AVTA's depot chargers as well as all five of the opportunity charging stations along the AVTA bus routes. One of the driving factors for evaluating this use case was the value attached to any Low Carbon Fuel Standard (LCFS) credits earned and sold. AVTA can earn different numbers of LCFS credits based on when the bus charging schedule. For this use case, the assumed value of those credits was $185/credit.
2. V1G Demand Response (DR) as an Energy Resource: Curtailing E-Bus charging to provide energy in the California Independent System Operator's (CAISO) Day-Ahead wholesale market. This report refers to this use case as "Proxy Demand Response (PDR) – Energy." This use case has an $18,000/year annual program cost assumed in its valuation.
3. V1G Demand Response as an Ancillary Service Resource – Spinning Reserves: Controlling E-Bus charging to provide spinning reserves ancillary services to the California ISO wholesale market. This report refers to this use case as "PDR – Spinning Reserves." This use case has an $18,000/year annual program cost and an upfront $5,000 real-time metering telemetry cost assumed in its valuation.
4. V1G Demand Response as an Ancillary Service Resource – Frequency Regulation: Controlling E-Bus charging to provide frequency regulation ancillary services to the CAISO wholesale market. For this report, frequency regulation capacity is bounded in each hour by 0 and twice the charging rate (up to 4.8 MW). Under current regulations and technological constraints, frequency regulation behind the meter is not possible. This use case illustrates the value that frequency regulation could offer AVTA if those barriers are overcome. This use case has a $18,000/year annual program cost and an upfront $5,000 real-time metering telemetry cost assumed in its valuation.
5. On-site Solar Photovoltaics (PV) with Battery Storage: Installing solar PV panels along with a battery energy storage system at AVTA's depot to reduce AVTA's carbon emissions and improve station resiliency to power outages. This use case also had AVTA

credit value as a key driving factor for its overall evaluation. AVTA can earn more credits by charging from less carbon-intensive resources. Charging from on-site solar PV would be less carbon-intensive than charging from the electric grid. This would generate more credits for AVTA. For this use case, the assumed value of LCFS credits was $185/credit. Unlike every other use case, this use case had an additional $15/kW-yr. cost for PV annual O&M costs in its valuation. It also assumed that 70 percent of the average depot charging load was covered by the on-site solar PV and battery storage. Due to utility rate regulations regarding behind-the-meter solar, the LCE+SCE TOU-8 Option E utility rate was used for this use case.

6. V2B Emergency Energy for Critical Facilities: Using AVTA's E-Fleet to provide uninterruptible power to critical facilities during natural disasters or other grid emergencies. This use case was only qualitatively analyzed so it is not extensively covered in this section.

Of these use cases, all but the "V2B Emergency Energy for Critical Facilities" case were further broken down into subsidiary use case scenarios to highlight the range of values available under various operating conditions. These use case scenarios are described in the next section.

Use Case Scenarios

After Olivine determined which use cases were most applicable for this project, their research team created multiple scenarios within each use case to model real-world operating conditions. These use case scenarios were designed to be applicable to AVTA specifically or to similar E-Fleets. The use case scenarios tested are listed in Table 5.

Table 5: Use Case Scenario Descriptions

Scenario (Use Cases)	Description	Key Factors
Using LCE+SCE TOU-EV-9 and TOU-EV-8 (Smart Charging, PDR – Energy)	Using the Lancaster Choice Energy (LCE) generation rates along with the Southern California Edison (SCE) distribution rates for SCE's TOU-EV-9 and TOU-EV-8 schedules	▪ Standard TOU energy rates ▪ 5-year demand charge holiday ▪ Default conditions case
A similar transit authority in PG&E's coverage zone using E-CEV-L utility rate (Smart Charging, PDR – Energy)	Applying Pacific Gas and Electric's (PG&E) proposed E-CEV-L schedule to a transit authority with the identical load profile as AVTA	▪ Standard TOU energy rates ▪ Subscription-based demand charge
A similar transit authority in SDG&E's coverage zone using Public GIR (Smart Charging)	Applying San Diego Gas and Electric's (SDG&E) tested Public Grid Integrated Rate (GIR) to a transit authority with the identical load profile as AVTA	▪ Day-ahead energy-based rates ▪ No direct demand charge
AVTA's commuter bus fleet day-charging at the LA terminus (Smart Charging, PDR – Energy, PDR – Spinning Reserves, Frequency Regulation, Solar PV)	Modeling AVTA's commuter fleet charging at the LA terminus and at the depot	▪ No depot charging ▪ $15,000 equipment and installation cost per charger ▪ No on-site battery storage for Solar PV use case
A similar commuter bus E-Fleet day-charging at its terminus in PG&E's coverage zone using E-CEV-L utility rate (Smart Charging, PDR – Energy, PDR – Spinning Reserves, Frequency Regulation, Solar PV)	Modeling a similar commuter bus fleet charging at the LA terminus in PG&E's coverage zone in a temperate climate and using the E-CEV-L utility rate	▪ Standard TOU energy rates ▪ Subscription-based demand charge ▪ No on-site battery storage for Solar PV use case
A school bus E-Fleet operating in PG&E's coverage zone (Smart Charging, PDR – Energy, PDR – Spinning Reserves, Frequency Regulation, Solar PV)	Modeling a school bus E-Fleet operating in PG&E's coverage zone	▪ 23 school E-Buses ▪ No on-site battery storage for Solar PV use case
Using Proterra Catalyst E2 Max buses for transit buses	Modeling fleet operations in the E-Fleet Energy Model with Proterra	▪ Higher energy capacity bus batteries

Scenario (Use Cases)	Description	Key Factors
(Smart Charging, PRD – Energy, PDR – Spinning Reserves, Frequency Regulation)	Catalyst E2 Max buses instead of AVTA's BYD K9 transit buses	
AVTA aggregation with LCE VPP (PRD – Energy, PDR – Spinning Reserves, Frequency Regulation)	Modeling the scenario in which AVTA would join the LCE Virtual Power Plant (VPP)	▪ No annual service fee for AVTA
AVTA aggregation with other distributed energy resources (DER) facilities (PRD – Energy, PDR – Spinning Reserves, Frequency Regulation)	Modeling the scenario in which AVTA would join an aggregation with other DER facilities	▪ 50% annual service fee for AVTA
100% on-site renewable energy with battery storage (Solar PV & Battery Storage)	Modeling the effect of fully powering AVTA's electric fleet (E-fleet) depot charging needs with solar PV and battery storage	▪ 22.5 MWh battery ▪ 3.362 MW solar nameplate DC capacity ▪ Single-axis solar tracking

Source: ZNE Alliance

As indicated by the table, most of the use case scenarios modeled were not applicable to every use case. All of the use case scenarios modeling AVTA buses using a different utility rate were conducted under the smart charging use case—due to the fact that all of the value from that use case was derived from energy and demand charge savings. The use case known as PDR (Spinning Reserves, Frequency Regulation) – Energy was included under two of these scenarios as well because day-ahead energy dispatch events would be expected to alter how much the buses charge over certain time-of-use periods. It was not used for the SDG-E GIR scenario because participation in the wholesale markets is prohibited under that rate.

The use case scenarios evaluating the impact of AVTA joining in a DER aggregation were only considered under the wholesale market-based use cases because they only impacted annual program participation fees. The use case scenarios dedicated to analyzing the commuter fleet or a school bus fleet were evaluated under all use cases with one exception; they only evaluated the impact of installing a PV charging system for the buses with on-site battery storage. This exception was made because these use case scenarios primarily deployed E-Fleet day-charging, in which configuration an additional on-site battery to store the captured solar energy would be unnecessary. For more details on each use case scenario, please refer to the Potential Value Streams from VGI Services and VGI Implementation Case Studies reports.

Along with conducting different scenario analyses on each of the applicable use cases, the research team at Olivine also performed a sensitivity analysis. This analysis involved finding key probabilistic variables with the base case scenario within each use case. These key variables were as follows:

- Energy price escalation rate.
- Spinning reserves price escalation rate.
- Frequency regulation price escalation rate.
- Discount rate.
- Real inflation.
- LCFS credit prices.
- PV annual O&M costs.

After these variables were identified, three sets of values were assigned to them: those that were most probable, probable, and least probable. The most probable values coincided with the values used in the base case. The probable and least probable variable were determined using extensive background research and expert analysis. More information about this sensitivity analysis can be found in the *VGI Implementation Case Studies* report.

The following section presents the financial results from evaluating each use case scenarios identified above. It also briefly discusses the results of the previously described sensitivity analysis.

Use Case Simulations and Evaluations

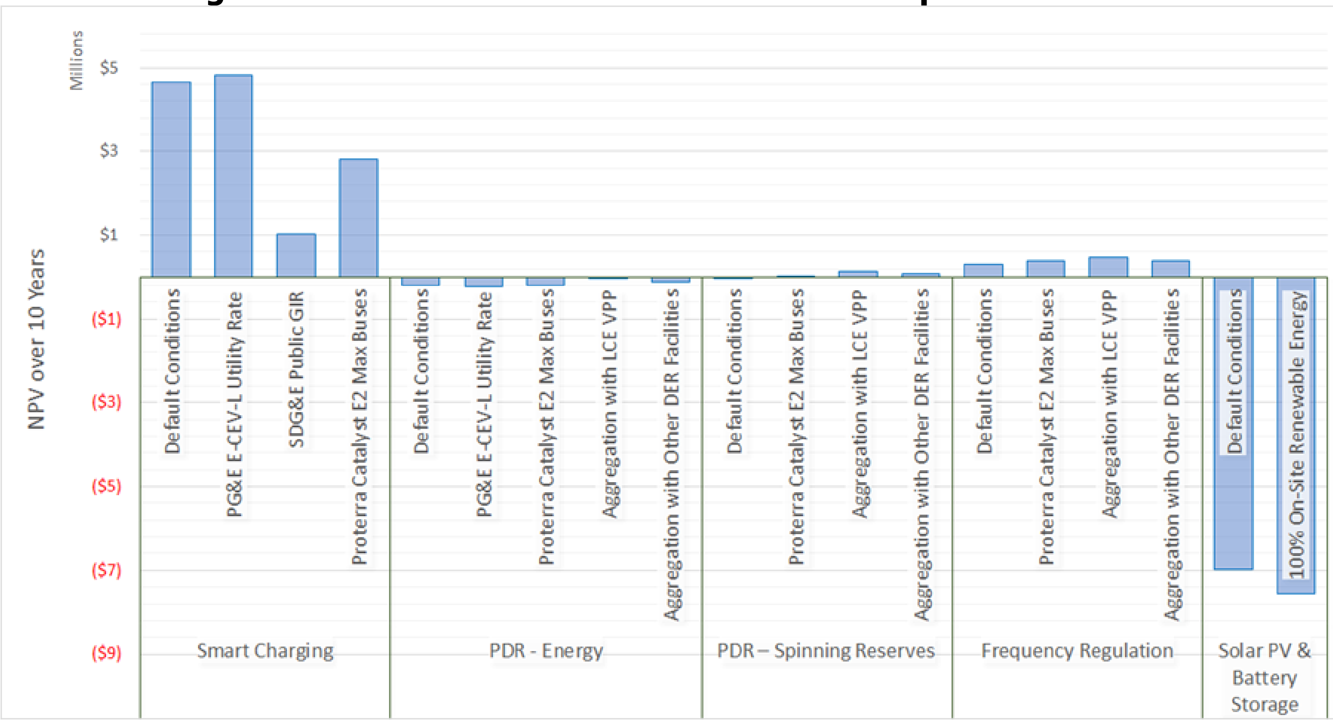
After forming the assumptions for each use case scenario presented in the previous section, each of these use case scenarios were evaluated using Olivine's E-Bus VGI Valuation Framework model. The resulting Net Present Value (NPV) for each of these tests are presented in the following figure. Although this figure and its presented results are distinguished as being transit bus specific, they still account for any financial impacts felt by altering the depot-charging strategy for commuter buses. This contrasts with the commuter bus specific use case scenarios wherein only the financial impacts of altering the commuter bus charging strategy was considered.

As illustrated in Figure 1, smart charging with the transit buses presented the most value for a 10-year plus period across every modeled scenario. Installing on-site solar PV and battery storage (given 2019 equipment prices) at the depot provided the greatest net loss across every modeled scenario. Of the smart charging use case scenarios, having a similar transit agency use SDG&E's Public GIR utility rate presented the least value. Smart charging under SCE's TOU-EV rates or under PG&E's proposed E-CEV-L rate offered the most grid service value and provided a 40 percent reduction in AVTA's monthly utility bill when compared to unmanaged charging.

- PDR – Energy only produced net losses over a 10-year analysis for every scenario modeled.
- PDR – Spinning Reserves produced little value for most of the scenarios modeled and produced net losses in the default conditions scenario.
- Frequency Regulation provided significant value for every scenario tested; however, regulatory prohibition of behind-the-meter frequency regulation along with current

technical limitations prevented this use case scenario from being implemented at this time.

