Valley Transportation Authority

ProspectSV

VTA Advanced Transit Bus Vehicle to Grid Integration (VGI) Project Guidance Document

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INTRODUCTION

California has established ambitious goals for zero emissions vehicles (ZEV) and renewable energy, including an expected target of 100% transit conversion to ZEVs by 2040 and 50% renewables by 2030.

Transit agencies across the state, including the Santa Clara Valley Transportation Authority (VTA), are working towards reduction transit fleet emissions according to state's goal by 2040. The VTA has a robust sustainability plan, including goals to reduce greenhouse gas emissions by 60% by 2025 and 90% by 2040. Additionally, the VTA also has goals to reduce criteria air pollutant emissions by 95% by 2040, and reduce revenue fleet energy consumption by 60% by 2040 . As a part of the agency's sustainability and emission reduction strategy, the VTA Advanced Transit Bus Vehicle to Grid Integration (VGI) Project represents a critical step in the agency's roadmap towards transit bus electrification.

Currently, electric transit buses are significantly more expensive than conventional diesel fueled or hybrid buses, have no integration with critical commercial operational tools, and conversion planning for agencies is complex and costly. In addition, renewable goals require more responsive energy services to address grid variability.

Figure 1: VTA Sustainability Plan Objectives and Targets [1]

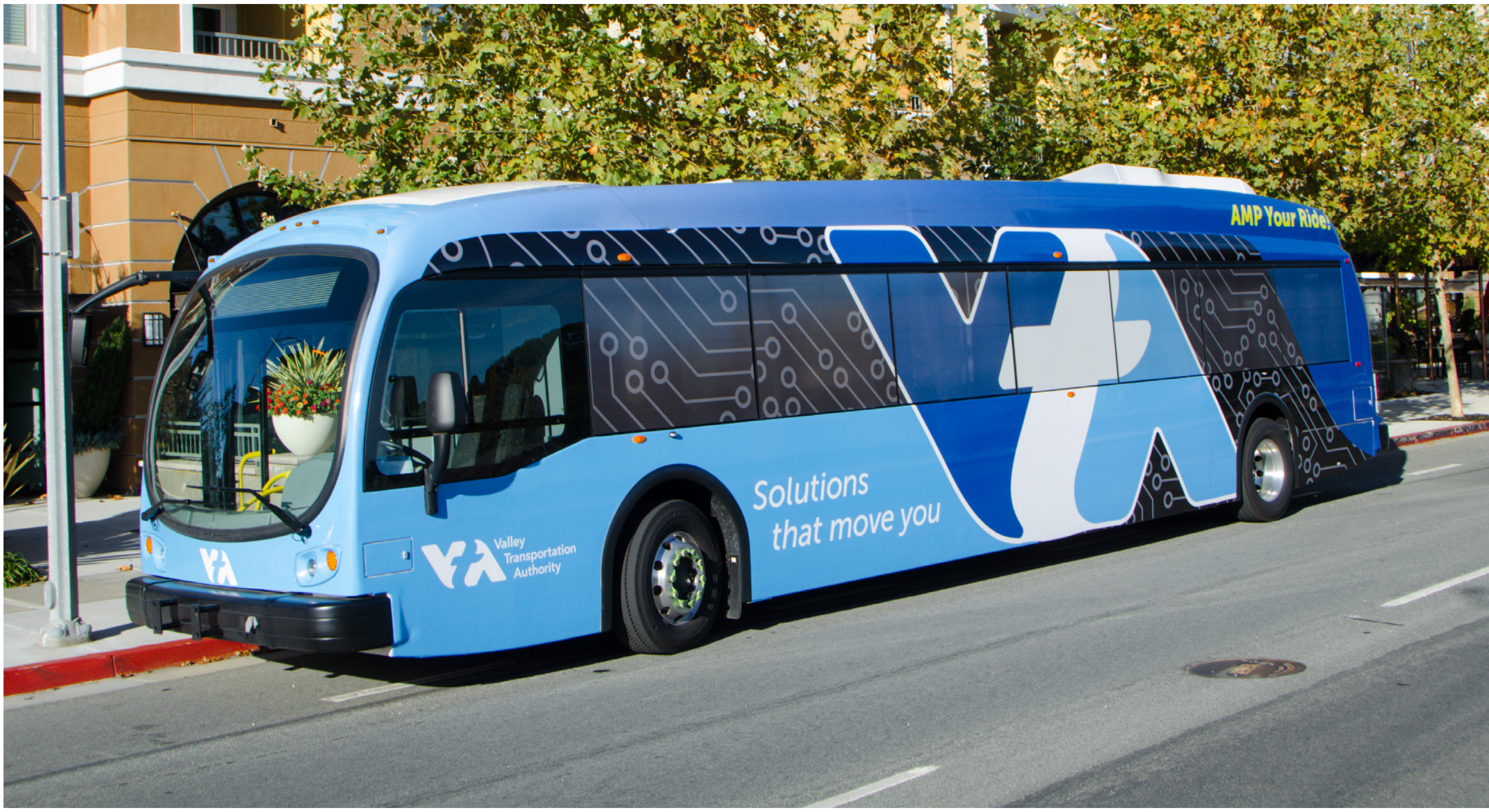
Key Performance Indicator[1]	Objective[2]	Targets[3]
Greenhouse Gas Emissions	Reduce greenhouse gas (GHG) emissions generated	• Reduce GHG emissions by 60% by FY 2025 • Reduce GHG emissions by 90% by FY 2040
Criteria Air Pollutants[4]	Reduce criteria air pollutant emissions generated	• Reduce criteria air pollutant emissions by 80% by FY 2025 • Reduce by criteria air pollutant emissions by 95% by FY 2040
Building Energy	Reduce building energy consumption	• Reduce building energy consumption by 15% by FY 2025 • Reduce building energy consumption by 40% by FY 2040
Fleet Energy	Reduce revenue fleet energy consumption	• Reduce revenue fleet energy consumption by 35% by FY 2025 • Reduce revenue fleet energy consumption by 60% by FY 2040
Water	Reduce potable water use	• Reduce potable water use by 45% by FY 2025 • Reduce potable water use by 60% by FY 2040
Waste Diverted	Increase waste diversion rate	• Increase waste diversion rate to 50% by FY 2025 • Increase waste diversion rate to 80% by FY 2040

