REV Demonstration Project:
Electric School Bus V2G
Q1 2022 Quarterly Progress Report

Dated: May 2, 2022

Contents

1.0 EXECUTIVE SUMMARY

Consolidated Edison Company of New York, Inc. ("Con Edison" or the "Company") submits this final quarterly report on the progress and completion of the Electric School Bus V2G REV Demonstration Project (the "Project") it implemented as part of the Reforming the Energy Vision ("REV") proceeding, as required by the *Order Adopting Regulatory Policy Framework and Implementation Plan*, issued by the New York State Public Service Commission ("Commission") on February 26, 2015.[1] Budget information has been filed confidentially with the Commission.

As the final report on the Project, this report will cover overall Project findings from its three years of operations and recommendations based on those findings.

1.1. Project Background

On June 8, 2018, Con Edison submitted the Project for approval by Department of Public Service Staff ("DPS Staff"). On June 20, 2018, DPS Staff approved the Project. Con Edison filed an implementation plan for the Project with the Commission on November 13, 2018[2]. The Project is the first deployment of five new, full-sized electric school buses in New York State. It is also the first to use school buses to perform "vehicle-to-grid" ("V2G") charging, when operators discharge the the buses' batteries to deliver energy to the grid. The electric buses deployed through this Project serve the school district of White Plains and are operated by National Express.

Three of the buses were used for V2G discharge analysis, and the remaining two buses were desginated as "control" buses and not used for V2G. All five buses were used for regular pickup and delivery operations. The Project activities included the operation of the buses and the new V2G technology. The buses have been operating since 2018. The site was authorized to export energy to the grid in October 2020 when it began V2G operations. Energy export continued throughout 2021. National Express assumed control of the buses on March 31, 2022 and will continue to use the buses for student transportation.

With the close of the Project in 2021, Con Edison worked with Project partners to analyze data gathered over the course of the Project and establish lessons learned. In a March 29, 2022 meeting, the Company shared its findings with stakeholders.[3]

[1] Case 14-M-0101*, Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision*, Order Adopting Regulatory Policy Framework and Implementation Plan (issued February 26, 2015).
[2] Case 14-M-0101*, Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision*, REV Demonstration Project Implementation Plan Electric School Bus V2G (filed November 13, 2018).
[3] *See,* Appendix D: Project Analysis & Results.

1.2. Project Overview

Electric School Bus V2G REV Demo Project

The **School Bus V2G** (vehicle-to-grid) demonstration project ("Project") examined the technical and operational viability of using school buses as both a grid resource and transportation asset. Key tests included assessing whether electric school buses function well for transportation purposes and are reliable as grid assets, and determining whether or not using them as grid assets causes excessive wear and tear on the equipment.

The buses began transportation services in Sept. 2018. The Project team completed Con Edison's interconnection process in 2020 and began V2G operations *i.e.*, exporting energy to the grid. V2G concluded at the end of 2021.

Project Start Date: June 2018
Project End Date: December 2021
Budget: $1.08M
Q1 2022 Spend: *Filed Confidentially*
Cumulative Spend: *Filed Confidentially*

Project Planning Completed → **Phase I: Operations & Analysis** Completed → **Phase II: Design & Construction of Charging & V2G** Completed → **Phase III: V2G Operations** Completed

Lessons Learned: Customers (bus operator)

- Reliable operation of the buses helped prove the technology to the bus owner/operators including the maintenance staff and drivers who used the buses
- V2G complicated bus operation and required maintenance staff to troubleshoot with technical experts

Lessons Learned: Market Partner

- Custom-built V2G required high engagement from technology providers for success
- Operators needed technical experts and service providers to assist with analysis of transportation use, electrical infrastructure, and V2G integration
- V2G impacts on battery, *i.e.*, use outside the core function of transport, had business

Application of Lessons Learned: Lessons learned can inform the work of transportation electrification stakeholders (i.e. manufacturers, operators, and regulators) as they operationalize V2G and reduce deployment costs. The Company is willing to share lessons learned as requested.

Recent Milestones: Project findings and data analysis were completed in Q1 2022.

2.0 PROJECT FINDINGS

2.1 Activities Overview and Updates

Con Edison worked with Project partners to analyze data collected over the course of the Project, identify lessons learned, and share these findings with stakeholders.

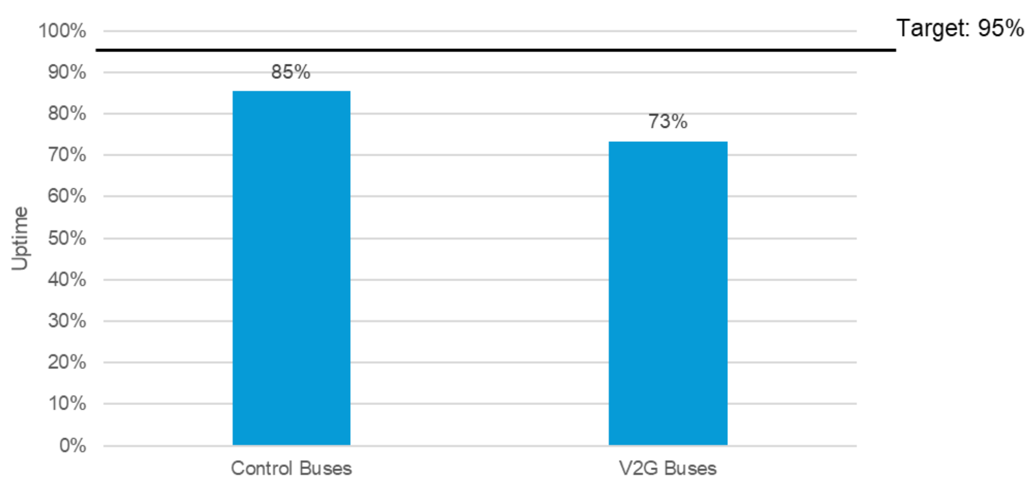
2.2 Electric School Bus Operations

I. Results

Demonstration Project management conducted a quarterly survey of White Plains bus operators and support staff. Respondents reported high driver satisfaction throughout the course of the Project. Operaters reported positive feedback on vehicle performance and driving experience and a healthier internal bus environment with no exhaust fumes, a quieter cabin, and a wider driver window and viewing periphery. Operators also reported that the buses attracted attention from the White Plains community and increased support for EVs in the region.

Two issues related to bus operations arose throughout the Project. The first issue was that the EV charging process initially felt complex to operators. To address this concern, the Project team conducted operator training in 2019 and 2021 to educate drivers on vehicle operations and charging process. The second issue was that the buses had insufficient cabin heating in the winter. To resolve the insufficient heating, diesel auxiliary heaters were installed on all five buses. The Project team noted this as an area for future developments where battery technology or other technology enhancements could fully eliminate the need for any fossil fuels to operate busses in colder climates in northern regions.