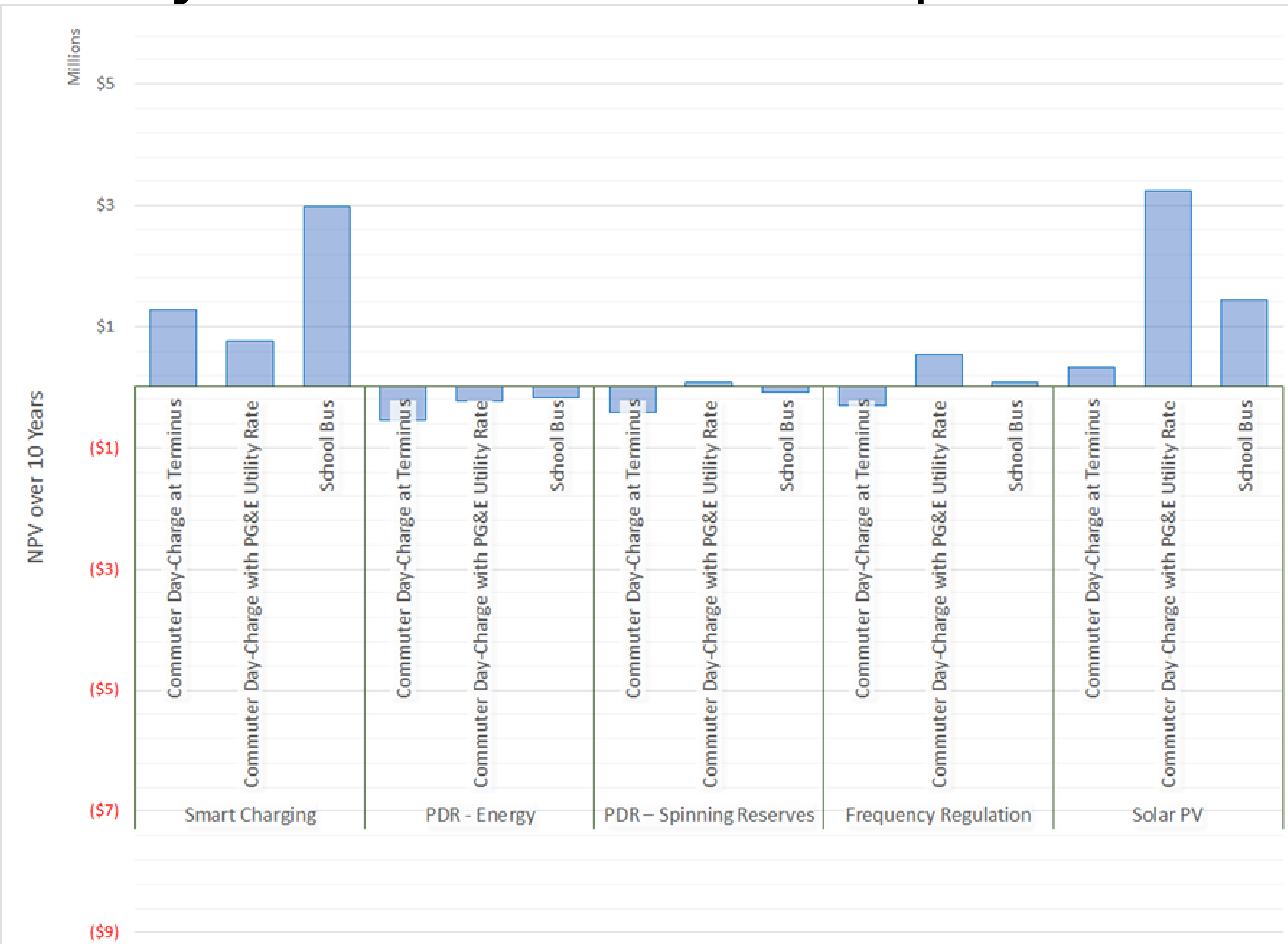
Figure 1: Transit Bus Use Case Scenarios' Comparative Values



Source: ZNE Alliance

Due to the inherent differences between the transit bus and commuter bus use case scenarios, each application was analyzed separately. Figure 2 presents the Net Present Value (NPV) found for each of the commuter bus use case scenarios over a 10-year period. These results are similar to those of the transit bus use case scenarios. Smart charging demonstrates considerable value, PDR – Energy presents net losses, and PDR – Spinning Reserves presents limited value under some scenarios. Significant net revenue (taking program costs into account) was gained from participating in frequency regulation with AVTA's commuter buses charging at the depot and in-route. Also, contrary to the transit bus use case scenario analysis results, significant value was found for all of the commuter bus scenarios with solar PV. This difference in results indicates how financially beneficial it is to directly offset energy costs using on-site solar PV for day-charging; and reflects the large costs associated with purchasing a battery with sufficient capacity to store solar energy for later use in a large fleet context.

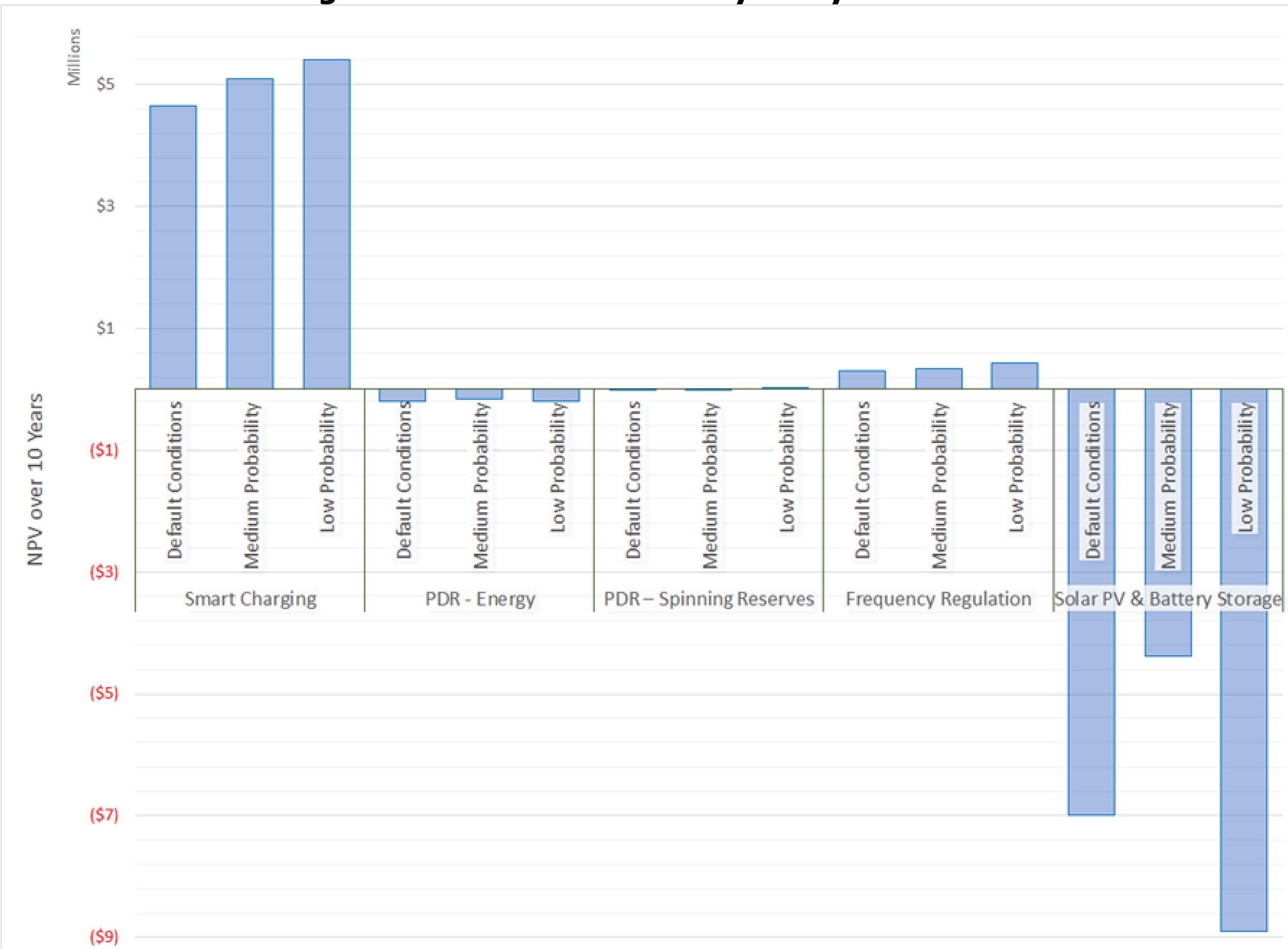
Figure 2: Commuter Bus Use Case Scenario's Comparative Values



Source: ZNE Alliance

The results of the use case sensitivity analysis are presented in Figure 3. In general, they follow the trends observed for the transit bus use case scenarios. More importantly, they show that there is no significant difference in results under multiple feasible conditions. They illustrate that the range in expected results for each use case is relatively narrow. The only use case to demonstrate markedly different results was the solar PV and battery storage use case; however, they still illustrate such a high negative value that the relative magnitude of losses is negligible.

Figure 3: Use Case Sensitivity Analysis Results



Source: ZNE Alliance

Key Findings

Analyzing the results from the previous section, the research team found the following:

Finding #1

Smart charging offers the most value to AVTA. PDR is unlikely to produce value for AVTA, while frequency regulation would be valuable if regulation and technology permitted its use. On-site solar PV would only be valuable to day-charging fleets without on-site battery storage.

By running a basic sensitivity analysis on the valuations of each use case, the research team found that smart charging would provide the most value to AVTA. They also found that PDR – Energy has almost no chance of providing value and PDR – Spinning Reserves has a small chance of providing value. Frequency regulation would produce value over ten years if both reg up and reg down were possible behind the meter. The costs associated with procuring, installing, and maintaining the resources needed to install on-site solar PV and battery storage at the depot would far outweigh the benefits based on current equipment pricing absent special grants or incentives beyond SGIP. Value was obtainable by eliminating the extra battery costs and having a capable E-Fleet (for example AVTA's commuter fleet or a school bus fleet) charge during the day. Olivine conducted this sensitivity analysis by sorting values of key uncontrollable factors into three future projections based on their likelihood of occurring.

Finding #2

For night-charging E-Fleets, day-ahead energy market-based utility rates will not offer competitive smart charging opportunities compared to traditional TOU rates. For day-charging E-Fleets, the opposite may be true.

By optimizing AVTA's charging profile around these rate structures—LCE+SCE TOU-EV-9 and TOU-EV-8, PG&E E-CEV-L, and SDG&E Public GIR—the research team found that smart charging under GIR produced the least value. The SDG&E Public GIR bases its rates on the wholesale day-ahead energy prices while the other two rates base their prices on the more conventional TOU time periods. Conventional TOU rates generally have their peak pricing in the middle of the day and late afternoon with off-peak and part-peak pricing occurring during the night and early morning. The wholesale energy market generally has its lowest prices in the middle of the day and has its highest prices from 6 PM to midnight. Night-charging E-fleets like AVTA's cannot take advantage of lower prices in the middle of the day due to their operational schedule. For this reason, night-charging E-fleets are better served by optimizing around conventional TOU rates. Conversely, day-charging E-Fleets may be better served by optimizing around day-ahead energy market-based utility rates.

As explained in the earlier AVTA project report titled *Barriers and Opportunities to VGI Services in Large Fleets*[3], the financial opportunity from smart charging will depend on which utility tariffs or rate structures align best with the typical charging needs of large fleets. Subscription-based rates for electricity are a promising new development and mimic the approach taken for other services such as internet bandwidth and cellular telephony. Pacific Gas and Electric (PG&E) introduced a pilot for electric vehicles that is the first subscription-based electricity rate in California. Customers pay a fee to purchase a set number of charging units. Smart charging software can optimize for setting a subscription level in addition to structuring vehicle charging. Time-of-use tariffs can be leveraged by smart charging to prioritize off-peak hours at night for overall bill savings and to limit demand charges. Peak demand can be reduced by spreading out the charging of buses across all the hours with lower prices (off-peak hours). More dynamic tariffs can vary hourly to reflect the actual cost of electricity throughout the day.

Finding #3

Fleets with low annual use rates present more opportunities for V2G services, especially if behind-the-meter resources are permitted to provide wholesale market services.

Commuter fleets are available for wholesale market participation at least twice a week, while school bus fleets can fully dedicate to wholesale market services for at least two months of the year based on their utilization rates. To allow for increased provision of VGI services by E-Fleets, the utilities, CPUC, and California ISO will need to work towards a model that will allow behind-the-meter resources to provide wholesale market services. While it will be difficult to separate out wholesale market services from retail operations, especially if both are occurring

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[3] Bird, Ryan. Kehmeier, Emily. Wang, Kitty. (Energy Solutions), 2019. Barriers and Opportunities to VGI Services in Large Fleets. California Energy Commission.

on the same day, there could still be a workable scenario wherein wholesale market services can be provided as long as there is no retail charging at the same time.