[1] As recommended by the American Public Transportation Association (APTA).
[2] Overall goal VTA seeks to achieve.
[3] Quantitative measures to track performance over time compared to Fiscal Year (FY) 2009 base
[4] Emissions from Reactive Organic Gas, Nitrogen Oxide, Carbon Monoxide, and Particulate Mat

1 Valley Transportation Authority, Sustainability Plan (2020), 5.

The Project developed and demonstrated advanced charging controls and reduced costs through deploying an integrated, smart charging platform. The Project also informed VTA's long-term electric bus infrastructure strategy for comprehensive bus electrification. Projects such as the Advanced Transit Bus VGI Project serve as an important step towards outlining transit agencies' paths towards building a more sustainable and resilient operations.

As transit agencies and other public fleets transform their bus fleets, there is a need to understand the challenges and lessons learned to enable smart charging for electrified transit fleets. This white paper was written to assist other transit agencies as they electrify fleets and consider similar infrastructure options as the Advanced Transit Bus VGI Project. This white paper may be useful to other owner/operators of bus fleets such as school districts, public hospitals, etc., making investment decisions about fleet optimization and smart charging.



THE VTA'S GOALS FOR THE PROJECT WERE THE FOLLOWING:

1. Establish an integrated energy management system and infrastructure to prepare for electrifying their bus fleet
2. Adhere to sustainability goals/decrease emissions
3. Reduce the need for operational resources
4. Reduce fleet maintenance costs
5. Understand the operational requirements to electrify their fleet
6. Understand the software requirements to integrate a charging management platform
7. Share lessons learned with transit agencies and fleet owners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WELCOME ABOARD

PROJECT PARTNERS AND ROLES

Transit Leadership - Santa Clara Valley Transportation Authority (VTA)

As project host, the VTA team assured that the pilot project would be realistic, provide meaningful data for the operations division, and integrate all operations. VTA is an independent, special district that provides sustainable, accessible, community-focused transportation options—including bus, light rail, and paratransit services—that are innovative, environmentally responsible, and promote the region's vitality. The VTA serves 44 million riders and an estimated underserved community of half a million.

Project Management - Prospect Silicon Valley (ProspectSV)

The ProspectSV team provided strategic management, analyzed best practices and commercialization opportunities and barriers, and overall project management to meet California Energy Commission requirements. A nonprofit cleantech innovation hub, ProspectSV focuses on advanced mobility and energy solutions for urban communities.

Charger Provider and Energy Management – ChargePoint

The team at ChargePoint supplied the chargers and developed the Energy Management Platform (EMP). An electric vehicle infrastructure company, ChargePoint designs, develops, and manufactures hardware and software solutions for electric vehicles and continues to grow the world's leading and most open electric vehicle charging network.

Technical Analysis - National Renewable Energy Laboratory (NREL)

NREL provided analytics, and measurement and verification, and explored revenue-generating grid services. NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Advisor - Energy Solutions

Energy Solutions advised the project team on communications and state recommendations. Energy Solutions is focused on creating large-scale environmental impacts by providing cost-effective, market-based carbon, energy, and water management solutions.

Bus Provider - Proterra, Inc.

Proterra provided the e-buses and advised the team on technology integration. Proterra is a leader in the design and manufacture of zero-emission electric transit vehicles.

Knowledge Transfer- CALSTART

CALSTART supported knowledge transfer initiatives. CALSTART is a non-profit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions.

Sister-Project Partner - ZNE Alliance

ZNE Alliance collaborated with ProspectSV on knowledge transfer goals and activities in its role as project manager for the Energy Commission's California E-Bus to Grid Integration in Southern California.

Workforce Education - NOVAworks

NOVAworks supported workforce education initiatives. A nonprofit, federally funded employment and training agency, NOVAworks provides customer-focused workforce development services.

Fleet Management - Clever Devices

Clever Devices is a transit technology leader focused on public transportation and helped integrate its fleet management applications with the ChargePoint Energy Management Platform. These modules support vehicle pull-out/pull-in, service management, route and schedule adherence, voice and data communications, and other operations.

Operator Software – Trapeze

Trapeze is a leader in transit operations management and a long-time technology partner of the VTA, helped integrate its operator bidding, dispatch, and timekeeping software with the ChargePoint Energy Management Platform.

The VTA serves 44 million riders and an estimated underserved community of half a million.