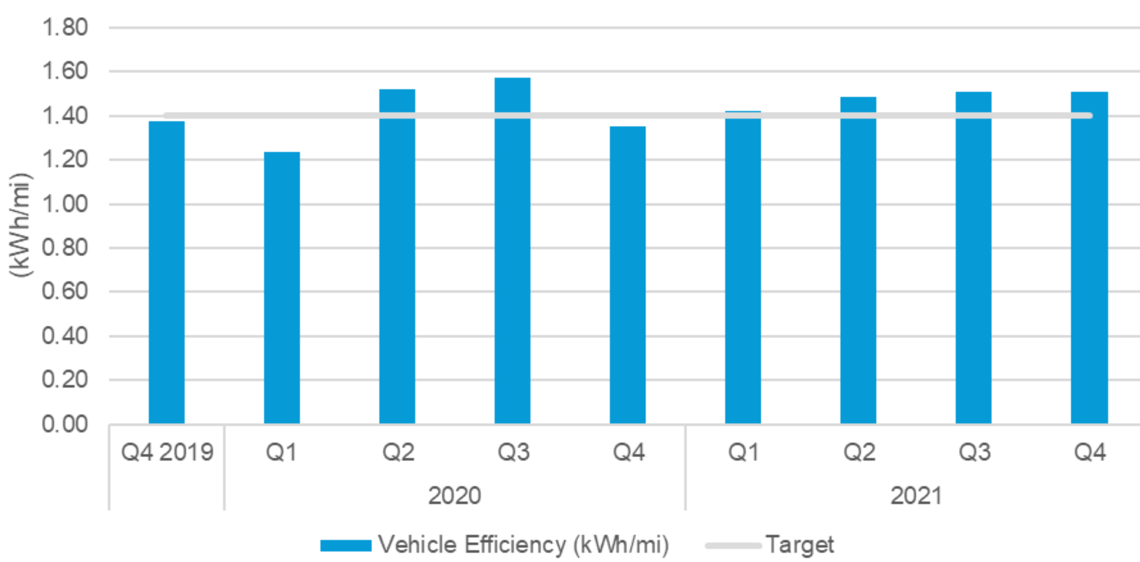
Figure 1: Control and V2G Bus Uptime. Control buses are electric buses that are not used for V2G operations. The 95% Target represents the industry expectation for diesel bus uptime.



In planning the Project, Con Edison hypothesized that electric school buses would operate as well as diesel buses. To assess this hypothesis, the Project team measured vehicle uptime as the percentage of scheduled hours when the bus was able to operate[4] and benchmarked against industry expectation for a diesel bus. Typical issues that decreased uptime included problems with bus components such as wiring and sockets. Although the uptime for the electric buses in this Project fell short of the industry expectation for uptime for a diesel bus (Figure 1), next-generation vehicles and supply chain development for replacement parts are expected to close this gap.

Electric buses that were used for V2G operations experienced lower uptime than Control buses that were not used for V2G operations. During this time, buses were taken out of service to test software, diagnose integration issues, replace parts or make other fixes. V2G bus uptime can improve with technology maturation. These issues will be discussed further below in the V2G Operations section.

Figure 2. Average Quarterly Electric Bus Fuel Efficiency.



The Project team also measured vehicle fuel efficiency in energy use per mile. This metric is important to operators because it provides support in planning bus routes during all seasons based on expected range of the bus. Because there are energy losses during charging, this planning requires scaling up the expected energy needed for a route by about 15% to account for those losses. For example, if a bus needs 60 kWh for its daily duty cycle then the operator should plan to purchase buses equipped with battery capacities of 70 kWh.

---

[4] EV bus downtime was recorded in maintenance service reports and does not include scheduled maintenance and inspections.

Energy use per mile averaged about 1.4 kWh/mi throughout the Project (Figure 2), meeting the manufacturer specification for vehicle fuel efficiency. This number was higher during warmer months when operators used the EV battery to power vehicle cabin air conditioning in addition to other bus operations.

II. Recommendations

Based on the results of electric school bus operations in White Plains, the Project team recommends:

1) Recurring operator training to inform staff of emerging issues and train new staff to operate EV buses.
2) Assignment of an on-site EV fleet manager to monitor vehicle performance, coordinate maintenance services, conduct operator training, and expedite troubleshooting and maintenance.
3) Operators should use fuel efficiency to plan charging behavior that meets route requirements at least cost.

2.3 V2G Operations

I. Results

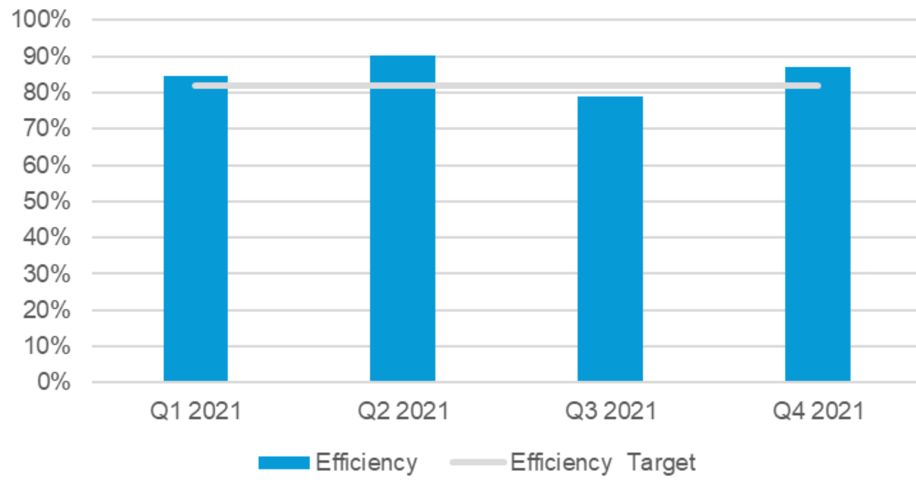
To understand the performance of V2G operations, Con Edison measured V2G efficiency and reliability.

The Company calculated efficiency of the energy discharged from the battery to the electric vehicle supply equipment ("EVSE) as the ratio of energy discharged measured at the EVSE to the energy discharged as measured at the battery. Observed losses from the battery to the EVSE were due to DC-AC conversion, current draw for other bus components (parasitic vehicle loads), and line losses.

The Company expected to see 18% losses[5], or 82% efficiency, across the Project. The Company observed an average of 15% losses over the period across all three V2G buses, exceeding expectations.

[5] Efficiency target is updated in this report to show that partners assume 18% energy losses during a V2G discharge event. *See*, "Apostolaki-Iosifidou, Elpiniki, et al. *Measurement of power loss during electric vehicle charging and discharging.* Energy. Vol.127 pgs. 730 – 742. March 2017.

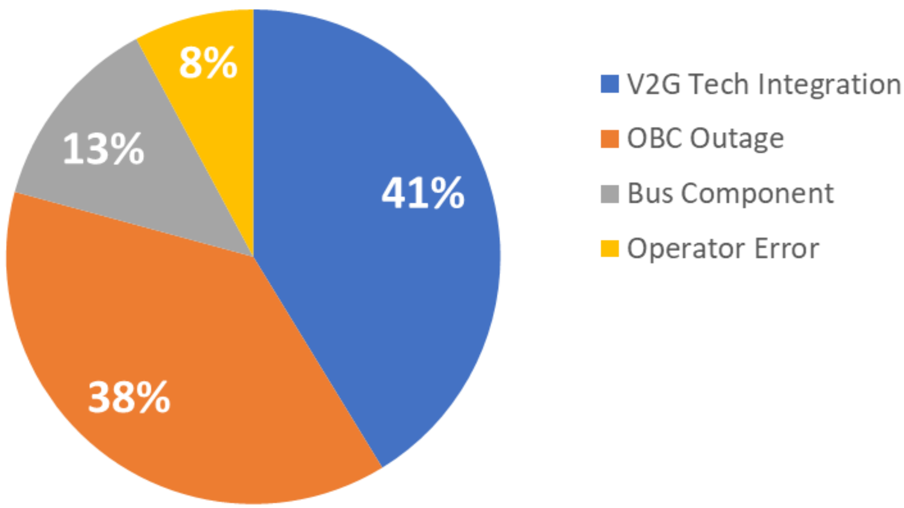
Figure 3: V2G Energy Transfer Efficiency.