As an alternative to full wholesale energy market participation, it may be possible to participate in wholesale frequency regulation markets without full energy settlement. Since school bus fleets are idle during much of the peak TOU hours, it is possible for these E-Bus batteries to provide Resource Adequacy (RA) value to the grid as well. This would require a regulatory change that allows for the provision of frequency regulation from behind-the-meter resources, and V2G resources that can export above facility load levels. If V2G is allowed, and E-Fleets are able to take advantage of it, they could provide similar services to stationary batteries for most of the day. This could reduce the amount of short- to medium-duration stationary battery capacity that is currently envisioned for meeting California's renewable goals. Additional storage capacity could in turn limit renewable curtailment in the middle of the day and reduce dependence on fossil fuel generation during peak hours. However, if California uses E-Fleet V2G services to augment stationary battery storage capacity levels, there must be clear regulatory guidelines and coordination between transit agencies, regulators, utilities, and energy providers such as Community Choice Aggregators.

Opportunities and Recommendations

The following recommendations are provided for consideration by AVTA and other transit operators based on the analyses completed for the use case scenarios described in this chapter.

Recommendation #1

E-Fleet operators should institute a smart charging strategy before trying to participate in additional VGI services.

For any and all use cases under consideration, it is essential that E-Buses are sufficiently charged every day to complete their routes without interruption. Moreover, in-route charging should not be overutilized compared to overnight charging just to enable participation in wholesale markets, as the increase in costs are likely to be greater than the revenue provided in most cases. Smart charging offers a VGI strategy that does not negatively impact daily bus operating range, while providing economic benefits. By offsetting charging from peak hours to off peak hours and limiting demand charges, E-Fleet operators can significantly decrease their monthly utility bills. The magnitude of those savings will depend on bus duty cycles and the applicable utility tariff.

Recommendation #2

Ancillary services can offer a valuable revenue stream; however, E-Fleet operators should exercise caution regarding the potential for market saturation.

Ancillary services are a potentially significant value stream if implementation costs are sufficiently low and there is regulatory support. As more variable renewable-based generation replaces conventional power generation, these services are likely to become in greater demand. However, ancillary service markets could saturate, and prices could come down significantly with high penetration by advanced storage technologies. The need for ancillary services is likely to remain relatively low compared to the pending influx of battery storage, smart inverters, and other grid-responsive loads. If all technologies capable of offering spinning reserves were to schedule into the market, once-lucrative revenue streams could dry up significantly. Even if regulatory policy and technological barriers are overcome to allow frequency regulation behind the meter, the same threat of market saturation for this currently more valuable revenue stream would still exist.

Recommendation #3

School Bus Fleets should consider transitioning to E-Buses, even in the absence of a regulatory mandate, to take advantage of higher VGI benefits available due to their unique schedules.

Of all fleet types, electric school buses are perhaps best suited to providing VGI services due to their typical downtimes during the day and in the early evening. As of 2018, California had a total of 24,213 yellow school buses, approximately 65 percent of which were owned by school districts (with nearly all of the remaining owned by contractors).[4] The two largest school bus fleets in California are Los Angeles Unified School District with 1,999 buses and San Diego Unified School District with 474 buses.[5]

Unlike transit fleets, school bus fleets are not mandated by CARB to transition to zero-emission vehicles, so the extent to which these fleets will transition to E-Buses remains to be seen and is currently driven largely by the state incentives and private financing made available to school districts. Some school districts in California are also investing their own regular replacement funds, citing both the overall environmental and local air quality benefits of transitioning away from diesel buses. In 2017, the Twin Rivers Unified School District serving parts of Sacramento became the first school district in the nation to use zero-emission electric school buses. Their zero-emission fleet currently stands at 25 buses with plans for more. As indicated in the VGI use case analysis later in this report, revenue from VGI and V2G enabled school buses can help fund more accelerated procurement of electric school buses, and improve the E-Bus value proposition vs. diesel alternatives.

Positive E-Bus Vehicle-Grid Integration Impacts and Benefits to Ratepayers

In addition to its direct benefits to AVTA and other transit operators, the California E-Bus to Grid Integration Project provides multiple benefits to California ratepayers as a whole. Qualitative benefits associated with cost efficient and accelerated E-Fleet adoption include: reduced noise pollution and superior comfort, health, and environmental attributes. These attributes are associated with increased ridership which lead in turn to reduced fuel expenses for residents, reduced highway congestion, reduced likelihood of accidents, and reduced incidents of childhood asthma. Diesel emissions are a major contributor to asthma outbreaks in California. Asthma results in a numerous workdays and school days missed per year. It also

[4] Pupil Transportation Statistics. School Bus Fleet. 2020. https://files.schoolbusfleet.com/stats/SBF-StateTransportationStats2017-18.pdf

[5] Top 100 School Districts Fleets. School Bus Fleet. 2018.https://files.schoolbusfleet.com/stats/SBFTop100SchoolDistrictSchoolBusFleets2018.pdf

contributes to many deaths, hospital intakes, and emergency department visits per year. Accelerated E-Bus and E-Fleet deployment has potential to help reverse these trends.

E-Fleets can also provide a reliable source of emergency backup power for facilities such as hospitals, schools, and emergency aid services, if these facilities are pre-equipped with the necessary bi-directional charging stations and smart electrical panels to provide Vehicle-to-Building power flow. This extra level of power security for medically vulnerable populations, eldercare, and healthcare facilities can help save additional lives. Improving health and labor productivity could deliver multiple additional benefits not discussed here. The increase in destructive fires over the recent years have increased the importance of exploring this service's potential. It is recommended that the state of California and utilities fund programs to enable E-Bus-to-grid backup power infrastructure, with emphasis on high fire risk areas.

CHAPTER 4: Operator Efficiency Program

Background

AVTA's transition of its entire bus fleet to E-Buses by 2020 will complete one of the largest E-Bus deployments in North America. One of the primary challenges of deploying E-Buses on such large a scale is controlling operational costs while maintaining reliable transit service. Maximizing vehicle efficiency can lower the electricity costs per mile and extend vehicle range, thereby minimizing the number of mid-route bus swap-outs due to low battery state of charge. Research suggests that operator behavior can have a significant impact on bus efficiency, with studies showing up to 30 percent improvement from efficient driving behaviors.[6]

Overview of Operator Efficiency Program

To minimize operating costs of agencies transitioning to E-Bus fleets, Energy Solutions designed and tested an E-Bus Operator Efficiency Program (OEP) for AVTA bus operators and supervisors. The goal of the OEP is to optimize benefits of E-Bus operation, by developing and implementing strategies that are scalable to other transit agencies in California and nationally.

To develop a framework for the OEP, Energy Solutions reviewed technical papers studying the effects of driving behavior on vehicle efficiency. In addition, Energy Solutions interviewed researchers and industry experts, fleet owners, and bus operators at AVTA and other agencies. Based on this research, Energy Solutions identified four elements of an improvement framework to drive operator behavior change:

1. Identify and prioritize factors that influence E-Bus efficiency performance through empirical data collection and analysis;
2. Develop and standardize efficient driving best practices;
3. Increase operator awareness and understanding of the efficiency imperative with effective training and feedback;
4. Increase operator motivation through incentives.

This chapter of the Final Report describes project accomplishments and lessons learned relative to each of the four elements in the logic model defined above, along with actionable recommendations for AVTA. The learnings and recommendations presented here can be applied to other transit agencies making the transition to a fleet.

[6] Rios-Torres, J., Sauras-Perez, P., Alfaro, R., Taiber, J. et al., "Eco-Driving System for Energy Efficient Driving of an Electric Bus," SAE Int. J. Passeng. Cars – Electron. Electr. Syst. 8(1):2015, doi:10.4271/2015-01-0158

Data Collection Components and Methods

Energy Solutions conducted quantitative and qualitative research from December 2017 through March 2018 to inform the development of an operator efficiency program design. The quantitative research consisted of data collection and analysis to:

- Identify factors that most influence E-Bus operator efficiency performance at AVTA
- Calculate a normalized kWh/mi efficiency metric to equitably compare operator performances to their peers and with fleet averages
- Develop a realistic operator efficiency improvement goal based on the estimated kWh/mi efficiency metric

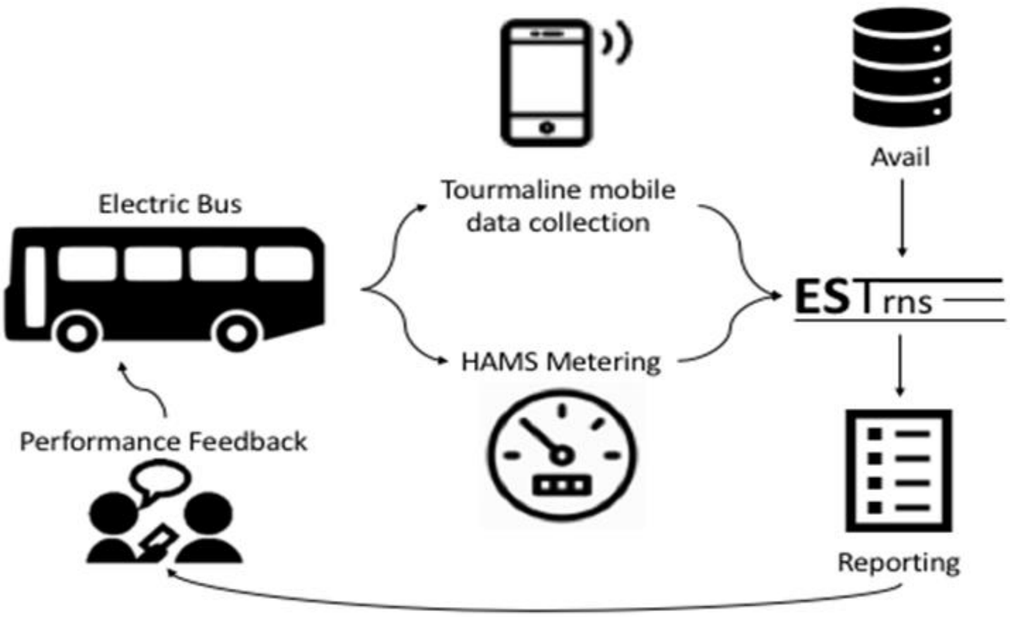
The qualitative research consisted of a literature review of technical papers studying factors influencing efficient performance of electric vehicle fleets, including passenger cars and buses. This was supplemented by interviews with researchers studying electric transportation, operators of electric fleets at other organizations, and AVTA's senior managers and operators.

Data Collection Components

Energy Solutions collected five distinct types of data to monitor and derive baseline performance of AVTA E-Bus operators. All data types (except for the one exception noted below) were collected using existing technology solutions and databases, such as on-board telemetry and AVTA's route scheduling system, and were available for all E-Buses. Figure 4 illustrates the software applications, data sources, and data flow. Key components in the data and telemetry system are noted:

1. Tourmaline Labs: The Tourmaline system is a commercially available wireless vehicle data collection platform that Energy Solutions procured via subscription service. Tourmaline uses a cellular phone to sense and measure sub-second information on speed, acceleration, and braking. Data on the Tourmaline platform are logged four times per second. Tourmaline data were accessed through an API with the Tourmaline Labs server.
2. I/O Controls – Health Alert Management System (HAMS): HAMS is the on-board telemetry system that collects data on power consumption, state of charge, location, speed, and charging status. HAMS data are logged at one to three-minute intervals. Data from the HAMS system are uploaded daily to a web portal accessed via username and password. Daily downloads of HAMS CSV files for each bus were automated using a software program built by Energy Solutions.
3. AVAIL System: AVTA uses the AVAIL fleet management platform for vehicle scheduling, operator and passenger tracking, and reporting. AVAIL Technologies, Inc. agreed to make certain data available for download on a regular basis. Energy Solutions created software for the automated download and processing of AVAIL data.
4. Dark Sky API: Open access API for weather data. Temperature and precipitation information were pulled from this API.
5. Zip Code GIS: Census data were used to obtain polygon definitions (geographical borders and the center, using GIS coordinates) of local Antelope Valley zip codes.

Figure 4: Antelope Valley Transit Authority Data Flow Diagram



Source: ZNE Alliance

Data from each data source were transferred into ESTrns, the data repository and data processing engine created by Energy Solutions. ESTrns was built using a PostgreSQL 10.7 database with postGIS installed. ESTrns imports data from disparate data sources and compiles it into a single processing engine to provide meaningful analysis of operator performance at the individual and fleet levels. The ESTrns platform was used in determining the operator efficiency improvement goal in the AVTA electric fleet. The platform was also used to populate the operator training and feedback tools in the operator behavior efficiency program. Full details on ESTrns are provided in the Technical Specification report previously submitted to the Energy Commission.

Quantitative Methodology for Operator Efficiency Program Design

To inform the OEP design, Energy Solutions developed a statistical regression model to analyze the impact of various elements of operator behavior on vehicle efficiency. Identifying and evaluating the independent effect of relevant efficiency factors required three steps:

1. Deriving summary statistics for the drivers and buses
2. Calculating the kWh/mile for each vehicle on each trip
3. Normalizing the drivers' performance against their peers.

Data imported to the ESTrns database were first indexed by timestamp. Congruent timestamps from each of the data streams were matched, then joined using SQL joins into a master data table. Then, the data were regrouped into "trips." A trip was defined as a sub-section of every AVTA bus route corresponding to the same start and end location and the same sequence of stops in between. Trips were labelled by route number, direction (inbound or outbound), and the first and last stop ID of the trip. Start and end locations were identified using AVTA's own stops and route data in the AVAIL platform.