PROJECT GOALS

Figure 2:
Integrated System Design

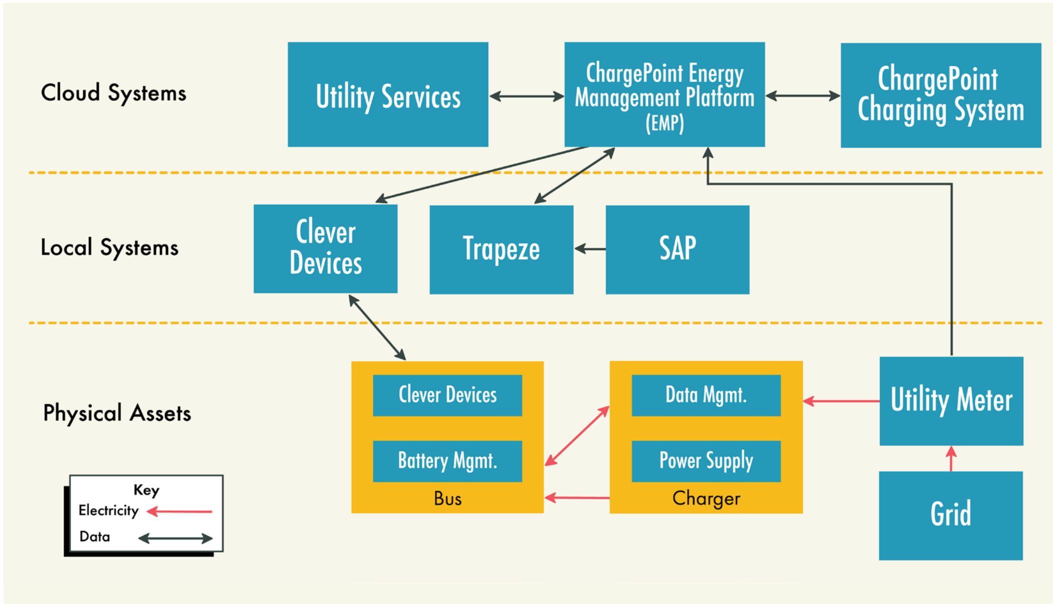
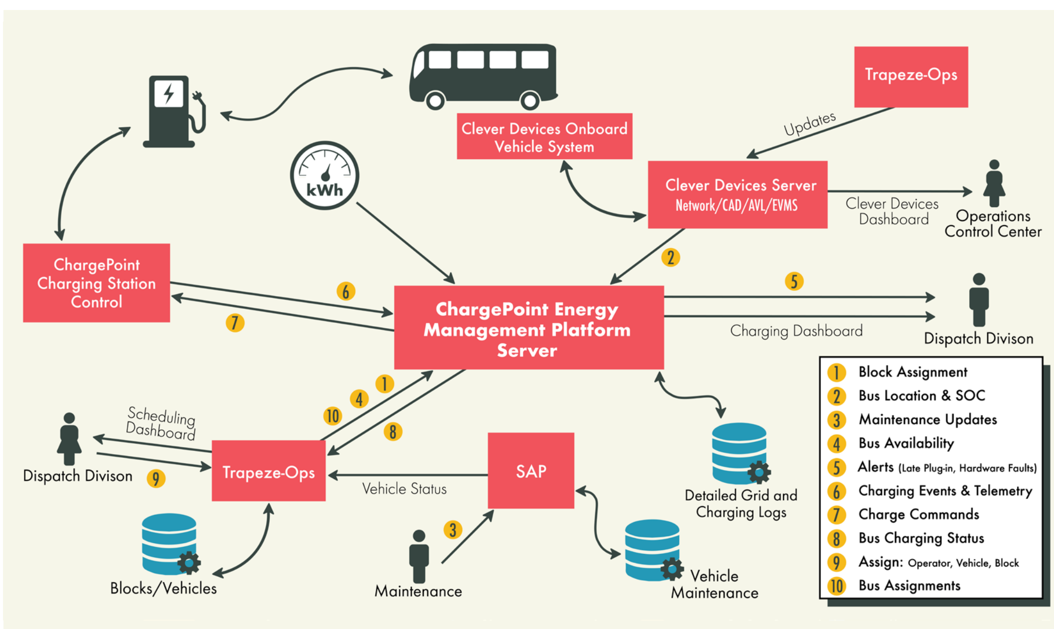


Figure 2 shows the layers of the system architecture and the flow of electricity and data between the components and layers, and Figure 3 illustrates how data flows through the infrastructure and vehicle components. Essentially, the ChargePoint Energy Management Platform (EMP) optimizes the charging schedule and minimizes the cost of charging. It controls charging through an interface with ChargePoint charging system, Clever Devices modules, and the Trapeze-Ops server, which exchange EV bus scheduling and charging-status data The ChargePoint EMP server also receives power and energy readings from a meter located at the site's utility connection.

Figure 3:
Data Flow of System Architecture



Figures 1 and 2 conceptualized by Intueor Consulting, Inc.; created by ProspectSV.

PROJECT TIMELINE

PHASE 0

DEPLOYMENT PLANNING

During Phase 0 of the project, VTA and the project team began gathering operational information and data to plan ahead for deployment, including comparing between the diesel-hybrid and electric buses, and operating with and without energy management and smart charging. VTA commissioned five Proterra Series E2 e-buses (Figure 4), five ChargePoint CP250 charging stations, and one (backup) ChargePoint CP200 charging station at the Cerone Bus yard (Figure 5); planned to operate the e-buses without automated charging or energy management; assigned e-buses only to routes that consumed 75% or less of the battery energy; and set charge time to seven hours or greater per bus at 60KW per hour.

PHASE 1

INTEGRATION SYSTEM DEPLOYMENT

In Phase 1, VTA integrated ChargePoint's Energy Management Program (EMP) with the VTA fleet and operational system, and with Clever Devices' on-board telematics on the VTA's e-buses. The EMP monitored the energy status of all five Proterra e-buses and generated charging plans that guided VTA operations staff on charging plans for each bus. VTA also expanded the number of routes the e- buses were running to continue gathering data and improve field monitoring using the additional software. All VTA-VGI system features were integrated in Phase 1, with the exception of the Trapeze-Ops bus routing system, which was delayed until Phase 2.