The Company defined V2G reliability as a bus's availability to export to the grid when scheduled to do so. A bus received a score of "1" if available on a scheduled V2G export day and "0" if unavailable. It received partial credit if it was available for a portion of the planned export session. The metric is expressed as a percentage of days available.

V2G reliability averaged 55% due to hardware replacement, software integration, and driver errors when interconnecting EV buses to chargers (Figure 3). As shown Figure 4, most issues were related to complications of the V2G components. The Project issues centered around integrating various manufacturers' technology or bidirectional on-board chargers ("OBC") that were still pre-market at the time. For example, there were multiple OBC replacements needed in 2021 due to overheating equipment or software communication issues. These issues are associated with initial deployment and are unlikely to persist as operators work through integration issues and as more integrated technologies become commonplace.

Figure 4. V2G Reliability Issues.



An issue arose in the beginning of 2021 related to the operators' ability to successfully plug in buses and confirming communication between EVSE and school buses. This was resolved with a new round of operator training that improved reliability.

Over time, the Company expects these minor operator issues will improve with experience, and improvements bus technology will lead to fewer maintenance incidents. More important to improving V2G reliability will be industry standardization of communications protocols, and the availability of busses that come pre-equipped with V2G capabilities, resulting in fewer integration issues.

II. Recommendations

Based on the results of V2G operations in White Plains, the Project team recommends that:

1) Planning for V2G value in a business case should consider energy transfer losses in discharging and the economic impact of using the battery for non-trasportation operations (further discussed in Section 2.4 below).
2) Performance issues should be remedied to assure operators there is reliable value associated with V2G.
3) Operator and bus component issues could be resolved through operator experience and wider school bus electrification.
4) V2G-specific equipment issues should improve with maturity of V2G industry.

2.4 Battery Health Impacts

I. Results

Con Edison calculated battery Capacity Estimate and State of Health (“SOH”) to assess battery health over the course of the Project. The Company used historic energy usage and state of charge[6] (“SOC”) data to assess battery health over the Project timeline and to forecast battery health over the course of a bus’s lifetime.

The Company based the Capacity Estimate on observed energy use and change in battery state of charge on each bus:

$$Capacity\ Estimate = \frac{Energy\ discharged}{Change\ in\ battery\ SOC} * 100$$

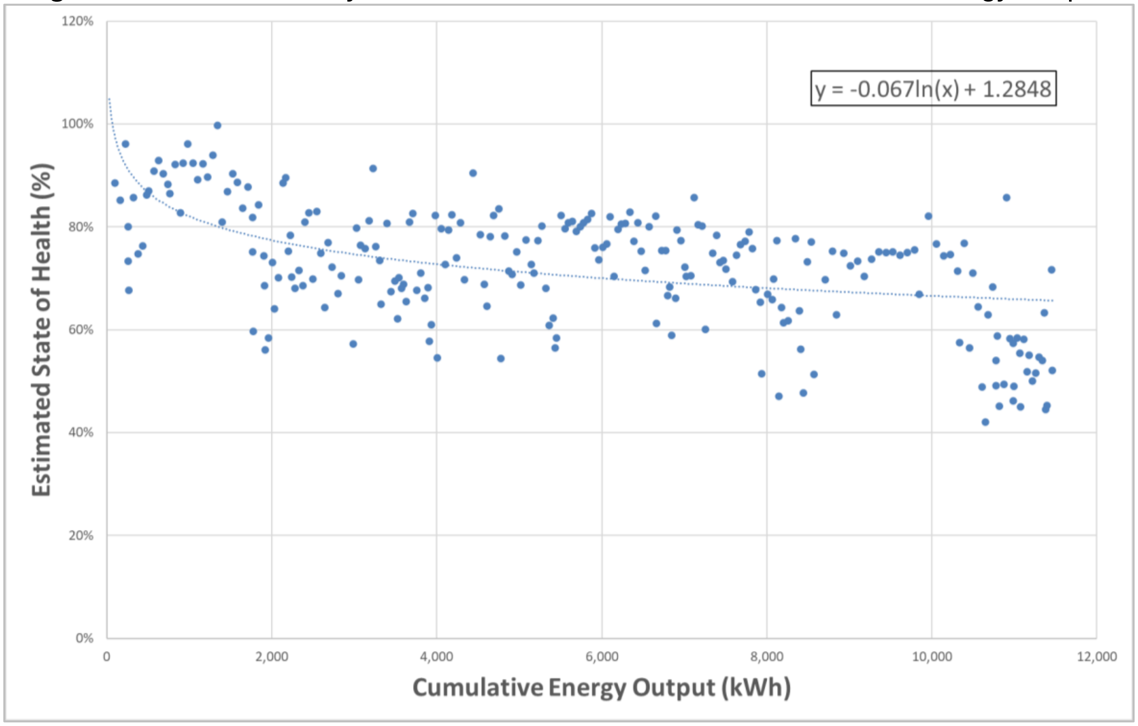
For example, if energy use data shows 10 kWh used corresponded to a 10% change in battery state of charge, then we infer the battery has a total energy capacity of 100 kilowatt hours.

The State of Health metric represents the remaining share of initial battery capacity. The Company calculated battery SOH by dividing battery Capacity estimate by the batteries’ initial listed usable energy:

$$State\ of\ Health\ (SOH) = \frac{Capacity\ estimate}{Capacity\ at\ beginning\ of\ life} * 100$$

[6] State of charge is the level of charge of an electric battery relative to its capacity.

Figure 5. Bus 772 Battery State of Health as Function of Cumulative Energy Output.



To forecast battery SOH, the Company used each bus's individual trendline to extrapolate Project data over 8 and 12 years. These time frames align with standard and extended battery warranty terms for the Project buses. Battery State of Health data indicated that the batteries' capacities declined with use (Figure 5).

Figure 6. Test and Control battery Impact Analysis – December 2020 to December 2021. Control buses were electric buses that were not used for V2G operations.

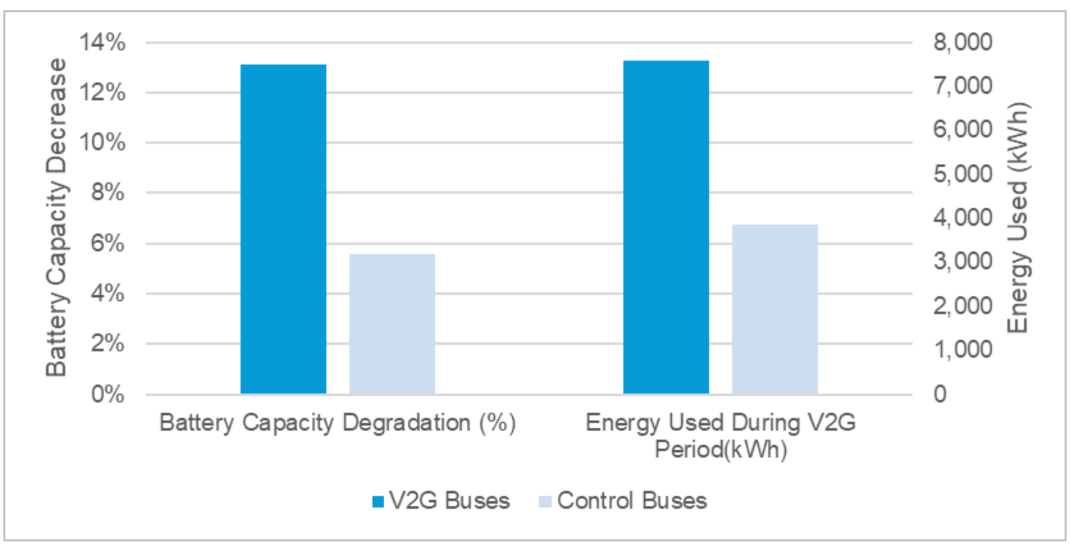


Figure 6 shows that the V2G buses used about twice as much energy for Project V2G operations and degraded about twice as much during the same period. Therefore, we find that energy transfer impacts batteries regardless of whether it is for transport or grid services. Operators should consider this degradation in planning their use of the buses and in evaluating whether they can justify the additional costs over any revenues they receive to deploy the bus battery for V2G operations, as compared to retaining it to use for transportation for a longer period of time.