Deriving Summary Statistics

Energy Solutions then calculated interim summary statistics of key variables over the length of each trip. The statistics were calculated from the raw data for each trip using a PostgreSQL data query of the ESTrns database. Other variables needed for the regression analysis—bus type (such as 40-foot or 60-foot), route, etc.—remained constant over the length of any trip and did not need to be summarized or averaged.

Calculating Kilowatt-hours per Mile for Each Trip

The project team divided the difference in battery state of energy from the beginning and end of the trip by the difference in odometer mileage. This calculated value was used as the dependent variable in the regression model.

Normalizing Kilowatt-hours per Mile Per Operator

The data, once summarized by trip, are then used in a linear ordinary least squares (OLS) regression model to examine the impact on vehicle efficiency of behaviors within the control of the operator. Full details on each term of the regression model are provided in the February *2019 Operator Design and Program Implementation Plan* report submitted to the CEC.

Qualitative Methodology for Operator Efficiency Program Design

Complementary to the quantitative analysis, Energy Solutions conducted additional research in the form of interviews, ridealongs, surveys, and literature reviews. Interviews with researchers at academic and research institutions and other electric fleet operators were conducted to understand the state of E-Bus technology, early E-Bus pilot deployment experience, pilot results, and lessons learned. The purpose of AVTA operator and management interviews was to understand operator and management insights and attitudes towards the new E-Buses. The operator and management survey responses were analyzed to identify gaps in knowledge that may require further training, as well as to gain input on challenges and opportunities to improving vehicle operating efficiency. Finally, the literature review added to the project team's knowledge of effects of driving behavior on vehicle efficiency; other technical factors influencing efficiency (for example drag, inertia, rolling resistance, space conditioning and auxiliary loads); and factors influencing behavior change (such as feedback, training, and incentives) based on behavior science research.

Analysis and Design of Operator Efficiency Program Elements

Energy Solutions processed data through January 2019 from nine 40-foot E-Buses and six 60-foot E-Buses—during a period in which the buses completed a total of 3,055 total trips. The dataset also included operating data from 96 unique operators, along with 26 different routes (counting inbound and outbound legs as distinct routes).

The regression model indicated that, controlling for confounding factors, the average rate of deceleration had a statistically significant effect on vehicle efficiency. There was no statistically significant relationship between average acceleration rate and vehicle efficiency. While many of the other regression terms showed statistical significance, only these two variables are within the operator's control. While data analyzed for this report only represents five of the 40-ft buses, and results may change once the regression model is updated with more data, the results suggested that behavior intervention strategies should emphasize slower deceleration rate over any adjustments to acceleration rates.

To address how operators approach deceleration, the team developed the following elements for an OEP:

- Operator training
- Operator feedback and engagement
- Operator incentive program

Operator Training

Limited documentation exists on behavior practices to improve E-Bus efficiency. To address this challenge, the project team developed a training program for E-Bus operators at transit agencies. The training program consists of a 37-minute DVD video, a trainer's guide, and an operator's study guide. The training content explained the benefits of E-Buses and efficient driving, where and when regenerative braking happens, how it is distinguished from coasting, and provides guidance on the operating conditions and options for leveraging regenerative braking.

To maintain operator attention, the video uses diverse views to break up the course and aid learning. There are high-quality animations supporting the learning content, as well as operator "pop-ups" to challenge the trainee and maintain interest. There are two different narrators delivering the narration, one male and one female. The training video has real-time video footage filmed on site at AVTA, interviews with AVTA managers and operators who operate these buses, and includes computer graphics to reinforce information discussed in the training. The video was produced by TAPTCO, which is the national leader in bus operator training. ZNE Alliance and Energy Solutions will be distributing copies of the video at nominal cost to transit agencies throughout California.

Operator Feedback and Engagement Dashboard

A review of the literature on behavior science reveals that feedback, if delivered well, can spur behavior change. Energy Solutions built a digital feedback dashboard that incorporates research-validated behavioral science techniques. The web-based dashboard elements were designed based on behavioral science research that calls for: creating a standard of behavior, using a specific and standard performance metric (in this case, kWh/mi), setting a goal, and providing feedback that is timely. The operator training program also uses driving score feedback from immediate past behavior as well as a view of progress across longer periods of time. Finally, the platform enables a comparison of how well the operator is doing currently compared to the company goal, their personal goal, and how their peers are doing.

Three dashboard pages were created. The operator page allows operators to view their own efficiency kWh/mi score as well as the company's, compared to the company goal. There is a dynamic graph at the bottom that shows an operator's historical efficiency performance and trends over time on the weekly and monthly basis. The managers' report provides a ranking of the top performing operators and access to each operator's reports. The company report shows the overall average kWh/mi for all operators and lists the top five high-performing operators to enable the recognition program. Users can log in daily to view reports as well as print them to review with supervisors.

Operator Incentives

In addition to information feedback, monetary incentives can help shift behavior. The normalized kWh/mi efficiency metric focused on the operators' deceleration rate will inform the allocation of incentives to the top-performing operators. Energy Solutions developed recommendations for AVTA to implement the incentives program. AVTA is currently considering either cash bonuses or gift cards, with a budget of $1,000 per month. One objective of the incentive design was to balance competition with collaboration. With that in mind, Energy Solutions proposed awarding the incentive to all operators who meet a specific kWh/mile goal, rather than to a pre-determined number of the most efficient operators. This approach could be combined with a lottery system that awards larger incentives once per year.

Developing an Efficiency Goal for Antelope Valley Transit Authority

In developing an efficiency goal for AVTA, Energy Solutions focused on deceleration behavior specifically. A goal was set for AVTA of a 15 percent improvement in the efficiency of deceleration behavior, measured in terms of kWh/mi. This goal is consistent with our review of technical studies, which reported efficiency improvements from training and feedback ranging from 5 to 30 percent. Another reason for this goal is that it was small enough to be attainable, but large enough that the effect size would be discernable upon program validation. Note that an improvement of 15 percent in the mean deceleration (kWh/mi) translates to just a 0.05 kWh/mi improvement in the overall efficiency kwh/mi, which is equal to approximately 4% in overall vehicle efficiency.

Operator Efficiency Program Implementation, Challenges and Lessons

Training Implementation

The video-based training package was completed in February 2019. Energy Solutions provided an orientation to the labor contractor, Transdev. Transdev deployed the training program as part of the previously scheduled safety trainings on March 19, 20, 26 and 27, and on December 23 and 24 of 2019. Energy Solutions visited AVTA on March 20 and December 24 of 2019 to participate in and observe the operator training. Energy Solutions staff took notes on operator questions and shared them with AVTA management, and provided responses for the trainers. Operators watched the training videos and participated in associated discussions with other operators and supervisors during planned breaks designed into the video. The end of the training included a 10-question quiz for operators to review with trainers.

Feedback Dashboard Implementation

Energy Solutions gave an orientation to the completed online dashboard to AVTA and Transdev management on July 18, 2019. Accounts were created for the managers and operators. Energy Solutions created fliers introducing the feedback dashboard to operators, a how-to guide for managers and a separate how-to guide for operators. Energy Solutions visited AVTA on August 16th to distribute the materials. The dashboard flier and operator how-to guide were inserted into operator mailboxes and the managers' how-to guides were distributed to management. The feedback dashboard was also set up on the company computer in the operator breakroom, as the homepage on both Safari and Chrome web browsers. The Transdev manager walked through the feedback dashboard with operators to suggest improvements to Energy Solutions.

Energy Solutions staff visited AVTA again on November 12, 2019 to acquaint operators with the feedback dashboard. Energy Solutions logged onto the dashboard with about 15 operators. Each of the 12 operators who were asked whether they found it useful responded affirmatively. There was substantial commentary amongst operators when taking turns in a group to log in and see each other's scores. Operators with good scores received encouragement and those with scores on the lower end receive some good-natured teasing. It is expected that this kind of social interaction around viewing feedback scores will cause more operators to start checking and improving their scores.

Operator Incentives Implementation

Operator incentives were planned to be rolled out last in the sequence of training program activities. To facilitate program performance evaluation, the original program design called for operators to first receive training to increase knowledge and awareness, then the feedback dashboard would be rolled out no sooner than two months following the training, and finally incentives would be implemented to further motivate behavior change. Due to the challenges described below, the feedback dashboard rollout was delayed, which in turn limited the collection of sufficient data to enable full implementation of an incentives program to equitably identify and reward the most efficient drivers. While it is expected that AVTA will introduce the full incentives program, because they could not be rolled out to operators within the project timeframe, analysis of the potential impact of incentives on operator behavior was not included as part of the program evaluation.

Training Challenges and Lessons

The training implementation went smoothly with few challenges. It was effective for Transdev trainers to lead the training as they have existing relationships with the operators.

Feedback Dashboard Challenges and Lessons

Originally planned for May 2019, a number of challenges delayed the rollout of the Feedback Dashboard until August. First, the three data providers—AVAIL, HAMS, and Tourmaline—all relocated their database to a new server in sequential order without pre-notifying Energy Solutions. This required the Energy Solutions team to write new programs to reconnect ESTrns to receive data from the new locations. Following the move, some types of data from AVAIL became unavailable and required AVAIL to create custom reports at additional cost. This required additional coordination with AVTA to obtain required authorizations (with AVTA covering the cost). In addition to database relocations, Energy Solutions discovered a timestamp issue with the HAMS data not correcting for daylight savings.

Another challenge encountered in data collection related to the Tourmaline system. The cell phones installed on the buses to collect motion data were turning off in some instances, without clear cause. Site visits showed that the phones were still plugged in to the power source with batteries fully charged. Tampering was ruled out as phones were locked in the instrumentation cabinets on the bus. Energy Solutions team experimented with purchasing a larger data plan with the cell service carrier, without noticeable results. The strongest theory is that the rate of charge of the power source cannot keep up with the rate the battery is depleted as the phone transmits motion data to the cloud. After the phones turn off, they are slowly charged back up by the time Energy Solutions team inspects them on site.

The original mobile data acquisition plan called for installation of a vehicle data collection app on each operator's personal cell phones. This way the data would be collected for every E-Bus operator. However, this was not possible given labor union policies regarding employee use of personal cell phones for work purposes, and Transdev does not issue work phones for its operators. Energy Solutions continues to investigate the data transmission challenge and is identifying additional motion data collection options. While data collection is not as robust as preferred, the Tourmaline data was sufficient to draw important conclusions regarding operating behavior, as summarized later in this chapter.

Supervisor check ins are also important for keeping operators engaged in the behavioral improvement effort. Supervisor involvement is particularly critical to offer encouragement for lower-performing operators (such as highlighting their improvement, listening to their concerns) who are at higher risk of disengaging. Transdev supervisors did not have the bandwidth for individual check ins, but Energy Solutions believes that additional individual attention could make an important difference in enhancing operator performance results.

Incentive Implementation Challenges and Lessons

Motion data were collected on a sample of AVTA E-Buses (rather than the entire fleet) to conform to the available budget. Along with the data challenges described above for the dashboard, this meant that some operators in any given month had robust performance feedback while other operators had limited or no feedback. This data inconsistency constrained the equitable determination of the most efficient operators each month.

Data inconsistencies also limited promotion of the feedback dashboard to operators. The original rollout plan included displaying company average kWh/mi scores on the operator break room electronic monitor and listing the most efficient operators. Energy Solutions continues its work to resolve data consistency issues and to research alternative motion data collection options. While AVTA operations are being significantly scaled back during the Covid-19 crisis (including the cancelling of all commute routes and reduction of all weekday service to a weekend schedule) it is anticipated that operator training and recognition programs will ramp up later in 2020 as the full complement of operators returns to work and regular training activities are resumed.