PHASE 2

SCALING AND ADDITIONAL FEATURES

Phase 2 goals were to extend the system capabilities, to increase smart charging benefits, prepare for future scaling, and collect enough data to demonstrate the project's value. The team integrated the Trapeze-Ops scheduling system with the EMP to provide routing, scheduling, and maintenance data to the system. They developed the interface between EMP and SAP to import vehicle and battery characteristics and vehicle availability. With these integrations completed, the team tested and validated all the EMP functions. The VTA planned to add five more buses, but delays in bus delivery meant that only three additional buses arrived before the end of Phase 2. The plan was to have all buses operate out of Cerone yard but eventually expand to the Chaboya and/or North VTA bus yards. Once the additional Proterra buses arrived, the team installed the Clever Devices EVMS system, though commissioning and troubleshooting continued into early 2021. Another goal for Phase 2 was to further minimize energy costs by having more e-buses than chargers. This would allow the buses to be charged enough to complete a block assignment, but not have to be charged fully. Bus delivery and other delays required the team to create a simulation to test and verify EMP's functions for managing the sequencing of bus charging when the bus-to-charger ratio is no longer 1 to 1.

PHASE 3

FUTURE PLANS

Phase 3 will occur after the VTA VGI project, but is a critical part of VTA's plans to advance their charger technology and expand the e-bus fleet towards full fleet electrification. VTA's goal is to eventually establish a microgrid in the Cerone bus yard to store excess energy and prepare for bus charging, emergency preparedness and providing energy back to the grid.

The team used data from over 11,000 hours of in-use VTA bus operation to compare the existing diesel-hybrid bus operation to that of the newly added Proterra e-buses, assessing both performance and emissions reduction potential.

DETERMINE THE FLEET ELECTRIFICATION OPERATION NEEDS EARLY AND METHODICALLY

In the Fall of 2017, VTA's bus fleet consisted of 461 buses in active service. All of the buses operated on diesel fuel, and half had a hybrid diesel-electric drivetrain. To address the VTA's goal of a fully electrified fleet, the project team analyzed VTA's bus fleet operation data to determine the potential for integrating e-buses into their operations. The buses used for this project, the Proterra Series E2, have batteries with 350kWh of usable energy. Assuming an electric bus efficiency of 2 kWh/mile, the maximum range of the Proterra buses is about 175 miles.[2] The team identified factors that impacted efficiency, including ambient temperature, humidity, and driver behavior, among others.

Project data has gone through a rigorous measurement and verification process led by the National Renewable Energy Laboratory (NREL). The team used data from over 11,000 hours of in-use VTA bus operation to compare the existing diesel-hybrid bus operation to that of the newly added Proterra e-buses, assessing both performance and emissions reduction potential. They also analyzed bus charging behavior and provided the VTA with a simulation tool for routes and energy to predict the impact to operation in different bus purchasing decisions. This is an important tool for transit agencies to figure out how they are going to manage their e-fleet before they purchase buses. NREL planned to estimate energy required based on the data available on the routes/blocks to influence charging decisions, and to evaluate the impact of field charging on longer operated bus routes and yard energy storage for emergency and power consumption curve flattening.

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

The results of this analysis demonstrated that the e-buses used far less fuel/energy than the hybrid buses, reflecting the efficiency of the electric powertrain technology:

The e-buses averaged 23.1 MPGe while the hybrid buses averaged 5.8 MPG, as shown in the left plot of Figure 6. The fuel efficiency analysis resulted in average efficiency of 1.8 kWh/mi for the e-buses compared with 2.25 kWh/mi for the diesel-electric hybrid bus (right plot of Figure 6). In analyzing fuel emissions, the team found hybrid buses' diesel engines produce 1.72 kg/mi CO2, 2.08 g/mi NOX, and 0.02 g/mi SOX of tailpipe emissions; the e-buses, of course, have zero tailpipe emissions, as shown in Figure 7.

Figure 6: Distribution of fuel economy (left plot) and Distribution of Daily Average Driveline Efficiency (right plot)

Provided by NREL

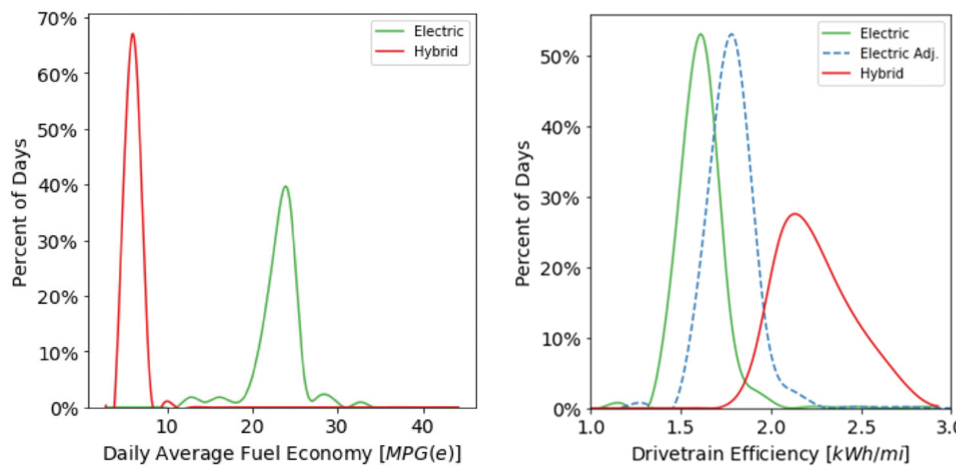
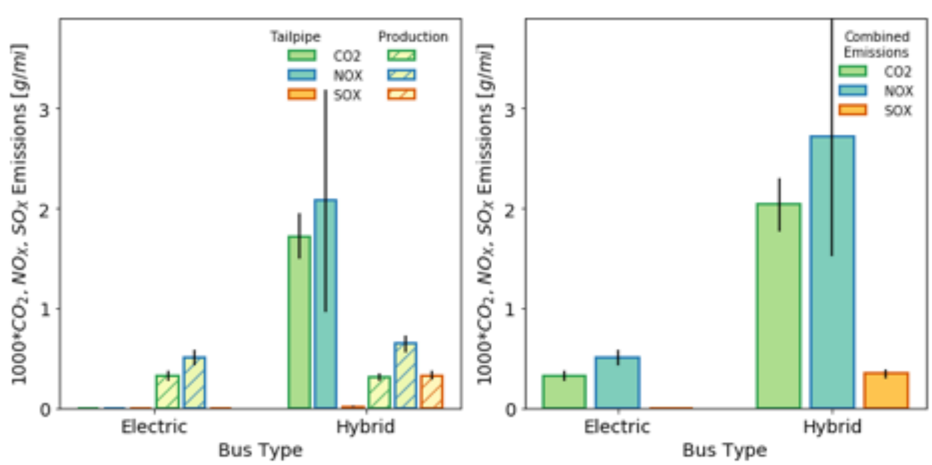