Significant impacts were not observed from other factors known to affect batteries -- depth of discharge, temperature, charging rate, and resting state of charge.

Forecasts considered 8- and 12-year timelines because the regular and extended, respectively, warranty provides a battery replacement if battery capacity dips below 65% SOH within those timelines. However, under the warranty that currently covers transportation services -- V2G is not considered “normal” use of the batteries.

Our forecast showed that the control buses are likely to remain within the warranty guarantee while the V2G buses are likely not.

II. Recommendations

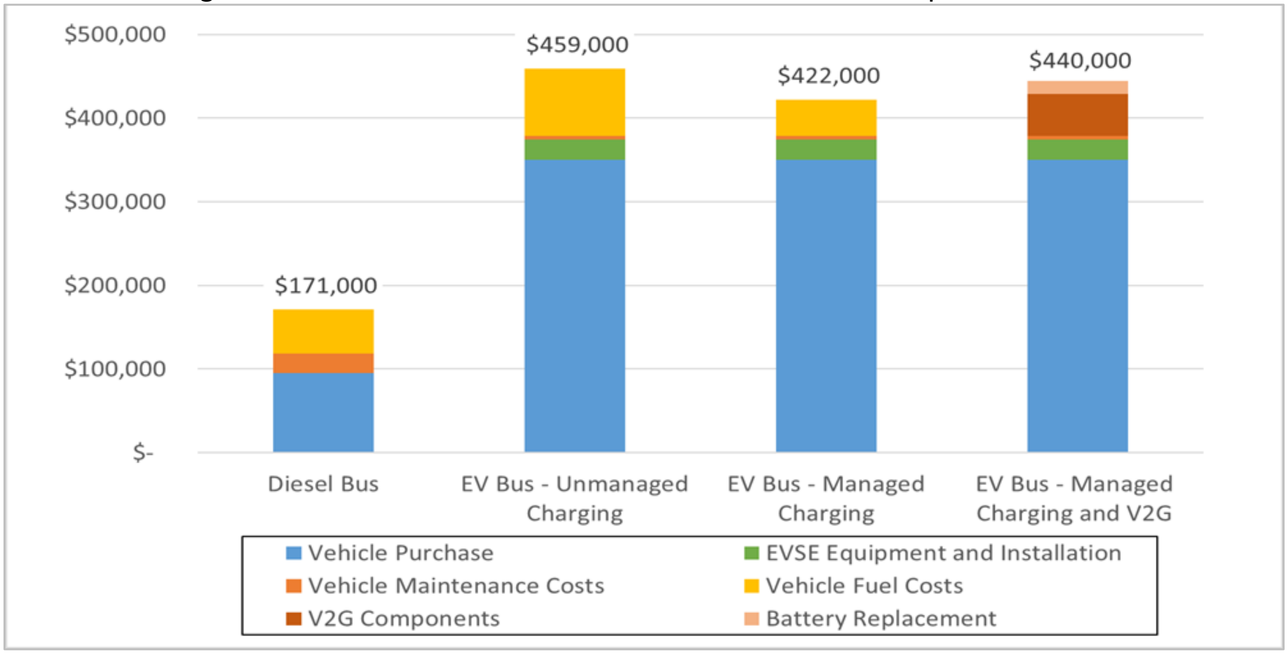
Several recommendations related to battery impacts come from the above results in White Plains:

1) Operators should consider potential battery degradation impacts on transportation. Mitigating solutions could include charging management, battery replacements, or transition to shorter routes for aged buses.
2) Bus manufacturers and operators should consider additional battery degradation as they amend warranty terms to cover V2G and carefully evaluate the additional costs as compared to the revenue potential of deploying bus batteries for V2G instead of retaining it for transportation.
3) Operators should manage battery hygiene factors (depth of discharge, temperature, charging rate, and resting state of charge) to extend battery longevity and asset life.

2.5 Total Cost of Ownership

I. Results

Figure 7. V2G Electric School Bus Total Cost of Ownership Model.



Con Edison worked with Project partners to develop a model of total cost of ownership ("TCO") (Figure 7). It includes assumptions based on Project and industry benchmarks. The analysis includes four model cases – diesel bus, EV bus with unmanaged charging, EV bus with managed charging, and EV bus with managed charging and V2G.

The unsubsidized incremental purchase price of the EV buses is much higher than the any purchase fuel and maintenance cost savings can overcome. The V2G case includes the additional cost of replacing the on-board charger with a bidirectional charger and installing a network protector switch to meet grid interconnection requirements. Because the battery health analysis found that increased energy use from V2G could require battery replacement, the TCO analysis also includes an assumed battery replacement during the 12 year bus life.

Modeled lifetime diesel fuel costs were lower than energy costs in the unmanaged case and higher than fuel costs in the managed charging case. These diesel prices are based on 2021 average prices[7] before recent increases in fossil fuel prices.

The unmanaged charging case assumes that all five EV buses charge at the same time on standard utility rates directly after the morning and afternoon trips. This includes charging during June and September which are part of the school year and also the utility summer season, when the standard electricity rates increase.

[7] NYSERDA Monthly On-Highway Diesel Prices: https://www.nyserda.ny.gov/Researchers-and-Policymakers/Energy-Prices/On-Highway-Diesel/Monthly-Diesel-Prices.

The managed charging case shifts all charging into the utility off-peak period and places the bus on time-of-day rates. The result of that shift is about 50% reduction in energy costs compared to unmanaged charging, and about 15% reduction compared to diesel costs.

In the V2G case, no fuel costs are shown because the bill credits generated through V2G operations exceed the electricity costs incurred by $4,000, but the cost needed to enable V2G and the cost of the battery replacement keeps the TCO higher than the managed charging with no V2G case.

This analysis did not evaluate cost changes over time for either capital or operating costs. The cost premium of electric school buses would decrease if batteries costs were to fall, if EV bus production increases yielding economies of scale, and if emissions control costs increase for diesel buses.

To manage and reduce costs in the V2G case, operators could use technology that doesn’t require the network protector such as an off-board AC-DC invertor or on-board technology that already includes certified electrical network protection, select buses with pre-integrated V2G capability, and explore ways to improve V2G reliability to increase V2G revenues.

II. Recommendations

Several recommendations related to TCO come from the above analysis:

1) Policy and program incentives for fleet and school bus electrification for upfront vehicle purchase costs and charging infrastructure costs are still needed to overcome TCO disparity.
2) Electric school buses should be charged during utility off-peak periods to improve business case through reduction of operational costs.
3) Further testing is needed to evaluate performance and cost improvements of the V2G business case as the Project demonstrates higher TCO associated with V2G.
4) The economic case for V2G can improve with technology improvements and integration standardization.