Evaluation of Operator Efficiency Program Performance

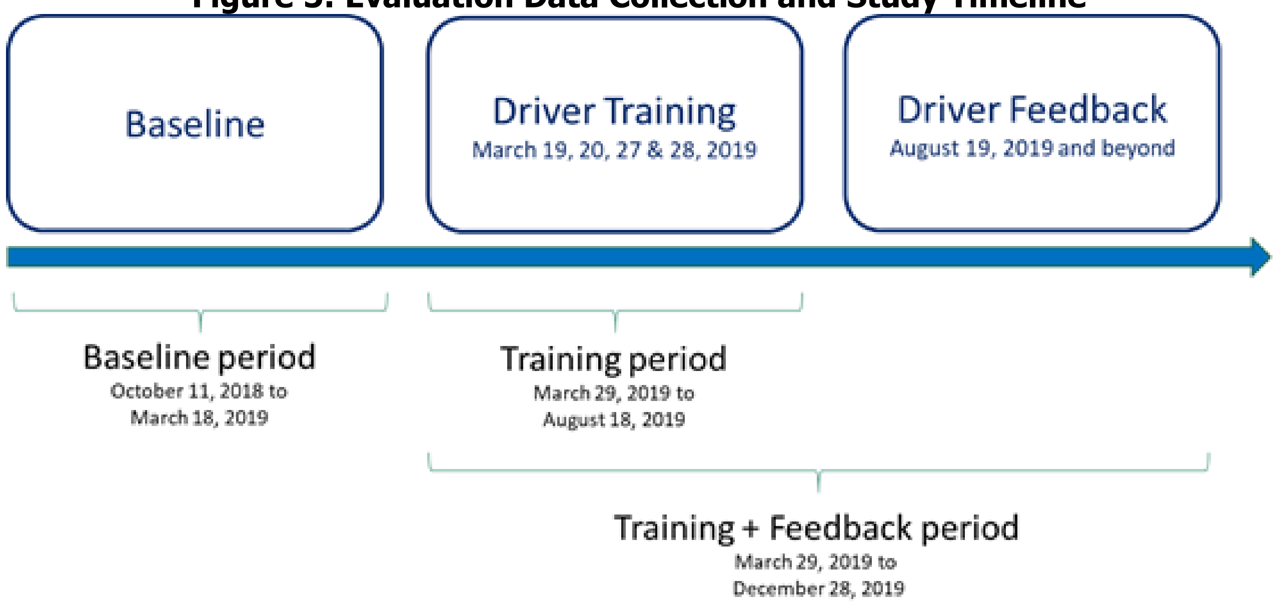
Fuel efficiency of the current AVTA E-Bus fleet varies greatly by both external factors (for example weather, route, traffic, and ridership characteristics) and operator characteristics (including behavior, skill, and experience). For example, before implementing the OEP, trips along one of the most heavily driven routes ranged from 1.0 kWh/mile, for the most efficient trips, to 6.0 kWh/mile for the least efficient trips. The OEP aimed to produce a 0.05 kWh/mile (or greater) improvement in fuel economy. This section documents the quantitative evaluation of the OEP conducted by the third-party measurement and validation contractor, Opinion Dynamics, including measured impacts on kWh/mile and cost effectiveness of the OEP.

Evaluation Data and Methodology

Using the data outlined, Opinion Dynamics analyzed data from more than 10,000 AVTA E-Bus trips—including trips from before and after the OEP took place—enabling rigorous assessment of OEP effects on fuel economy. Opinion Dynamics used a pre-/ post-program evaluation design, comparing pre- and post-OEP data for each driver (namely, fuel economy) while statistically controlling for factors that could affect bus efficiency, such as bus length (40-ft and 60-ft), time of day, whether the trip occurred on a weekend versus weekday, route, trip direction (inbound and outbound), and weather variables (including temperature, precipitation intensity, and windspeed). To ensure there was sufficient data to meaningfully compare driving behavior in the pre- and post-intervention periods, Opinion Dynamics only included drivers in the evaluation analysis that had complete data for at least five trips in the pre-OEP period and five trips following the roll out of the OEP. Additionally, any trips on E-Buses with in-route wireless charging capability were excluded, as in-route charging confounds measurements of driver efficiency.

The data used in this evaluation included E-Bus trip data and weather data collected from October 11, 2018 through December 28, 2019. Figure 5 depicts the full study timeline and key data collection periods.

Figure 5: Evaluation Data Collection and Study Timeline



Source: ZNE Alliance

Opinion Dynamics used two multilevel linear mixed models to test the effect of the OEP interventions (training and training plus feedback) on driver efficiency, measured in kWh per mile. The first model addresses whether training itself had an impact on driver efficiency; and compared kWh/mile achieved by drivers in the pre- vs. post-training period (before feedback was provided). The second model addresses whether training plus feedback had an impact on driver efficiency, comparing kWh/mile achieved by drivers in the pre- vs. post-training+feedback period. Exogenous factors that can impact fuel economy (such as weather) were statistically controlled in both models. The *E-Bus Efficient Operations Challenges and Opportunities Report* contains a detailed description of the quantitative evaluation method.

In addition, Opinion Dynamics conducted cost effectiveness analysis to determine if any OEP energy savings (specifically, corresponding electricity bill savings) found in the quantitative evaluation exceeded the costs of implementing the OEP (including all labor, software, and hardware costs).

Operator Efficiency Program Evaluation Results

Impact of Driver Training and Feedback on Efficiency

The first model assesses whether drivers tended to use less energy (kWh per mile) on their trips after training was offered compared to before the training events, and thus whether training (without feedback) had an impact on driver efficiency. Results from this first model suggest that training had a statistically significant ($p<.001$) impact on driver efficiency. Specifically, after controlling for confounding variables known to impact fuel efficiency, drivers used .12 fewer kWh per mile in the post-training [but before feedback] period compared to trips driven before training was offered.

The second model assesses whether drivers tended to use fewer kWh per mile on their trips after training and online feedback was offered compared to before the training events. This specifically addresses whether feedback combined with training had an impact on driver efficiency. Results from the second model suggest that feedback and training combined had a significant ($p<.001$) impact on driver efficiency. Specifically, after controlling for confounding variables that may impact fuel efficiency, drivers used .084 fewer kWh per mile in the post-training and feedback period compared to trips driven before training was offered.

Thus, Opinion Dynamics' quantitative evaluation of the OEP reveals that the program exceeded its goal of a 0.05 kWh/mile (or greater) improvement in fuel economy.

Estimated Energy Savings

Given the measured improvement of .084 kWh/mile over the course of the post-OEP evaluation period (March 29, 2019 to December 28, 2019), the OEP is estimated to have resulted in potential fleet-wide energy savings of 229 MWh during the post-OEP evaluation period. The post-OEP data collection period included a total of more than 16,000 trips. Each trip was defined as a sub-section of every AVTA bus route corresponding to the same start and end location and the same sequence of stops in between. In bound and out-bound directions are considered separate trips.

Estimated Cost Savings

Given the measured improvement of .084 kWh/mile over the course of the post-OEP evaluation period, the OEP is estimated to have resulted in approximately $28,000 in electricity cost savings during the post-OEP evaluation period. Despite these significant cost savings, designing and implementing this first generation of the OEP far exceeded the electricity cost savings stemming from decreased charging needs. However, since the great majority of the costs to deliver the training program are associated with one-time upfront development costs (namely, developing the training video), subsequent applications of this training program by other transit agencies (that is, using the same materials and videos) could pay for themselves in less than a year via electricity cost savings from improved fuel efficiency (as subsequent training costs would not include training video development costs). Further, if AVTA operator efficient driving behaviors persist at the current level, electricity cost savings are likely to exceed training costs (including upfront video production costs) in the following year.

Since all drivers had the potential to be exposed to either OEP intervention (and since training preceded the feedback dashboard), it is not possible to isolate the effect of feedback alone on efficient driving behavior. Therefore, this evaluation is unable to isolate the cost-benefit of the feedback dashboard specifically. Since training costs exceeded estimated cost savings, the cost of the OEP as a whole (training plus feedback) also exceeds estimated cost savings achieved by the end of the post-OEP evaluation period. However, the costs associated with developing and implementing the feedback dashboard are significantly greater than that of the training. Ultimately, this evaluation suggests that the feedback dashboard—at least in its current form—will struggle to ever generate enough electricity cost savings to achieve a net positive return on investment given current costs. However, if the feedback dashboard is incorporated into future bus hardware or telematics platforms as a very low cost or standard offering, the net economic impact could be highly favorable. In any case, the data elements needed to generate the dashboard were foundational to this evaluation; Opinion Dynamics' evaluation of the OEP could not have taken place if it were not for these data elements. Thus, although the feedback dashboard did not appear to generate sufficient cost savings given pilot project development cost factors, it facilitated the evaluation of the training program, a considerable non-energy benefit.

Discussion of Operator Efficiency Program Results and Implications for Antelope Valley Transit Authority

Energy Solutions developed a behavior modification strategy consisting of four elements for influencing operator behavior change: 1) identifying and prioritizing factors that influence E-Bus efficiency performance through empirical data collection and analysis; 2) developing and standardizing efficient driving best practices; 3) increasing operator awareness and understanding with training and feedback; 4) increasing operator motivation through incentives. This project highlighted the important operational and behavioral changes that need to occur to support a successful transition to electric fleets, beyond the technical aspects of vehicle and charging operations. The *February 2019 Operator Design and Program Implementation Plan* provides additional discussion on the OEP results and implications.

Data Collection and Analysis

The limited numbers of E-Buses in operation in the United States today has limited the amount of empirical data and analysis currently available on E-Bus operator behavior. Therefore, enhanced data collection is particularly important at this stage of market development. Using the right technology solution for data collection is important for cost effective quantitative analysis in all aspects of the E-Bus deployment journey. The motion data collected by the mobile telephony tool provided useful empirical data, but were indirect measurements of operator acceleration and deceleration driving behavior. Ideally, data would be collected at the bus throttle (formerly known as the gas pedal) and at the brakes to measure the rate of acceleration and deceleration.

Standardizing Efficient Driving Practices

Using normalized efficiency metrics enables a fair comparison of performance across operators. By further assessing specific dependent variables such as deceleration, managers can more clearly determine if operator A, driving a circuitous route during a hot day, is more efficient than operator B driving a straight line and a direct route in the evening with lower ridership.

Operator Training and Feedback Program

The training video can be administered manually in the classroom or online via a learning management system. AVTA opted for the classroom training format, so that their own trainers could interact with the students during each training segment, discuss key points and answer operator questions, which proved effective. If other transit agencies implementing a similar program have the bandwidth, Energy Solutions recommends on-road training sessions to reinforce the key points from the efficient driving training video.

The feedback dashboard focused on the operators' deceleration behavior, in kWh/mi. A slower rate of average deceleration over the operator's shift indicates greater use of regenerative braking. The dashboard is accessible from any internet connected device. Transit agencies can set up a company computer for operators who do not have a personal computer or email account for logging in to the online system.

Operator Training and Feedback Program Evaluation

Comparisons of the evaluation results from the two intervention timeframes may lead some readers to conclude that training plus feedback has a slightly weaker (though still statistically significant) effect on driver efficiency than feedback alone. However, a review of drivers' use of the feedback website suggests that this relative decline in kWh/mile improvement is more likely to be indicative of "decay" of the first intervention's impact as opposed to a reduced effect caused by the second intervention. Without the implementation of the planned incentive program, use of the feedback dashboard was more limited than would have been the case with the incentives and recognition program. As of January 2020, only 16 percent of all drivers had logged into the feedback website at least once since the website was introduced to drivers in August 2019. Thus, the bulk of efficiency improvements in the training+feedback period (over the pre-training period) likely stem from the original training events, as too few drivers used the feedback website to have a meaningful impact on overall average driver efficiency. Despite the persistence of the training's effect, it appears to have lessened over time; a common phenomenon in any one-time behavior change intervention.[7] This suggests that drivers became somewhat less efficient over time; a consequence of decay of the training intervention's effect, as opposed to a lessening effect caused by the second [feedback] intervention. It is also possible that average driver efficiency would have decayed even more if it had not been for the feedback website. However, this study is unable to isolate the unique influence of feedback on driver behavior.

[7] Allcott & Rogers (October 2012). The Short-Run and Long-Run Effects of Behavioral Interventions: Experimental Evidence from Energy Conservation. National Bureau of Economic Research.

Based on the results of the evaluation of the OEP, Opinion Dynamics present the following conclusions and recommendations:

- Conclusion #1: E-Bus Operator Training provides a successful behavior change mechanism to encourage improved efficient driving behaviors. Following the implementation of the training program (but prior to the launch of the feedback website), efficient driving practices improved by .12 kWh/mile.

  Recommendation #1: E-Bus operators should offer training opportunities for E-Bus drivers based on proven operator efficiency improvement resources and methods.

- Conclusion #2: The impact of the feedback website on efficient driving behavior is unclear and may offer little behavior change benefit in its current implementation, but increased use of the tool may help increase or maintain driver efficiency. Following the launch of the feedback website, efficient driving practices continued to demonstrate improvement over the pre-training period, but kWh/mile improvements found in the prior post-training period were not magnified (or even maintained at the same level) via the feedback website intervention. The reduced improvement associated with the inclusion of the feedback period is likely related to the fact that only 16 percent of drivers accessed the website in the months following the website launch. Due to the study's design, the feedback site's potential for further improving driver efficiency is unclear. However, driver efficiency may see further improvement if more drivers accessed the feedback website (especially if they used it frequently).

  Recommendation #2: E-Bus fleet managers should encourage vehicle operators to use an efficiency feedback dashboard. Consider reassessing the methods for announcing the feedback website; use as many tactics and mediums as possible to advertise the site (such as flyers, emails, vocal announcements, newsletters). To train drivers on how to best use and interpret the results on the site, consider providing educational demonstrations of the feedback website to drivers. To the extent possible, hands-on trainings that require each driver to log-in during the training may be particularly successful in encouraging subsequent use.

- Conclusion #3: Efficiency improvements stemming from E-Bus Operator Training may not persist without subsequent interventions. Although driver efficiency practices witnessed a slight yet significant improvement following the training events, efficient driving behaviors somewhat decayed over time (despite the eventual launch of the feedback intervention). If no further interventions are employed, efficient driving practices may return to their pre-training levels.

  Recommendation #3.1: Continue offering E-Bus Operator Training events in the future, including to those that have already attended a training event in the past. Due to staff turnover (for example new staff starting after training events have passed), and natural decay associated with any behavior modification intervention, consider re-offering the training on a regular basis, such as quarterly or semi-annually.