Figure 7: Emissions from Tailpipe and Production Sources (left plot) and Combined Emissions (right plot)

Provided by NREL



LESSONS LEARNED AND RECOMMENDATIONS

NREL found that e-buses could replace around 70% of VTA's transit bus fleet trips.[3] They identified benefits and drawbacks of five methods for improving these results:

1. Increase charger power
2. Purchase larger vehicle batteries
3. Deploy on-route charging
4. Purchase additional buses and swap them to enable the existing routes/blocks to be met
5. Redesign routes and blocks

NREL developed a strategy to enable full fleet electrification by increasing charger power or allowing intraday charging as an alternative for the options mentioned above. This method allowed them to analyze the impacts and trade-offs of full-fleet electrification.

Increasing charger power allows for vehicles to charge more quickly when they are available. This can enable electrification of routes where the vehicles are operating many hours a day and do not have much time to charge. Additionally, this can increase the flexibility of a fleet with smart charging and potentially reduce the number of chargers required to charge the fleet. Higher power chargers are more expensive to purchase and often slightly more expensive to install so the added benefit must outweigh the cost. Lastly, while this can enable electrification of typically long, low energy use routes, it does not enable routes that require longer range buses (i.e., larger batteries).[4]

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

4 National Renewable Energy Laboratory, VTA Fleet Electrification Impacts Assessment, Sept 2018


chargepoint
DC FAST
EV CHARGING ONLY
chargepoint
DC FAST
EV CHARGING ONLY
Combo Connector
CHAdeMO Connector
CHARGER #3
EATON
ON
OFF
ZERO EMISSION
Solutions that move you


7504
ZERO EMISSION
Solutions that move you
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Buying larger vehicle batteries allows greater range at the expense of additional cost and reduced efficiency for the bus, because of the added weight. On the other hand, larger batteries can enable electrification of high energy use routes but does not necessarily enable long, low energy use routes where charging time is a constraint. That is to say, if a transit agency's electrified bus fleet have large batteries but do not have enough charger power or time to charge, then buying a larger battery is not helpful.

NREL analyzed bus duty cycles and charging pattern scenarios. Buses charge on PV whenever possible and fluctuate their charging to complement the facility load and avoid peak energy periods and increasing demand charges. Measuring fuel cost reductions shows that duty cycles that allow for mid-day charging on PV at Cerone are the most beneficial, followed by duty cycles that start later in the day or extra early in the morning (before 05:00). The worst duty cycle for electric buses is to leave at 06:00. While operating e-buses for fewer hours a day could have a greater cost reduction per mile, it makes more sense from a total fuel cost reduction perspective to put e-buses on the longest routes possible.[5]

The VTA worked with NREL to determine the fleet operation needs early in the project. NREL's analysis proved essential to understanding the project needs. However, as with any agency, the VTA will need to continually review new technologies to identify the best available options for achieving 100% electrification. With 350 kWh of usable energy, the current bus technology, does not support the distance required for all the current blocks. For example, a newer 440 kWh battery bus will run 220 miles, compared with VTA's current buses' 170 miles. And the next generation of buses promises a 1 MW battery without increasing the bus weight. Alternatively, the agency may consider hydrogen buses to achieve the last 20% of electrification.

With 350 kWh of usable energy, the current bus technology, does not support the distance required for all the current blocks. For example:

A newer 440 kWh battery bus will run 220 miles...

compared with VTA's current buses' 170 miles.

5 National Renewable Energy Laboratory, Operating Scenarios Document, Aug 2018

The team also compared the cost of energy consumed by the hybrid and e-buses over 2020. As Table 1 shows, there was no significant difference in energy costs for operating the new electric buses. As a result, the expected savings in maintenance costs over the life of the e-buses will not be offset by increased energy costs to operate the buses. These savings will be calculated once the e-buses are no longer under warranty and the VTA performs maintenance in-house.

Comparing Cost of Energy

	Diesel-Electric Hybrid	Electric Bus
Total miles travelled in 2020	2,251,247	56,778
Number of buses	56	5
Distance/bus	40,201	56,778
Average miles/fuel	5.9 MPG	1.85kWh/mile
Quantity of energy used	380249 gallons	105039.3 k/Wh
Energy cost	$2.33/gallon	0.221/kWh
Cost/mile/bus	0.3935	0.4088

DEVELOP A ROBUST DRIVER TRAINING PROGRAM

Driver training was a critical part of VTA's e-bus performance efficiency. Drivers were taught to use regenerative braking, control acceleration, and manage HVAC usage. Training included other members of the VTA staff as well. For example, additional training of the yard staff on using the EMP Dashboard helped synchronize EMP charging plans with actual charging activity. An agency must train all their staff on each facet of the fleet's VGI system: Drivers, dispatchers, maintenance staff, and management need to know how the VGI system works, how to operate it, and how it may have changed standard operating procedures.