3.0 SUMMARY OF RESULTS AND RECOMMENDATIONS

	Project Questions	Summary Results	Recommendations
EV School Bus Operations	What are the financial and operational benefits of EV compared to diesel?	• Satisfactory vehicle performance compared to diesel • Upfront vehicle and infrastructure costs remain a barrier	• Continue public policy and incentive support to encourage EV adoption • Operator training and an on-site EV Fleet Manager can help
Vehicle-to-Grid Operations	Is V2G technically and operationally viable?	• Successful V2G design, installation and operations	• V2G technology should seek required certifications to simplify Project implementation
	Does V2G perform and dispatch as expected?	• V2G reliability was challenged but energy transfer met expectations	• Fully integrated systems should mitigate technology integration issues
Battery Health Impacts	Is battery degradation from V2G significant?	• Battery capacity loss correlates with energy use regardless of end use, transport or V2G	• Operators should practice battery hygiene to maintain useful life
	Is V2G cost-prohibitive?	• V2G adds cost to EV bus including additional battery degradation	• Further integration standards to improve economic case

4.0 APPENDICES

The following appendices are included at the end of this Quarterly Progress Report:

Appendix A: Description of Phases

Appendix B: Work Plan

Appendix C: Procedures and Policies

Appendix A: Electric School Bus V2G Description of Phases

Phase	0. Project Planning	1. Electric Bus Operations & Analysis	2. Design & Construction of Charging & V2G	3. V2G Operations
Milestone (Stage Gate to Next Phase)	*Agreements Completed* • DPS approval • Partner contracts signed	*Buses perform as vehicular transportation* • Operating metrics measured by data collected by a diagnostic device installed on bus controller area network port	*Design, install, and commission V2G* • Retrofit buses with on-board inverter • Complete site work for Con Edison approval	*Operate EV buses as grid assets* • Project ends
Key Elements	• Con Edison – First Priority Agreement • Con Edison – National Express Agreement • DPS approval of Project proposal and implementation plan	• Meet minimum range requirement of 65 miles for 80 kWh during peak HVAC use • Provide necessary information to the drivers so that bus range and readiness could be reasonably anticipated • Achieve vehicle uptime of 95% or greater	• Install the bi-directional charging stations • Complete the charger-side software • Modify the buses' battery management systems • Meet Con Edison SIR requirements	• Perform vehicle range analysis before and after V2G periods • Vary V2G discharge protocols to provide data on V2G impacts on battery range.
DER Categories	N/A	• Electric vehicles	• Electric vehicles • Battery energy storage	• Electric vehicles • Battery energy storage

Appendix B: Work Plan

			2018				2019				2020				2021				2022
Task No.	Activity Description	Lead	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
0	Phase 0: Demonstration Planning	Con Edison																	
0.1	Obtain Commission Approval	Con Edison																	
0.2	Finalize contract with NELLC	Con Edison																	
0.3	Finalize contract with FPGF	Con Edison																	
1	Phase I: Electric Bus Operations and Analysis	FPGF																	
1.1	Buses shipped to NJ from Montreal	FPGF																	
1.2	Buses pre-inspected, customized, detailed, prepped	FPGF																	
1.3	Buses delivered and inspected	FPGF																	
1.4	FPGF provides operational/technical training	FPGF																	
1.5	Buses operational	WPBC																	
1.6	Buses generate performance analytics	FPGF																	
1.7	Quarterly Data analysis, measurement and evaluation	FPGF																	
2	Phase II: Design and Construction of Charging and V2G Infrastructure	FPGF, Nuvve, Lion																	
2.1	Site assessments and engineering drawings	FPGF, OLA Consulting																	
2.1	Electrical service request	FPGF, OLA Consulting																	
2.3	Utility assessment and service plan	ConEd																	
2.4	EVSE assessment and site plan	Nuvve, Healy Electric																	
2.5	Ordering of equipment/hardware	Nuvve																	
2.6	Installation of networked charging stations (without V2G)	Healy Electric																	
2.7	Testing of interface with buses	Nuvve, Lion																	
2.8	Chargers operational	Nuvve																	
2.9	EVSE operational training	Nuvve																	
2.1	Electricity consumption patterns analysis	Nuvve, Lion																	
2.11	Design and software coding	Nuvve, Lion																	
2.12	Charging stations upgrade with inverters and software	Nuvve, Lion																	
2.13	Buses modified (BMS modifications and SAE Combo plugs)	Lion																	
2.14	Network integration and system beta testing	FPGF, Nuvve, Lion																	
3	Phase III: V2G Operations and Analysis																		
3.1	V2G battery baselining	Nuvve, Lion																	
3.2	V2G launch	Nuvve																	
3.3	Bi-monthly V2G data analysis	Con Edison, Nuvve																	
3.4	V2G battery closeout	Nuvve, Lion																	
3.5	Final V2G analysis report	Con Edison																	
3.6	Data collection from Energy Management Platform	Nuvve																	
3.7	Quarterly Data analysis, measurement and evaluation	Con Edison, FPGF, Nuvve																	

Appendix C: Procedures and Policies

CYBERSECURITY AND PERSONALLY-IDENTIFIABLE INFORMATION PROTECTION

Consistent with Commission policy related to cybersecurity and the protection of personally-identifiable information ("PII"), each partner agreement executed for the implementation of the Project includes specific protections related to cybersecurity and PII. This protection is critical in encouraging customers to sign up with new and innovative services offered by utilities.

ACCOUNTING PROCEDURE ESTABLISHED

On February 16, 2016, in Case 15-E-0229, Con Edison filed an accounting procedure for the accounting and recovery of all REV demonstration project costs.[8] This accounting procedure establishes a standardized framework that will govern how the Company categorizes and allocates the costs of the REV demonstration projects, and will facilitate analyzing each project to determine the overall financial benefits of the program to customers.

COSTS, BENEFITS, AND OPERATIONAL SAVINGS

Budget information for all of the Company's REV demonstration projects is being filed confidentially with the Commission, concurrently with the filing of this document. All costs filed are incremental costs needed to implement the projects. To date, no tax credits or grants have been available to reduce the net costs of the projects, but Con Edison will take advantage of such offsetting benefits when, they are available. Due to the early stage of implementation for the Project, there are no operational savings to report at this time.

[8] Case 15-E-0299, *Petition of Consolidated Edison Company of New York, Inc. for Implementation of Projects and Programs that Support Reforming the Energy Vision*, General Accounting Procedure (issued February 16, 2016).

Appendix D: Project Analysis & Results Stakeholder Presentation

Electric School Bus Vehicle-to-Grid Demonstration Project Analysis & Results March 25, 2022

Agenda

- Executive Summary
- Project Overview
- EV School Bus Operations
- Vehicle-to-Grid Operations
- Battery Health Impacts
- Summary Results and Recommendations
- Questions?

Executive Summary

	Summary Findings	Recommended Actions: Bus Owner / Operator	Recommended Actions: Utility
EV School Bus Operations	• Electric school buses (ESB) performed to operator satisfaction • Manageable technical challenges provided ongoing lessons learned • ESB business case requires incentives and managed charging	• Offer recurring operator training to inform on emerging issues • Assign an on-site EV fleet manager to monitor vehicle performance, coordinate maintenance services, conduct operator training, etc.	• Policy and program incentives are still needed to overcome TCO disparity
Vehicle-to-Grid Operations	• Successful V2G was mitigated by technology difficulties • V2G could provide value but appears to be a net cost	• Consider V2G-ready vehicle to mitigate technology integration risk • Further testing of V2G technologies needed to evaluate performance and value to owner	• Further testing of V2G technologies needed to evaluate performance and value to grid
Battery Health Impacts	• V2G energy transfer resulted in lower bus battery capacity	• Manage battery hygiene (within fleet operations needs) to extend useful life • Weigh battery degradation impacts on transportation operations and bus costs against value of V2G	• Consider battery degradation impacts over time when evaluating load relief incentives

Project Overview

In 2017, Con Edison requested proposals to test vehicle-to-grid (V2G) electric school buses as dual-purpose assets

Demonstration Project Questions	
EV School Bus Operations	What are the financial and operational benefits of electric school buses as compared to diesel equivalents?
Vehicle-to-Grid Operations	Is V2G technically and operationally viable for electric school buses and project partners?
	Does V2G perform and dispatch as expected?
Battery Health Impacts	Is battery degradation from V2G significant?
	Is V2G cost prohibitive?