  Recommendation #3.2: Consider making repeated training attendance mandatory. The impact of training on average driver efficiency can be maximized by requiring all drivers to attend a training event. The Continuing Education Unit (CEU) model can help additionally compensate drivers for the extra time to attend a training course (and/or pass a test on the content) on a regular basis.

- Conclusion 4: Incentives may constitute an additional successful behavior change strategy and may boost improvements in fuel economy. Only education-based behavior modification strategies were employed in this program, which achieved (and even exceeded) their desired results of 0.05 kWh/mile improvement in fuel economy. Incentive-based interventions (such as contests and cash prizes for efficient driving behaviors) may have the potential to help ATVA further improve E-Bus fuel efficiency.

  Recommendation #4: Consider instituting an incentive campaign to encourage improved fuel efficiency outcomes. Consider various incentive strategies to motivate drivers to improve and maximize their efficient driving practices (such as ongoing rewards). Further, ongoing (for example monthly) incentives can help mitigate decay of efficient driving behaviors. Consider both monetary and non-monetary incentives, (such as tickets to sporting events or movies, gift certificates to restaurants)

CHAPTER 5: Knowledge Transfer and Learning Outcomes

Introduction

As part of the California E-Bus to Grid Integration Project, the AVTA project team collaborated with Prospect Silicon Valley (ProspectSV) and CALSTART on Knowledge Transfer Activities to provide outreach, education, lessons learned, and best practices in E-Bus Deployment with key stakeholders such as transit agencies, E-Bus manufacturers, and policymakers. The Knowledge Transfer team collaborated on 27 events overall, including two joint Technical Advisory Committee meetings. Key stakeholders were engaged and interested in learning more about the E-Bus projects, especially technical findings that could be useful for future projects. Most recently, more than 200 attendees participated in a webinar that summarized learnings from both the Santa Clara VTA and Lancaster AVTA projects, with representatives from multiple transit agencies, E-Bus OEMs, and public agencies. The team is planning to continue to engage Knowledge Transfer activities through future events and technical resources through the end of 2020. This chapter summarizes knowledge transfer objectives, partners, target audiences, and our outreach approach, including events and conferences, and the development and dissemination of technical resources.

Knowledge Transfer Objectives

The primary objectives of the knowledge transfer activities were to educate and engage a diverse set of stakeholders including transit agencies, vehicle OEMs and suppliers, utilities and energy service professionals, and local, regional, state, and federal policymakers. Stakeholders were informed and engaged via presentations on the overall project framework, our economic and energy outcomes, challenges and approaches, and policy considerations for E-Bus deployment. Outreach and education occurred primarily through events and dissemination of technical resources.

Knowledge Transfer Partners

With the encouragement of the CEC, the ZNE Alliance and Prospect Silicon Valley established a joint Technical Advisory Committee to provide oversight on the California E-Bus to Grid Integration Project, and the Advanced Transit Bus VGI Project. The Santa Clara project was led by Prospect Silicon Valley with the participation of the Valley Transportation Authority, NREL, and CALSTART. The Advanced Bus VGI project demonstration is focused on the VTA fleet deployed in Santa Clara County and the greater Silicon Valley. These findings will be relevant to all E-Bus operating agencies in California and beyond. As part of the joint project activities, the two projects coordinated closely on the development of their respective Knowledge Transfer plans, and are producing a common *E-Bus Deployment Guide* that addresses the technological, operational, and workforce issues required to successfully integrate E-Buses into a transit fleet. The lead contractor for the *E-Bus Deployment Guide* editorial process is CALSTART. However, the ZNE Alliance and ProspectSV contributed key information resources to the *E-Bus Deployment Guide*, and provided technical information and case studies to inform the guide development.

Prospect Silicon Valley

Prospect Silicon Valley (ProspectSV) is a nonprofit cleantech innovation hub that focuses on advanced mobility and energy solutions for urban communities. By collaborating with key public and private partners and providing resources for entrepreneurs in the field, ProspectSV is working to improve urban sustainability. ProspectSV's role was to lead the strategic management of the Advanced Transit Bus VGI Project (fellow recipients of California Energy Commission grant funds for GFO-16-303) in partnership with the Valley Transportation Authority, NREL, and CALSTART. The project objective is to research, develop and demonstrate an advanced energy management system for electric transit bus fleets. ProspectSV led Knowledge Transfer coordination with AVTA project partner ZNE Alliance on joint activities such as TAC meetings, conferences, and webinars.

CALSTART

CALSTART is a nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions. The CALSTART network connects companies and government agencies, including technology firms, transit operators, vehicle manufacturers, and research institutions, offering state-of-the-art technical information and support for technical demonstrations and market acceleration activities in the clean transport domain. CALSTART's role was to lead development of the E-Bus Deployment Guide and participate in the knowledge transfer initiatives led by Prospect Silicon Valley, which complement and were fully integrated with the efforts of ZNE Alliance and its California E-Bus to Grid Integration project team.

Target Audience

The project team successfully engaged with a large number of organizations and individuals, conveying not just the goals and methods but also the unique challenges involved in Fleet Electrification. Examples of key stakeholders for Knowledge Transfer activities included:

1. Electric Bus Fleet Operators: The project team engaged E-Bus operators to address VGI E-Bus benefits, challenges and strategies. Transit agency staff targeted included Executive Directors, General Managers, Fleet Managers, Chief Innovation Officers, fleet engineers, fleet operations personnel, marketing/PR and finance staff, and more. Key transit agency channels included the California Transit Agency, CARB, the CIO Summit, the American Public Transit Association (APTA), Metropolitan Planning Organizations, local transit agencies, etc.
2. Electric Bus Manufacturers and Technology Partners: Electric bus OEMs have an important role to play in assisting with systems integration and education of fleet operators relative to VGI issues and operator training. Accordingly, project materials (notably the E-Bus Deployment Guide) are being distributed through OEM channels. Examples of major transit and school bus OEMs include Lion Bus, Proterra, BYD, New Flyer, Volvo, Ford, Daimler, Bluebird, Thomas, etc.
3. Policy Makers: Project team members were actively engaged in technical and regulatory working groups and workshops to ensure that project results and policy recommendations are communicated to policy makers and other market actors (including EV, EVSE, and VGI OEMs, systems integrators, utilities, and financiers.) Key working groups in which project team members participated included the Clean Transit

Rule development process at CARB, and the VGI Working Group co-sponsored by CEC, CARB, and California ISO. Specific events and project team participation therein are described below.

4. Load Serving Entities: Project partners in both the California E-Bus to Grid Integration Project and the Advanced Transit Bus VGI Project produced VGI data and results that are highly relevant to load serving entities (LSEs), including investor-owned utilities (IOUs) and community choice aggregations (CCAs). Specifically, the *E-Bus Deployment Guide* incorporated results from Olivine (in the case of the AVTA project), and NREL and Energy Solutions (for the VTA Project), on the scope of E-Fleet VGI energy services and resulting implications for LSE program development. To disseminate these results, outreach was conducted to IOUs and CCAs, as well as energy service professionals, through groups such as the Association for Energy Service Professionals (AESP) and others. Key dissemination targets include PG&E, SCE, and San Diego Gas & Electric (SDG&E), as well as leading CCAs and the public utilities, Silicon Valley Clean Energy (SVCE), San Jose Clean Energy (SJCE), Peninsula Clean Energy (PCE), Clean Power Alliance (CPA), CalChoice, SMUD, etc.

To support E-Bus market acceleration, the team presented key project findings and lessons learned to key stakeholders during events and conferences, and provided a wide variety of technical resources representing best practices. The principal transit agency-facing resource developed under the joint auspices of the two project teams is the *E-Bus Deployment Guide* (to be delivered in third quarter 2020.) This guide will harvest lessons learned across both projects, and assist market adoption by educating transit agencies and prospective E-Bus operators on the most cost-effective technical, operational and behavioral solutions, policies and programs for transitioning to an all-electric bus fleet.

Outreach Approach

Throughout the project timeline, the project team carried out a robust joint Knowledge Transfer Plan which included sharing of project progress, findings and lessons learned through the events and outreach activities.

Knowledge Transfer Events and Conferences

Project team members attended and presented at 27 events including industry conferences, symposia, workshops, panels, webinars, and the TAC) meetings. The project team presented summaries of project learnings, program concepts, and policy recommendations at the following events:

- Workshops: In collaboration with Prospect Silicon Valley, the project team hosted five workshops featuring speakers presenting on topics relevant to the project. Outreach for these workshops were conducted via contact lists curated by ProspectSV, as well as industry contacts curated by ZNE Alliance.
- Webinars: Project partners participated in four webinars to educate fleet operators on opportunities to implement VGI systems in future projects and share lessons learned from both the AVTA and VTA projects.

- Industry Conferences: Project team members attended and presented at 11 industry conventions and meetings, largely in California, to network with industry professionals and share findings about the E-Bus Projects.
- Energy Commission Symposia: Project partners participated in two of the annual EPIC symposia and workshops as requested by the Energy Commission.
- Prospect Silicon Valley Innovation and Impact Symposium: The ProspectSV Innovation and Impact Symposium was an annual event bringing together more than 250 innovators, industry leaders, and policymakers in transportation, energy, and the built environment. Members of the project team were included in panel discussions, had a booth to talk about the projects, and gained media visibility through the event. ProspectSV hosted three Symposiums that featured the E-Bus Projects.
- Technical Advisory Committee (TAC) Meetings: ZNE Alliance and Prospect Silicon Valley used the joint TAC's domain experts to disseminate information from the project, provide input into final deliverables, and encourage industry-wide information sharing. The TAC included representation of more than 100 transit agencies, policy makers, utilities, and companies in the E-Bus vehicle, charging, and VGI supply chain. During these events, team members provided specific and detailed knowledge to the targeted audience group and networked with other industry, technology, and policy professionals. In addition, the project team developed valuable findings from these events, including project learnings, program concepts, and policy recommendations. The TAC met twice from 2018-2019, and included key stakeholders, project team members, and solution providers, including VTA, AVTA, ChargePoint, NREL, PG&E, Proterra, Trapeze, Clever Devices, Electriphi, NOVA, ZNE Alliance, ProspectSV, Olivine, Energy Solutions, and the CEC.
- Private Sector Solution Provider Engagement: The project team engaged with third party E-Bus service provider AMPLY to identify charging solutions developed to address BYD bus VGI challenges (currently being used at Tri-Delta Transit), and to explore retrofit opportunities to address the persistent charge control challenges at AVTA. AMPLY is a cloud-software charge management system that ensures service level (every vehicle charged at the start of every shift) and energy cost optimization (smart charging at the cheapest energy rates).
- Policy Engagement: The project team participated in the State's VGI working group, providing feedback and comment to ongoing conversations on V2G policies in the commercial fleet segment. Additional information on policy recommendations is provide throughout this report.

In collaboration with the project team, Prospect Silicon Valley created the Joint E-Bus Knowledge Transfer Calendar to track Knowledge Transfer events for both the VTA VGI and AVTA projects. The calendar includes all relevant events that were hosted, presented at, or that were attended, and summarizes key information and links to resources from each knowledge transfer event. For detailed information on all events please refer to the Knowledge Transfer Report.

Technical Resources

Technical resources developed by the project team include:

- *E-Bus Deployment Guide*: *The E-Bus Deployment Guide* is the primary technical assistance resource that was developed as a result of learnings from the AVTA and VTA projects, as well as a thorough review of other relevant projects and related literature.
- E-Bus Resource Library: To support development of the *E-Bus Guide*, the project team also developed a resource library that includes: (1) case studies of California E-Bus deployments, (2) E-Bus, charging, and VGI sensors, controls and management platforms technology overviews and specifications, (3) Listing of financial assistance programs and funding opportunities, and (4) All of the deliverables from the AVTA project.
- E-Bus Policy and Program Recommendations: E-Bus policy and program recommendations were developed for the CEC, California Public Utilities Commission, and CARB, covering: Electric Vehicle VGI tariffs (with special focus on Medium and Heavy-Duty vehicles and E-Buses, interconnection streamlining, and other policy mechanisms that could accelerate deployment of grid-integrated E-Buses.
- Guidance on E-Bus VGI Program Design: This program design was included in the *E-Bus Deployment Guide* and in the program recommendations These program guidelines address the needs of transit operators and utilities to create standardized VGI E-Bus program offerings that streamline interconnection, optimize savings and revenue opportunities, and encouraged the use of renewables and storage.
- California E-Bus-to-Grid Integration Project Case Study: This case study addressed the key dimensions of "people, process, and technology" involved in the transition to a 100 percent E-Fleet at the AVTA.

CHAPTER 6: Conclusions and Recommendations

The project determined that optimized smart charging management and operator efficiency training programs demonstrated significant actual and potential benefits for AVTA. Additional research is needed to validate simulated results under a real-world controls deployment scenario. Moreover, recent innovations in third party control of BYD charging systems provide a pathway to rapid implementation of the smart charging management strategies modelled using real-world AVTA and California ISO data. The results and recommendations below summarize potential recommendations for the enablement of VGI services, operator efficiency programs, and policymakers.