As the VTA experience shows, training is an ongoing process reflecting the dynamics of a complex, scaling-up system. Training directly impacts bus performance, smart charging, efficiency, and costs. Training is also part of a positive feedback loop: data collection and analysis of bus performance create new insights that are integrated into the training; driver results are benchmarked for further improvement and monitoring. Other ideas for agencies include partnering with unions to run an apprenticeship training program, as well as partnering with technology providers to include automated system feedback to drivers, trainers, and operations management on individual drivers' performance and impact on energy efficiency.

BE AWARE OF TECHNOLOGICAL ADVANCEMENTS AND CHARGER INFRASTRUCTURE REQUIREMENTS

It is important that agencies understand the extent of electrical and charger infrastructure upgrades that might be necessary to support bus electrification, as well as future technological advancements in charging infrastructure that will impact their operations.

The VTA examined two charging strategies:

Immediate Charging

- the bus is charged as soon as it arrives
- charging produces a higher maximum value as well as extended periods of time unused equipment

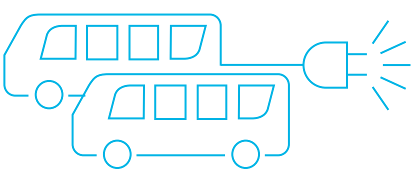
Smart Charging

- the bus is charged and uses a controller to determine the best times to charge to achieve the lowest operating cost
- smooths out operation and effectively reduces peak power consumption between 31% and 65%
- lower demand charges and costs for system upgrades

Deploying and integrating new technology impacted nearly every aspect of the project. While agencies need to build in extra time for commissioning, their teams must also be flexible, willing to troubleshoot, solve problems collaboratively, and create workarounds.

On-route charging involves using short periods of bus dwell time to quickly charge the bus. It extends range or allows for smaller bus batteries which are typically less costly, however there are increased infrastructure costs and operational challenges. First, the chargers need to be high power, which often results in higher equipment and installation costs than a lower powered depot charger. Second, because of the high power, short duration electricity consumption profile, the electricity cost to operate on-route chargers is typically higher than depot charging with more time available to shift and spread the charging load.

In the VTA operation, each bus is assigned to a "block" that includes multiple routes of timed runs; buses can complete more than one block in a day, and multiple buses are needed to complete all the runs of each route. By analyzing the blocks, the team collected typical bus operations and, most importantly, the number and types of blocks serviceable by e-buses. Specifically, the average speed and range of a block determined whether the battery would be sufficient to power a bus for the entire block, or a combination of blocks, assigned for a day. Initial findings showed that battery electric buses could accommodate the majority of current VTA blocks (including a 25% buffer reduced this). However, there were many routes less than 100 miles that were currently available, and VTA discussed constructing a new set of blocks that could maximize e-buses benefits and usage.



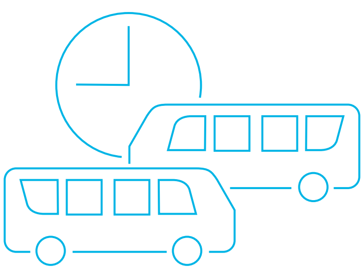
Charging needs are unpredictable. The team was surprised to learn that a bus's energy consumption varied widely over a driving block and using an EMP to give 'just enough charge' based on mileage in a block wasn't possible. Driver's habits, daily temperature, traffic and other factors wouldn't allow a perfect strategy. Unfortunately, VTA personnel feared depleting battery resources and a full-charge strategy became the norm. With more data, the VTA is confident that the EMP could absorb these variations.

Additionally, ever since the project started, charger technology has dramatically changed. If the VTA started today, it would likely install only one or two of the newest chargers equipped with multiple dispensers rather than purchasing five 62.5 kW chargers. For example, in the latest designs, a 1.5 MW charger can distribute power to twenty vehicles, increasing operational flexibility and lowering the charger installation cost. Chargers, like the buses, are a capital investment. For reference, the VTA spent $1.5 million for the purchase and installation of five chargers. Deploying and integrating new technology impacted nearly every aspect of the project. **While agencies need to build in extra time for commissioning, their teams must also be flexible, willing to troubleshoot, solve problems collaboratively, and create workarounds.**

TAKE INTO ACCOUNT BOTH THE VALUE AND COMPLEXITY OF BI-DIRECTIONAL SERVICES

The VTA readily acknowledges it did not appreciate the scope and complexity of enabling grid services. In the initial project scope, VTA planned to develop and demonstrate controlled, bi-directional energy transfer between electric transit bus batteries and end-loads, and grid-connected facilities. In the VTA's assessment of bi-directional energy transfer they identified that the transit buses purchased in 2018 and charging platforms installed in 2019 did not support bi-directional energy transfer and modifications to this system were too costly. In late 2020, bus manufacturers and charging infrastructure started addressing bi-directional energy transfer. The manufacturer can convert the latest generation of buses for bidirectional flow, but customers must specify this. Likewise, the latest 1.5 MW chargers are capable of bidirectional flow. However, at the beginning of the project, the technology was not ready for bidirectional grid services.

Furthermore, the project team learned that the current market for grid services is not well suited for transit agency participation. Generally, with the rate schedule being the most profitable if energy can be directed back into the grid in daytime buses are unavailable due to being in transit service, and even if buses are not servicing daytime routes engaging in grid services are available pay too little to make it a practical value proposition.



To summarize, **buses are typically not charging when grid services are available, and when they are charging, the value for grid services is too low to be worth the participation.**

For Example:

80 to 90% of the VTA transit vehicle fleet was in operation with pull out times between 4:00 am to 6:00 am and buses returning after 6:00 pm.

Returning transit buses have only a 15% to 25% state of charge.

The majority of the bus fleet is being charged from 9:00 pm to 4:00 am, therefore when the grid would need stored energy to help supplement the load, transit buses are not available to provide this.

Therefore, the NREL and VTA assessment showed that bi-directional energy transfer would be a poor return on investment for the VTA and other transit agencies with similar operation schedules .