Collaborative project structure included multiple roles and responsibilities for Con Edison, solution providers and operators

conEdison
- Lead project management
- Co-funding for EV Bus and V2G
- Utility service interconnection

NEW YORK STATE OF OPPORTUNITY. | NYSERDA
- Co-funding for EV Bus

1 FPG ELECTRIFIED
- Project developer
- Project management

national express
- Bus owner / operator
- Project co-funding

LION
- EV school bus OEM and service provider

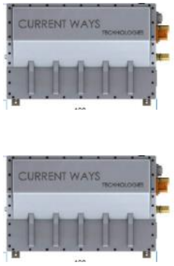
NUVVE
- EVSE OEM and service provider
- V2G operations and reporting

CURRENTWAYS TECHNOLOGIES
- Bi-directional on-board charger OEM and service provider

Operations incorporated several elements to successfully inject energy to utility distribution system

On-Board Vehicle

- Five EV buses equipped with 104kWh Li-ion batteries
- Three V2G buses with bi-directional on-board chargers (OBC) and two Control buses
- Total capability: 13.2kW per V2G bus



Off-Board Vehicle

- Five Level 2 EVSE
- Integrated communications
- Discharge pre-scheduled for availability e.g., weekends, school holidays
- Network protection system installed per New York State requirements
- Left to right: utility meter, electrically-held shut-off switch, electric panel, and relay

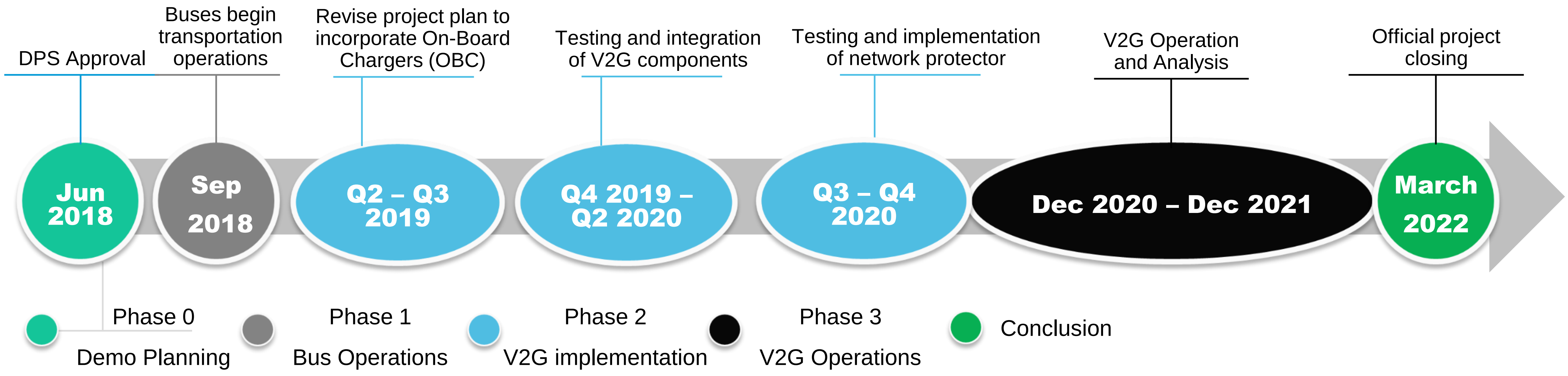
Off-Property

- Tested technical capability to safely discharge energy to utility grid

Standardized Interconnection Requirement (SIR) process required bus modifications and site work

Project Requirements	Equipment Requirements	Project Actions
• Buses modified for two-way power flow capability	• On-board bi-directional charging added to bus	• First attempt with off-board AC inverter was not technically viable • AC-DC-AC bi-directional on-board charger (OBC) selected
• DER interconnection for grid injections that meets New York State SIR requirements	• Con Edison requires Underwriters Laboaratory certification to IEEE standards • Alternatively, customer must install network protector	• Project team confirmed OBC did not meet required standards • Con Edison approved network protector

Key highlights from three years of continued success



Electric School Bus Operations

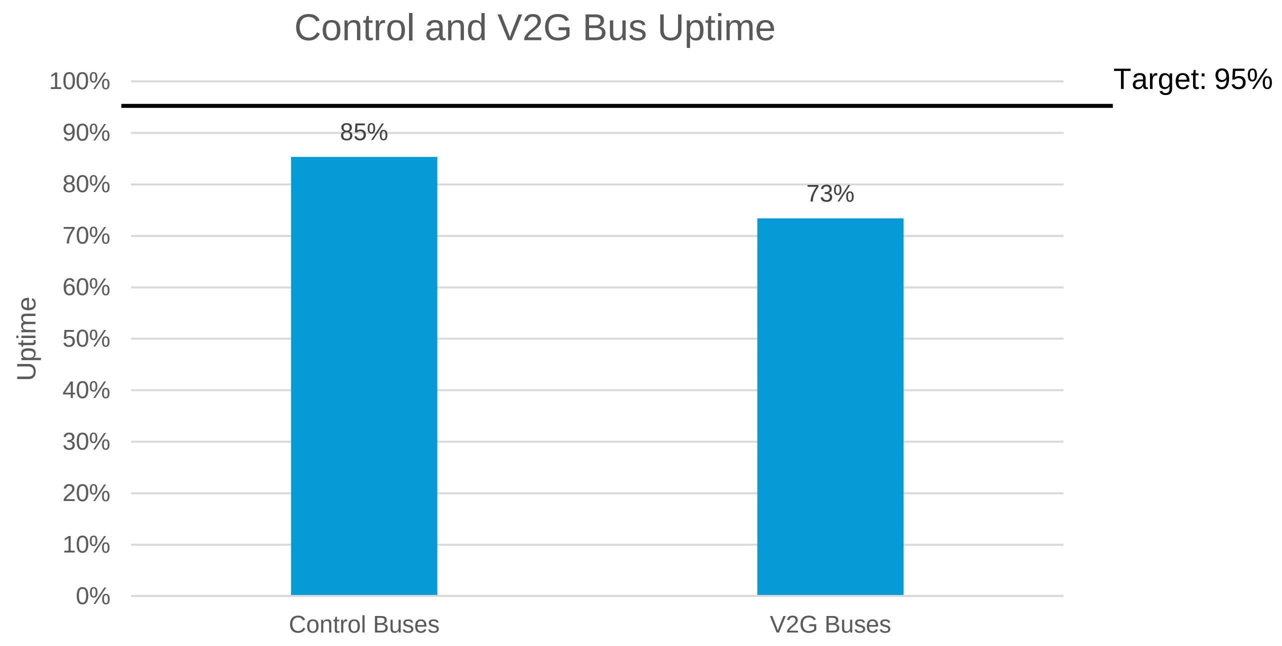
Operators reported overall high satisfaction with the buses and all identified issues were successfully resolved