Key Results of Vehicle-Grid Integration Simulation Modeling

- (1) Smart charging strategies offer the most value to AVTA (and likely to similar transit agencies) relative to other VGI strategies assessed. (2) Bidding into the California ISO wholesale energy market via the Proxy Demand Resource (PDR) mechanism is unlikely to produce value for AVTA. (3) Frequency regulation would be valuable if regulation and technology permitted its use, which may be the case in the near future. (4) On-site solar PV would only be valuable for fleets that can charge in the daytime (in the absence of on-site battery storage).
- For night-charging E-Fleets, day-ahead energy market-based utility rates will not offer competitive smart charging opportunities compared to traditional TOU rates. For day-charging E-Fleets, day-ahead rates may be beneficial.
- Deploying on-site solar PV with battery energy storage at AVTA is not an economically feasible option for night-charging E-Fleet operators seeking to improve grid resiliency or reduce the agency's carbon footprint. Deploying on-site solar PV without battery energy storage may be economically feasible for day-charging E-Fleets.
- AVTA fleet use rates and associated charging requirements were determined to be incompatible with V2G applications. Fleets with low annual utilization rates present more opportunities for V2G services.

Operator Efficiency Program Results

- E-Bus Operator Training provides a successful behavior change mechanism to encourage improved efficient driving behaviors. Drivers engaged by the E-Bus Operator Efficiency Program (OEP) demonstrated an 0.084 kWh/mile improvement in fuel efficiency, equivalent to a 4 percent overall vehicle efficiency gain.
- Given the measured improvement of .084 kWh/mile over the course of the post-OEP evaluation period (March 29, 2019 to December 28, 2019), the OEP is estimated to have resulted in approximately 229 MWh savings during the post-OEP evaluation period.

- The impact of the feedback dashboard on efficient driving behavior is unclear and may offer little behavior change benefit in its current implementation. However, more sustained and intensive use of the tool may help increase or maintain driver efficiency.
- Efficiency improvements stemming from E-Bus Operator Training may not persist without subsequent interventions.
- Operator incentives may constitute an additional successful behavior change strategy and may further boost improvements in fuel economy.

As a result of the project engagement the team recommends the following next steps for policy makers, transit agencies, and other stakeholders looking to accelerate E-Bus adoption, operational efficiency, and V2G integration including:

Operator Efficiency Program Improvement Recommendations

- E-Bus operators should offer training opportunities for E-Bus drivers based on proven operator efficiency improvement resources and methods.
- E-Bus fleet managers should encourage vehicle operators to use an efficiency feedback dashboard.
- E-Bus operator training events should be held on a regularly recurring basis to sustain efficiency gains.
- Transit agencies should institute incentive campaigns—with operator feedback on incentive design—to encourage improved efficiency outcomes.

Recommendations for Policymakers

State-level policies and programs can accelerate development of a scaled-up VGI commercial ecosystem and foster improved integration of vehicles, chargers, and the grid. These efforts will materially improve the electric vehicle value proposition for fleet operators, especially in the medium and heavy-duty vehicle segments, including E-Buses, and provide enhanced benefits to California ratepayers. The following recommendations are offered to policy makers as the most critical opportunities for accelerating VGI implementation:

- Require operational demonstration of VGI and V2G functionality of buses and charging systems as a condition of CEC and CARB grant support for E-Bus equipment.
- Continue to develop V2G specifications and building code requirements for heavy duty charging applications—including requirements and technology considerations for bidirectionality, especially for state funded projects.
- Incorporate load profile analysis into TOU rate development for the MD/HD use case or consider subscription-based pricing structures to incentivize smart charging practices.
- Reconsider SGIP's current exclusion of mobile batteries. By enabling E-Buses to capture SGIP incentives, additional flexible capacity can be developed from E-Buses that operate as mobile batteries when not being used for transportation applications.
- Encourage or mandate Load Serving Entities, in partnership with EV and charging system OEMs and solution providers, to establish dedicated programs to scale V1G and V2G programs.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
API	Application Programming Interface: a programming interface which defines communications between multiple applications
DER	Distributed Energy Resource: distribution-connected renewable generation resources, energy efficiency, energy storage, electric vehicles, and demand response technologies.
DR	Demand Response: a change in power usage in response to the supply of power on the grid
CAISO	California Independent System Operator
NPV	Net Present Value: The discounted sum of all future cashflows resulting from project investment
V1G	Smart Charging: one-way power flow from the electrical grid to the vehicle, with the power levels controlled by charging management systems.
V2G	Vehicle-to-Grid: two-way power flows between the electrical grid and the vehicle, allowing the vehicle to import energy from the grid and export energy back to the grid
V2B	Vehicle-to-Building: two-way power flows between a building and the vehicle, allowing the vehicle to export energy to the building
VGI	Vehicle-to-Grid Integration: a term encompassing technologies related to managing vehicle charging using data and signals from the electrical grid
SGIP	Self-Generation Incentive Program: a program that gives rebates for qualifying distributed energy systems installed on the customer's side of the utility meter
TOU	Time-of-Use: a utility rate structure that has different energy prices at different times of the day

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APPENDIX A: Technical Advisory Committee Participants

Table A-1: Technical Advisory Committee Participants

Name	Organization	Title/Role
Bill Boston	Trapeze Group	Project Manager/Sales Engineer
Chris Ramirez	Trapeze Group	
Len Engel	solutionLab	Executive Director (formerly CEO, AVTA)
Salvador Llamas	Alameda-Contra Costa Transit District	Chief Operating Officer
Doug Black	Lawrence Berkeley Lab	
Pam Gutman	City College of SF	Bay Area Regional Director for Advanced Transportation
Cal Silcox	PG&E	Program Manager, Electric Vehicles
Ahsan Baig	Alameda-Contra Costa Transit District	Chief Information Officer
Michael Jones	ChargePoint	VP, Sales
Sam Hil-Cristol	Alameda County	Climate Corps Fellow
Seth Nishida	Sumitomo	
Kyle Yamaguchi	Sumitomo	Business Development Manager
Wendy Fong	Lehigh University	
Bhavin Khatri	SF MTA	
Kent Leacock	Proterra	Director Gov't Relations & Public Policy
Rafael Reyes	Peninsula Clean Energy	Director of Energy Programs
Peter Klauer	California ISO	Expert in grid stability, VGI
Rajit Ghadh	UCLA	Professor, UCLA, Smart Grid/EV/AV
Michael Wygant	San Diego Metropolitan Transit System	Director of Fleet & Facilities
Rajiv Singhal	Proterra	
Benjamin Waxler	ChargePoint	Applications Engineer
Dean Roussinos	Clever Devices	Software Engineer

Name	Organization	Title/Role
Ken Kelly	NREL	Sr. Engineer
Seamus McGrath	Proterra	Manager, Charging Systems
Mike Kilpatrick	Intueor	Principal Consultant and Leader for the Asset Management Practice
Phillip Kobernick	Alameda County	Transportation Operations, AlCo GSA
Betty Seto	DNV-GL	Head of Department
Mark Goody	FleetCarma	Manager, EV Programs
Mike Ferry	KnGrid	COO
Fred Barez PhD.	San Jose State University	Professor of Mechanical Engineering
Scott Moura	UC Berkeley	Professor
Mark Kosowski	EPRI	
Emre Kara	SLAC National Accelerator Lab	Associate Staff Scientist
Brian Shaw	Stanford University	Director, Stanford Parking & Transportation
Bjor Christiansen	NUVVE	Chief Strategy Officer
Timothy Doherty	SF-MTA	Senior Planner
Tim Lipman	UC Berkeley Transportation Sustainability Research Center	Co-Director
Ramses Madou	City of San Jose	Transportation Planner
Dean Kunesh	PG&E	Account Manager
Marley Miller	SF-MTA	
Alan Suleiman	Silicon Valley Clean Energy	Director of Marketing and Public Affairs
Lori Mitchell	City of San Jose	Director of Community Energy
Darryll Harrison	ChargePoint	Director, Global Communications
Ryan Popple	Proterra	CEO
Muffi Ghadiali	ChargePoint	Sr. Director, Product Management
Sila Kiliccote	SLAC National Accelerator Laboratory	Staff Scientist
Antonio Castillo	Santa Cruz Metro	Maintenance Supervisor

Name	Organization	Title/Role
Greg Nolen	Santa Cruz Metro	Maintenance Supervisor
Eddie Benson	Santa Cruz Metro	Maintenance Manager
Dan Bowermaster	EPRI	Program Manager, Electric Transportation
Jonathan Burroughs	PG&E	Expert Program Manager Demand Response Policy and Pilots
Roger Thorn	Sacramento Regional Transit	
Don Bray	Silicon Valley Clean Energy	Manager of Account Services
Tim McRae	Silicon Valley Leadership Group	Director of Energy Policy
Project Team Member	**Organization**	**Title/Role**
Paul Lipkin	Kisensum (now CharPepoint)	Project Manager
Clay Collier	Kisensum	Co-Founder
Luther Jackson	NOVA Workforce	Program Manager
Joonie Tolosa	VTA	Analyst
James Wilhelm	VTA	Engineering
Manjit Chopra	VTA	Program Manager
Gary Miskell	VTA	CIO/CTO
Joshua Eichman	NREL	Analyst/Engineer
Christian Hosler	Prospect Silicon Valley	Project Manager
Mike Harrigan	Prospect Silicon Valley	Senior Program Manager
Venkatesh Nadamuni	Prospect Silicon Valley	Project Manager
Hilary Davidson	Prospect Silicon Valley	Communications Director
Doug Davenport	Prospect Silicon Valley	CEO
Richard Schorske	ZNE Alliance	Executive Director
Sam Irvine	ZNE Alliance	Senior Program Manager
Hitesh Soneji	Olivine	Senior Solutions Design Engineer
Beth Reid	Olivine	CEO
Fernando Pina	CEC	Office Manager
Robin Goodhand	CEC	CAM

Name	Organization	Title/Role
Jeffrey Sunquist	CEC	CAM
David Erne	CEC	Supervisor
Edward Ortiz	CEC	Media Office
Tamara Perry	Energy Solutions	Quality Analysis
Jasna Tomic	CALSTART	Research Director

Source: ZNE Alliance

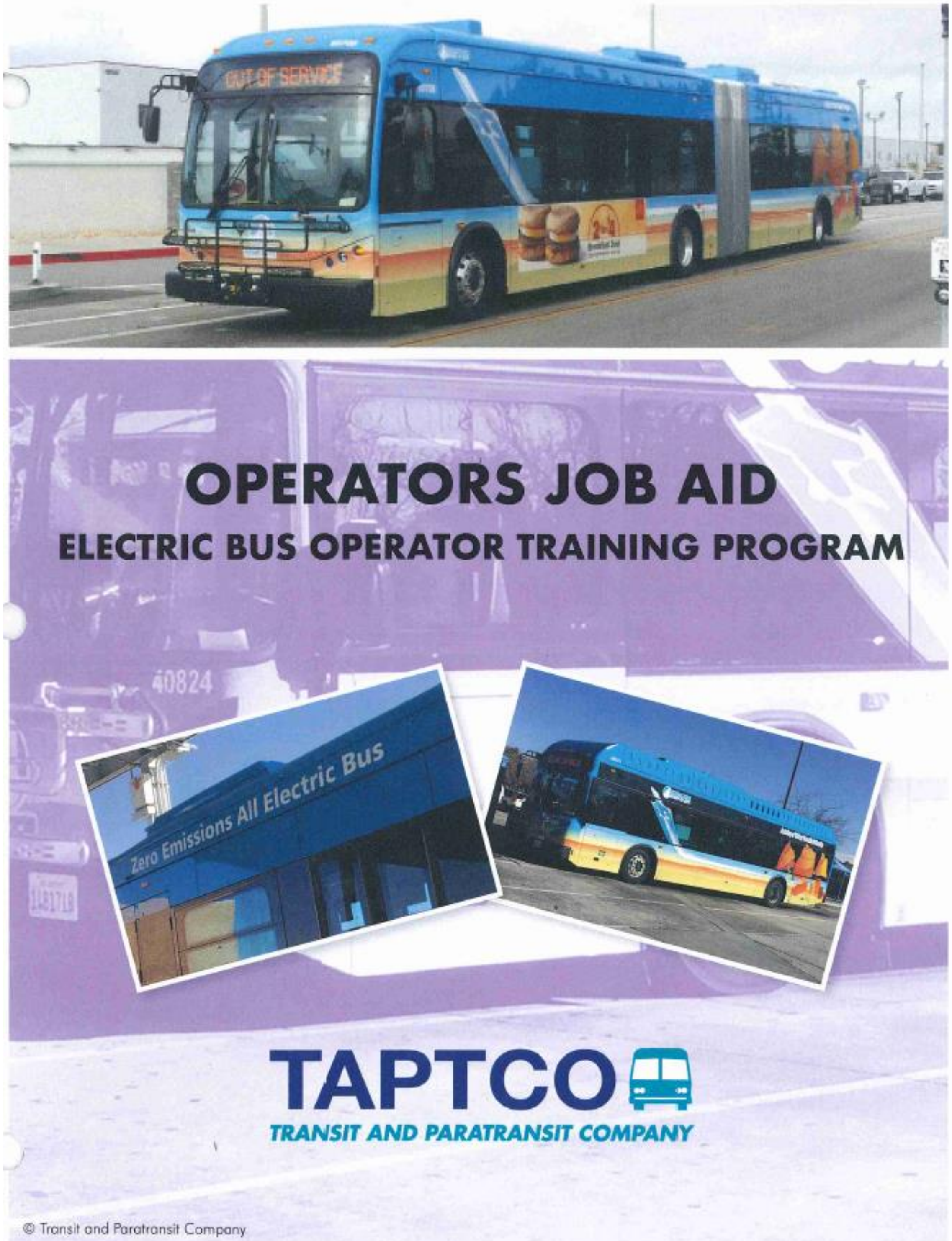
APPENDIX B: Sample Operator Efficiency Program Training Package Materials