Despite the VTA's experience, bi-directional grid services has the potential to provide tremendous value, and there are multiple ways that agencies can prepare their site for grid service capability. For example, solar panels can provide energy storage on-site. The solar panels in VTA's Cerone Yard generate 960 kW, which could power 21 e-buses. It's also possible the stored energy could be used to source power for grid services since the timing of services would not be an issue. The cost and time required to add energy storage and build a microgrid to test and validate the value of storing this solar energy for charging the buses at night, exceeds the scope of this grant funded project The VTA plans to explore these opportunities in the next steps in its electrification effort.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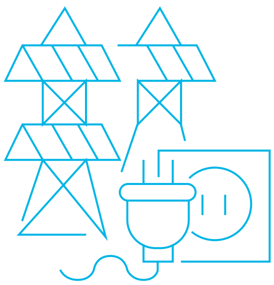
APPLY FORWARD THINKING IN INFRASTRUCTURE PLANNING AND BI-DIRECTIONAL GRID SERVICES DEPLOYMENT

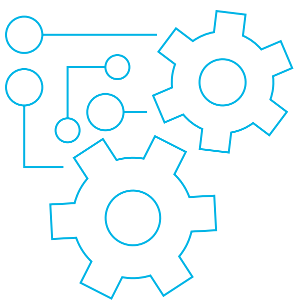


It is important for agencies to understand that infrastructure upgrades are initiated by an increase in the level of demand at a given facility. **In order to support a higher level of demand, the utility will need to understand the impact on the surrounding grid.** When discussing the level of electrical upgrades with the utility it is important to keep this in mind to determine the maximum amount of demand. Without this knowledge the utilities could default to a worst-case scenario where all vehicles are charged at once and make the transit agency upgrade more than is necessary. Essentially, communication with the utility is important to help minimize the required upgrade and resulting costs.

Agencies can look into LCFS credits, which represent revenue by offsetting diesel emissions of heavy-duty buses. Compared to the diesel-hybrid scenario, battery electric bus scenarios have higher capital costs, charger costs, and electricity costs, but reduce the diesel fuel costs, fixed operation, and maintenance costs, and also increase revenue from LCFS credits. The LCFS credit plays an important role in offsetting the additional capital cost.

Additionally, changing driving patterns for e-buses could substantially change the opportunity for providing grid services. Returning buses to the depot or transit hub to charge for two to four hours during the day would increase the potential for using more low-cost solar power and extracting better value from retail DR programs and wholesale market participation. Also, as ridership decreases in the evening, the ancillary service prices increase. If electric buses were to arrive at 17:00 or 18:00 and were immediately connected to chargers, they could support the grid as the load falls after the evening peak electricity load. The potential value must be balanced with the utility rate, particularly considering the time-of-use bins to avoid on-peak costs.

Grid services can also provide value beyond the typical benefits. In the San Francisco Bay Area, transit buses have an emergency response role in evacuating and transporting residents after earthquakes, fires, and other natural disasters. Some have suggested that transit e-buses could also generate back-up power for hospitals. But given transit buses' primary transportation role in emergencies, policymakers should consider enlisting electric school buses to generate emergency power. School buses run just 20-25% of the miles a transit bus runs, so they don't serve the same role as transit buses in an emergency. If electric school buses were equipped with a mobile charger to convert voltage for the hospitals, they could perform this power back-up role.



PRIORITIZE EARLY PLANNING AND PARTNER SELECTION FOR AN INTEGRATED SOFTWARE SYSTEM

It is essential that agencies plan early to monitor vehicle operations and charging in real time. **This allows for agencies to get alerts if there is a communication error with a bus or charger and troubleshoot accordingly.** Also, this enables a transition to automatically monitor the charging process and adjust automatically in the future. This is crucial for decreasing the need for operational and staff capacity, and also reduces manpower for any other operational or maintenance on the buses, such as cleaning, charging schedules, etc.

Transit agencies need to identify collaborators willing to invest in electrification projects because they believe establishing a new clean transportation industry will deliver long-term benefits. In the VTA's case, integration was made more complex by having to interface with multiple vendors' products and troubleshoot communications with new hardware and software technologies. While the team adopted existing industry standards, there were no communications standards for an energy management platform application, which didn't exist before this project. Agencies should keep this in mind when pursuing vendors to partner on their project.

COMMUNICATE PROJECT LEARNINGS TO PROMOTE EDUCATION AND CREATE ECOSYSTEM READINESS

It is important that learned project experiences are shared with others that may be pursuing similar projects or activities. **VTA coordinated with project partners on events to share project findings and lessons learned with relevant stakeholders, technical advisory committee members, and the general public.** VTA also produced a video highlighting the VGI Project for marketing and educational purposes. This was included in VGI marketing materials and shown at multiple events to students and stakeholders. VTA collaborated these activities with project partners NOVAworks and CALSTART, to help students gain knowledge for the workforce.

Photograph by ProspectSV staff

Looking forward, agencies and technology companies have a role in helping vocational training and higher education institutions develop a workforce to support the industry. Organizations can transfer critical knowledge about designing and using the technologies they create through internships and collaborations with educators. Also, policymakers should consider the importance of developing a talent pipeline to support a new clean transportation industry. Currently, educational systems separate the key disciplines into silos: software engineering, environmental sciences, automotive technology, and robotics. But the industry will need workers skilled across these domains. The required workforce will offer employers a hybrid skillset integrating highly technical knowledge, systems thinking, and an aptitude for life-long learning.

A PATH TO SCALABILITY

The VTA is planning to electrify their entire bus fleet in the near future. From the pilot project findings, the VTA has determined that the path to scalability requires three essential factors: Infrastructure, Technology Planning, and Operations.