Operator Feedback	Resolved Operator Issues
• Vehicle performance and driving experience • Attracts attention and increases support for EVs from community • Healthier internal bus environment – no exhaust fumes, quieter cabin, etc.	• Cabin heating supplemented with diesel auxiliary heaters on all five buses • Training conducted in 2019 and 2021 to educate drivers on vehicle operations and charging process

Recommendations

- Enhance recurring operator training to inform staff of emerging issues and train new staff to operate EV bus
- Assign an on-site EV fleet manager to monitor vehicle performance, coordinate maintenance services, and conduct operator training

Control bus uptime approached target while V2G bus uptime lower due to equipment outages



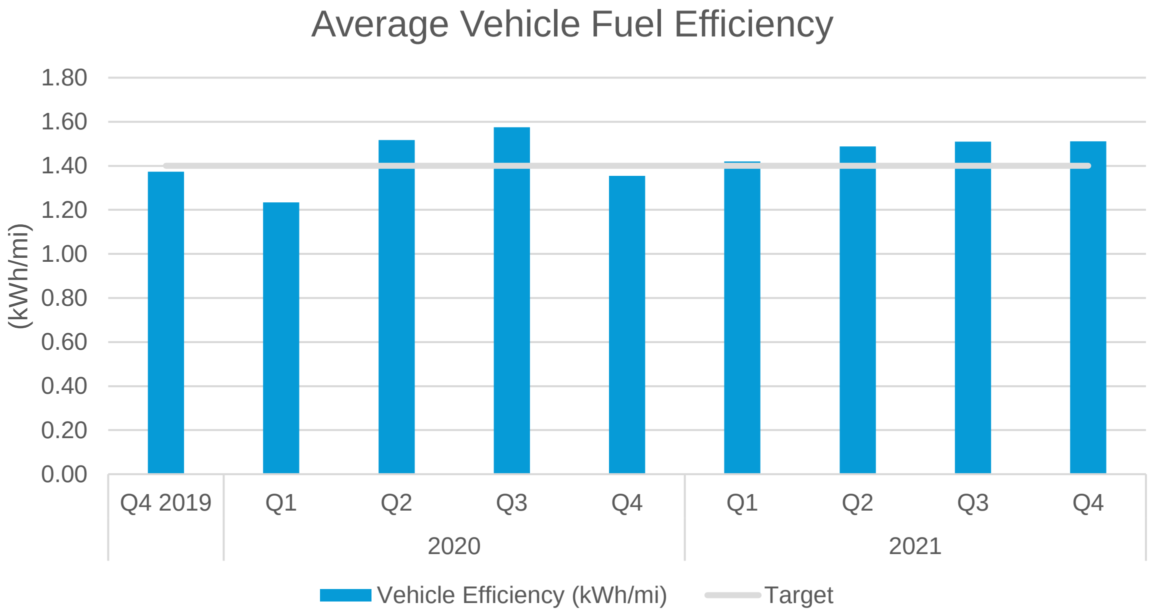
Uptime: Percentage of actual hours available to scheduled hours. EV bus downtime recorded by Lion in maintenance service reports. Uptime metric does not include scheduled maintenance and inspections.

- Bus availability is most important to operators and uptime is the key metric
- All buses experienced ~10% downtime due to bus components, e.g., wiring
- V2G buses experienced additional downtime due to technology integration issues

Recommendations

- Onsite EV manager can help expedite troubleshooting and maintenance
- Vehicle V2G-ready prior to delivery and operations can mitigate downtime for on-site technology integration

EV buses met fuel efficiency specifications and range requirements



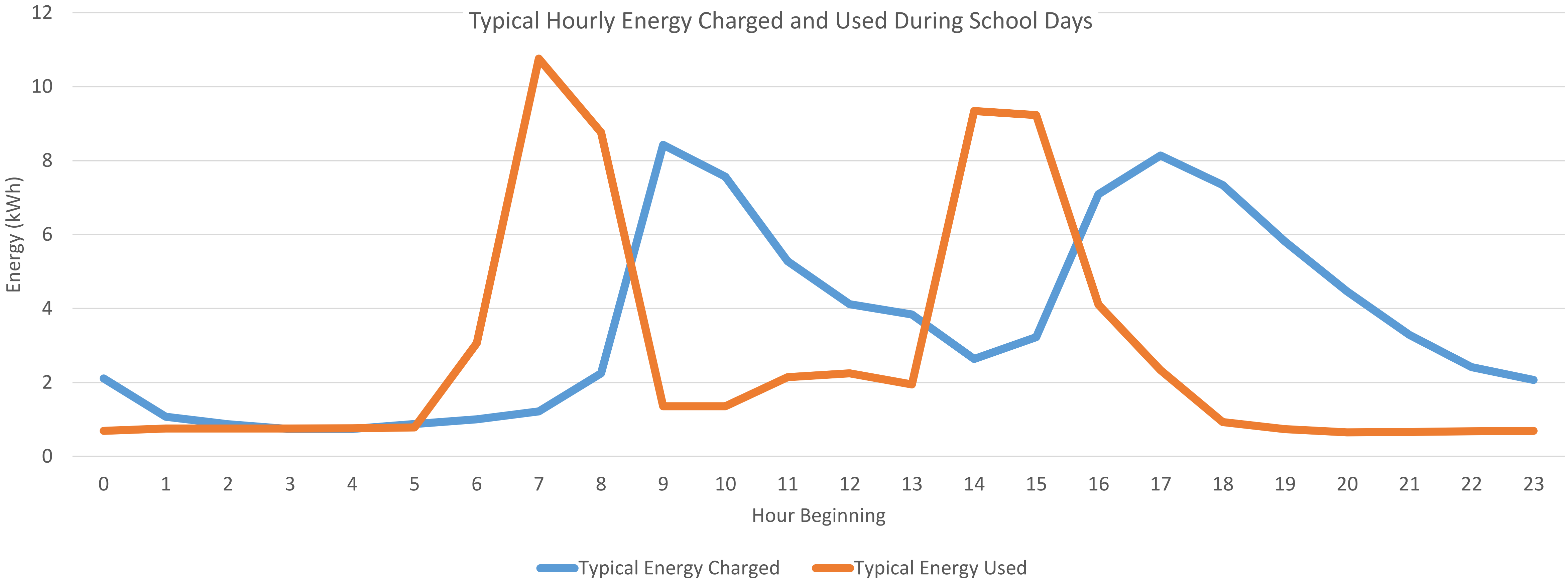
Fuel Efficiency: Energy discharged while driving (excluding energy from regenerative braking) per mile driven. Average of each bus using data from telematics.