Figure B-1: Sample Page from Training Video Script

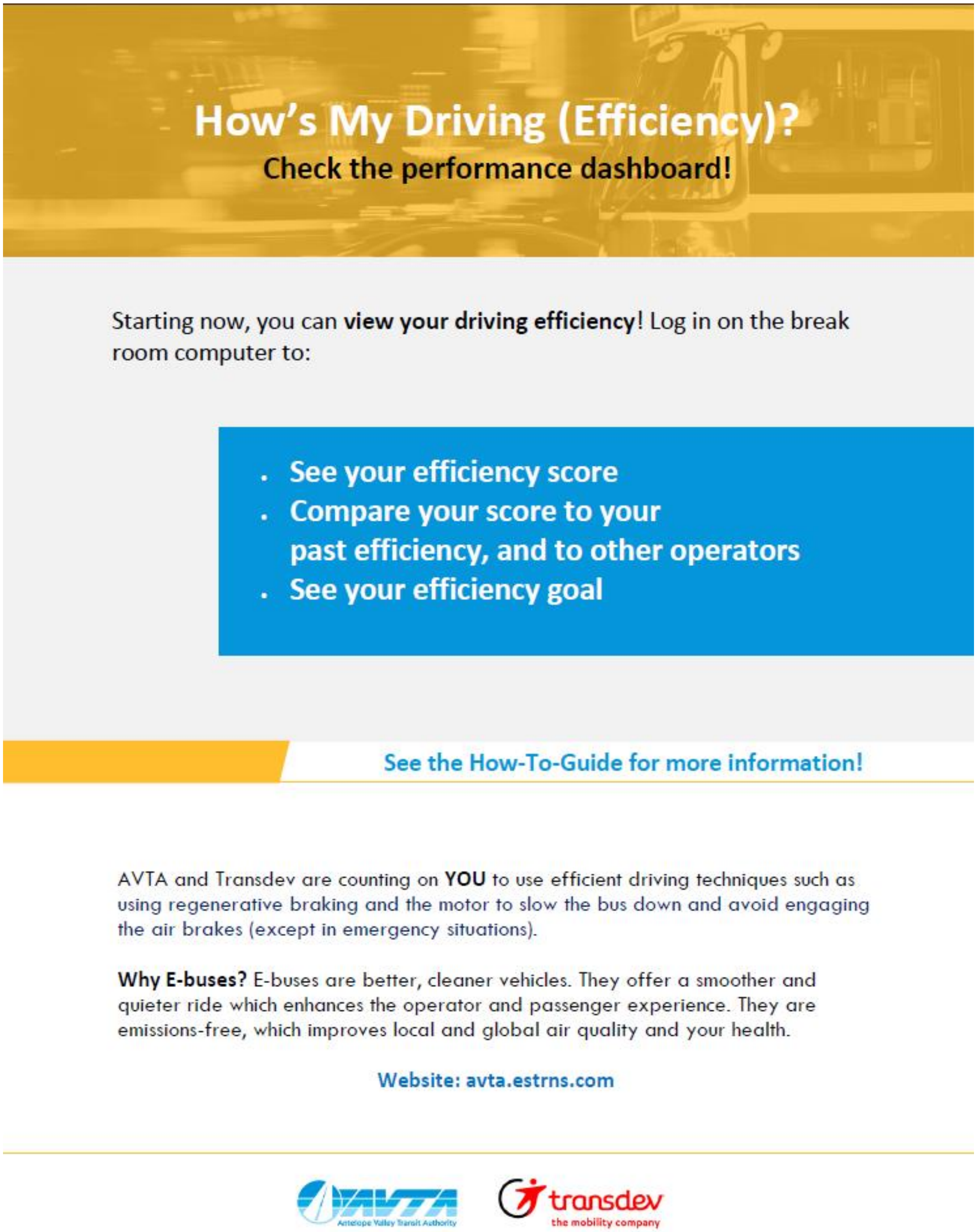
TRANSIT & PARATRANSIT COMPANY PRODUCTION VERSION: 1/2/2019
OPERATOR TRAINING COURSE – E BUSES

MOVIE 1 – INTRODUCTION & OVERVIEW OF DIFFERENT TECHNOLOGY WITH AN E BUS	
START MOVIE 1	***START MOVIE 1***
UP ON NARRATORS **SHOW E BUSES, POSSIBLY FROM DRONE** **CG E BUSES OR ELECTRIC BUSES**	NAR 1 Hi there, I'm John and this is Linda. Together we're going to present you with all the training you need to safely and efficiently operate E-buses… NAR2: That's buses which are solely powered by electricity with zero tailpipe emissions. These buses are either referred to as E-buses or electric buses.
OR B-E-B. BATTERY ELECTRIC BUSES ELECTRIC CHARGING STATION BUSES POURING OUT FUMES CG GAS DIESEL CNG	NAR1: That's right Linda, so let's get started by explaining exactly what an E-bus is. NAR2: Well, like we said, an E-bus is powered by electricity. That means there are no fossil-fuels being consumed; everything is run on batteries. NAR1: Today, most buses are powered by an internal combustion engine and fueled by Diesel, Gasoline, or Compressed Natural Gas. Now these fuels are burned to generate energy and as such they give off smoke and fumes that come out the exhaust pipes and pollute the atmosphere. Then there are the hybrids.
A BUS OPERATOR POPS INTO VIEW	**Operator Pop up** Okay, so what exactly is a hybrid and how does it differ from an E-bus?

Figure B-2: Cover Page from the Operator Study Guide



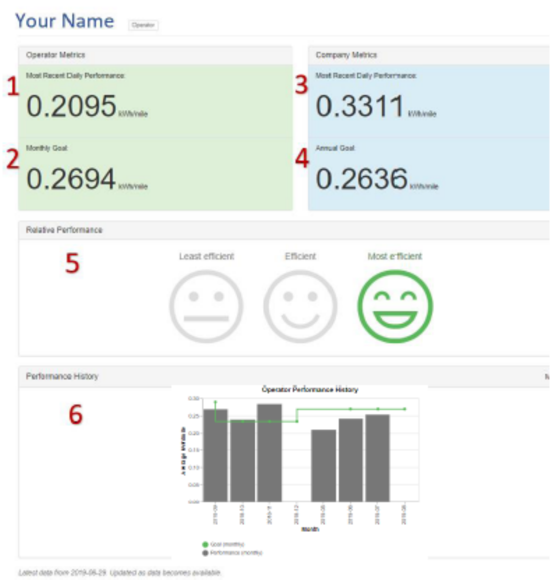
APPENDIX C: Operator Efficiency Program Operator Feedback Dashboard Materials



Source: ZNE Alliance

How-To-Guide for Reading Your Personal Efficiency Feedback

Website: avta.estrns.com
Available on the break room computer and any computer with internet access.



1. **Most Recent Daily Performance (You)**

   This is your actual driving efficiency, for the most recent day that your driving was measured. This number is determined by your driving behavior. Specifically, **smooth deceleration.** Factors out of your control (such as weather and traffic) are removed from your E-bus efficiency to get to this number.

2. **Monthly Goal**

   This is the efficiency goal for all operators for the current month. This month's goal is based off the 15 most efficient operators from last month, so it's an ambitious but achievable goal.

3. **Most Recent Daily Performance (Company)**

   This is the average daily efficiency of all operators, on the same day as your most recent daily efficiency (#1) score. You can use this number to compare how you did with how the average operator at the company did that day.

4. **Annual goal**

   This is AVTA and Transdev's goal for a 15% improvement in operators' average efficiency this year compared to last year.

5. **Relative Performance**

   These emojis are another way to quickly compare your most recent efficiency to that of other operators. The middle face lights up for operators in the middle 50% of efficiency scores, the left face lights up for operators with an efficiency score lower than 50%, and the right face lights up for operators with an efficiency score above 50%.

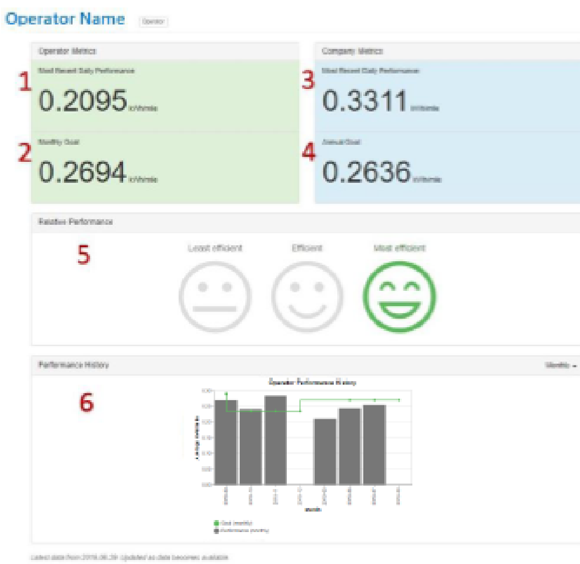
6. **Performance History**

   This chart allows you to compare your most recent efficiency score with your historical performance. The green line indicates the monthly goals (#2) and the bars indicate your past performance. You can change the timescale of this graph from Monthly to Daily, in the top right corner of this box.

Source: ZNE Alliance

Reading the Operator Feedback Dashboards

Website: avta.estrns.com
Available on the break room computer and any computer with internet access.



1. **Most Recent Daily Performance (Operator)**

   This is the operator's actual driving efficiency, for the most recent day that their driving was measured. This efficiency number is determined only by their driving behavior, specifically smooth deceleration. Factors that are out of their control (such as weather and traffic) are removed from the overall e-bus efficiency to get to this number.

2. **Monthly Goal**

   This is the efficiency goal for all operators for the current month. This month's goal is based off the average efficiency of last month's 15 most efficient operators, so it's an ambitious but achievable goal.

3. **Most Recent Daily Performance (Company)**

   This is the average daily efficiency of all operators, on the same day that the given operator's most recent daily efficiency (#1) comes from. Operators can use this number to compare how they did with how the average operator at the company did that day.

4. **Annual goal**

   This is AVTA and Transdev's goal for a 15% improvement in operators' average efficiency this year compared to last year.

5. **Relative Performance**

   These emojis are a way to quickly see how the operator's most recent efficiency compares to that of other operators. Operators in the middle 50% of efficiency scores have a regular smiley face, operators with an efficiency score lower than the middle 50% have a neutral face, and operators with an efficiency score above the middle 50% have a very smiley face.

6. **Performance History**

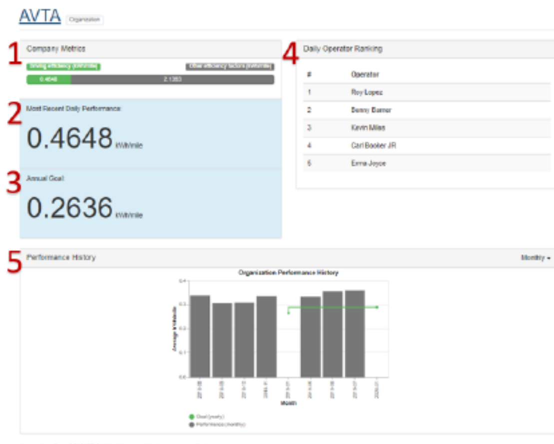
   This chart allows operators to compare their most recent efficiency score with their historical performance. The green line indicates the monthly goals (#2) and the bars indicate your past performance. You can change the timescale of this graph from Monthly to Daily or to Yearly, in the top right corner of this box.

Source: ZNE Alliance

Reading the Organization Feedback Dashboard

Website: avta.estrns.com
Available on the break room computer and any computer with internet access.
Updated August 15, 2019

All the data found here is the same as data found on the manager dashboard, except that the Operator Ranking table (#4) is on a daily basis, while the Operator Ranking table on the Manager dashboard is on a monthly basis.



1. Most Recent Daily Avg Driving Efficiency

This bar shows the most recent daily average efficiency of the E-buses and indicates which fraction of total efficiency is coming from the operator's behavior (the green portion). The total efficiency of the E-bus is determined by many factors, such as weather, traffic, and route. The green part is the operators' driving behavior contribution, specifically their deceleration behavior.

2. Most Recent Daily Performance

This is the most recent daily average efficiency of all operators.

3. Annual goal

This is AVTA and Transdev's goal for a 15% improvement in operators' average efficiency this year compared to last year

4. Daily operator Ranking

This table displays the top 5 operators based on their average efficiency score for most recent day with data available.

5. Performance History

This chart allows you to view average efficiency scores for the organization on various timelines. The green line indicates the monthly operators goals (based on the previous month's 15 most efficient drivers) and the bars indicate operators' performance. You can change the timescale of this graph from Monthly to Daily or to Yearly, in the top right corner of this box.

Source: ZNE Alliance