INFRASTRUCTURE

Normally transit agencies are not power infrastructure experts. It is essential for agencies to leverage the utility provider and power industry partners who are experienced in deploying primary grid connections, high-capacity charging stations, solar, microgrid systems, energy storage, and energy management control systems. A multi-megawatt grid connection needed to charge a 50 plus electric bus fleet can run into major upgrades in the utility transmission system and require new power infrastructure from the transmission line to your megawatt chargers. From the VTA's fleet deployment assessment, leveraging the latest megawatt chargers with 20 plus power dispensers per charger and an energy management system provides the maximum charging performance flexibility and reduces the cost per dispenser, allowing the agency to have a one-to-one ratio of buses to dispenser (Figure 10).

Figure 10: Proterra 1.5 MW Chargers (left) and 20 Proterra Charger Dispensers per charger (right)

LESSONS LEARNED AND RECOMMENDATIONS

Depending on the agency's utility tariff and energy cost in the late afternoon and evening, solar energy generation with a microgrid control system and energy storage can dramatically impact the electric cost and reduce peak demand charges (Figure 11). In the Northern California area, the VTA has seen over a 25% savings in energy cost. This also gives the transit agency power resiliency by allowing the solar to charge the fixed energy storage even if the power grid is down, and therefore buses can be charged off the solar and energy storage.

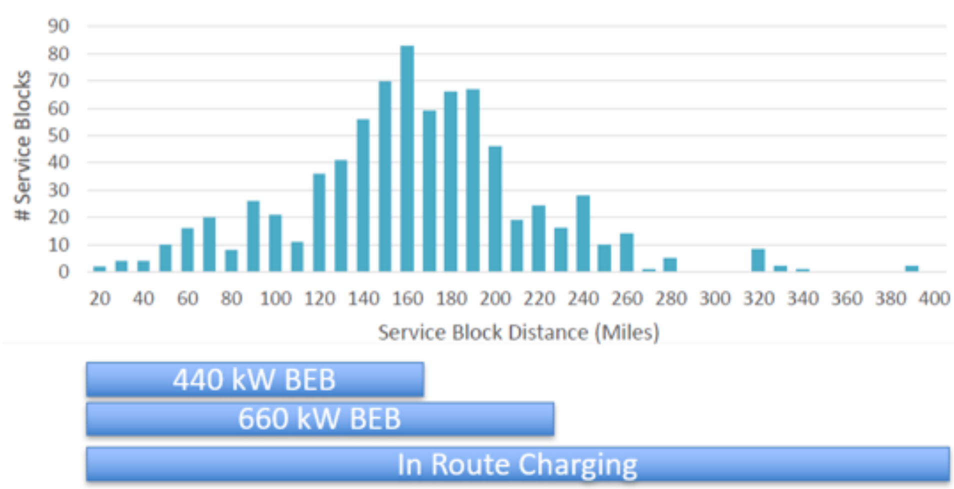
Figure 11: Overhead bus charging and solar canopy (top left), 1.56 MW installed solar (top right), Microgrid Control (bottom left), and 1MW/4MWh Battery Energy Storage (botom right)

PLANNING AND TECHNOLOGY

Currently, Battery Electric Bus (BEB) technology does not offer unlimited range and thus is a key parameter that must be managed. As mentioned previously, bus manufacturers or non-profits such as the National Renewable Energy Lab (NREL) have built simulation tools to help evaluate an agency's routes and blocks. A comprehensive assessment helps to identify the impact BEB efficiency and battery size would have and guides an agency's BEB purchasing. A higher efficiency bus with experienced drivers can make a significant impact in the miles per KWH. In addition, a BEB with a medium size battery of 440 KWH for shorter mile blocks of 180 miles between charges covers much less distance than a larger 660 KWH battery BEB covering 230-mile blocks in nominal weather with an average passenger load of 30. (Figure 12). The VTA plans to leverage more efficient and larger battery buses in the future to increase the distance the buses can travel.

Transit agencies operating in climates with extreme temperatures need to take air conditioning and electric heating into account - they can dramatically impact the vehicle range. For example, on a hot 88 deg. F day with a passenger load of 30, the bus on average will consume 1.8 kW/mile. Conversely, on an average 72 deg. F day with the same 30 passengers, the bus will consume 1.5 kW/mile. Temperature has a huge impact on the KW per mile even with the same passenger load. The energy management platform and the fleet monitoring software designed to support BEBs will make managing these parameters much easier and give the agency more confidence in operating a large fleet of BEBs.

Figure 12: Battery Electric Buses and Service Block Distance Capability



Operations

Operating electric buses require changes to a fleet's operations simply due to the differences between electric bus operation, time necessary in charging, and maintenance compared with diesel or Compressed Natural Gas (CNG) buses. Transit agencies must be flexible and open to change business processes, especially as they scale-up the number of BEBs in their fleet. VTA needed to modify operating procedures especially around giving BEBs priority through cleaning and maintenance. The energy management software can help manage the BEBs while in the yard.

A critical component to improve operational efficiency for a BEB fleet is bus driver efficiency, measured in KWH consumed per mile. A BEB fleet will find that bus driver efficiency has an additional layer of importance due to the interaction of vehicle range and BEB efficiency. Fleets should encourage, train, and incentivize their drivers to maintain driving efficiencies at reasonably high levels. The BEB vehicle monitoring software provides the driver and operations with a dashboard to track driver performance by route, by time, and climate. The VTA has also seen a 3 to 5 KWH per mile difference when comparing an untrained driver versus a driver who has completed BEB training. Giving the drivers efficiency metrics and comprehensive driver training are necessary to achieve an effective KWH per mile.

The VTA hopes that other Transit Agencies find these recommendations helpful, and can use the VTA's learnings from this project as a springboard to electrify their own bus fleets.

For questions or comments on the Guidance Document, please email ProspectSV at **hello@prospectsv.org**