- Buses averaged 1.4 kWh / mile, on target
- Average during warmer months was 1.5 kWh / mile; attributed to air conditioning loads
- In all operations EV range was no issue – though White Plains routes are shorter than New York State average

Recommendations

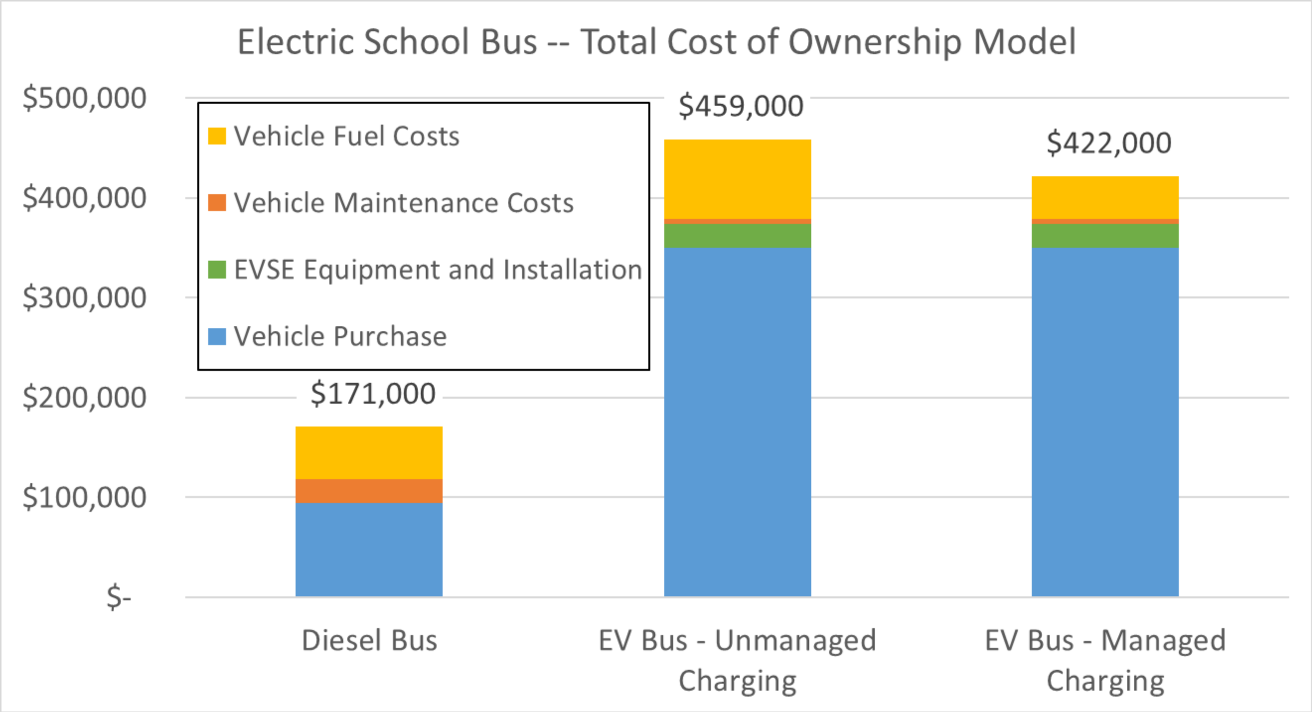
- Operators should use fuel efficiency to plan charging behavior that meets route requirements at least cost

Typical operator behavior included unmanaged charging following morning and evening student transportation



Typical Energy Charged and Typical Energy Discharged: Average plus one standard deviation for each hour for each bus.

Incremental cost per EV bus compared to diesel remains a barrier – incentives and managed charging improve business case



- Unmanaged charging assumes five buses charge including during utility summer season June and Sept
- Managed charging assumes overnight sessions meets energy requirements
- EV purchase ~4x Diesel including cost of EVSE

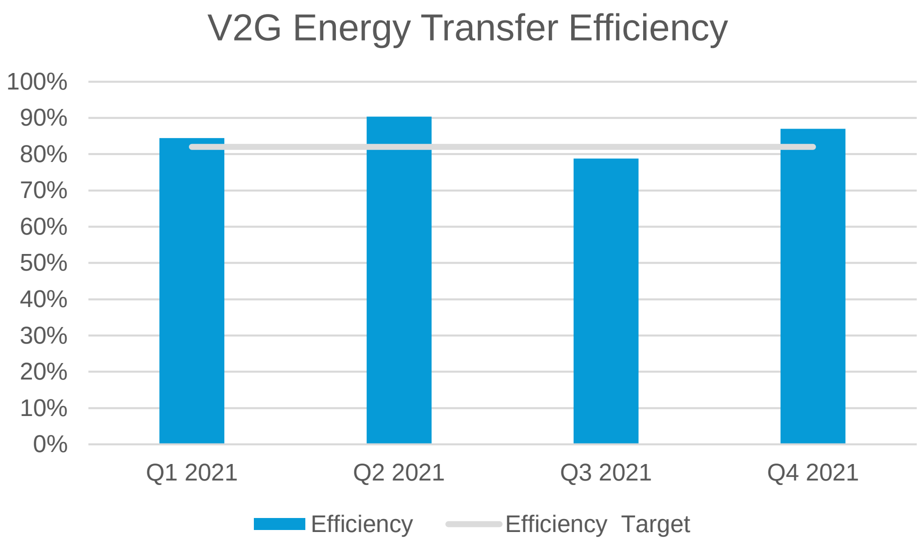
Total Cost of Ownership (TCO): Model includes unsubsidized actual project capital costs and assumed operating costs for five buses over 12-year operating life. Does not include assumptions for capital maintenance on diesel bus. All costs in nominal dollars.

Recommendations

- Policy and program incentives are still needed to overcome TCO disparity
- EV bus managed to charge only in utility off-peak periods improve business case

V2G Operations

Charging and discharging energy transfer losses were as expected – actual V2G transfer efficiency performed to target



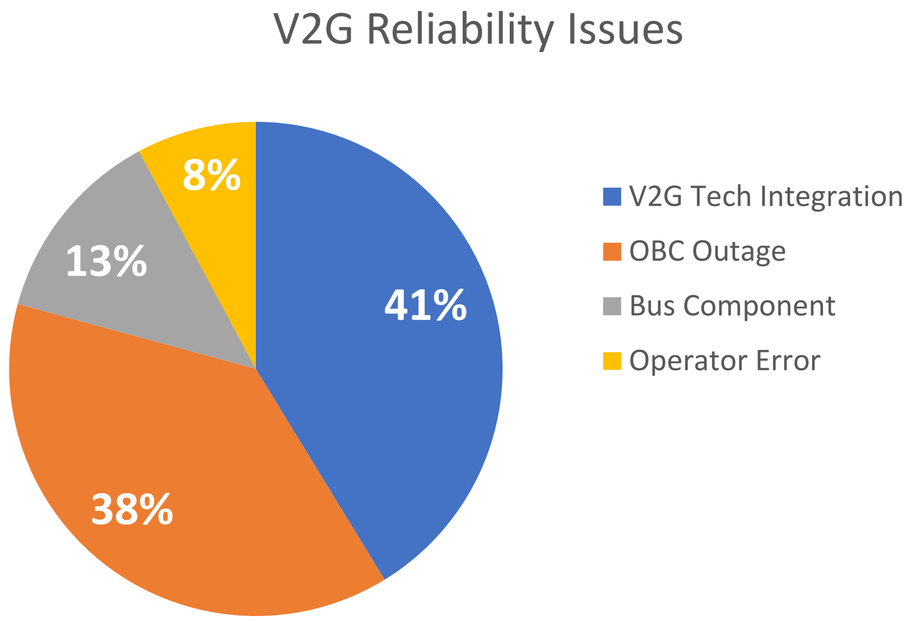
Transfer Efficiency: Actual energy injection compared to energy output from EV bus. Energy output losses measured as difference in energy output reading from each bus.

- Literature review established expected losses target of 18% during charging and discharging from DC-AC conversion, parasitic vehicle loads, and line losses
- V2G value based on energy (kWh) exported to distribution system as measured by utility meter

Recommendations

- Asset Managers must plan for energy transfer losses in EV charging and V2G
- Planning for V2G value in business case should consider energy transfer losses in discharging

Buses were challenged to meet scheduled discharge events due to several technical and operational issues



Reliability: Percentage of actual hours available for grid export relative to scheduled grid export hours.

- Reliability averaged 55% due to:
  - Hardware replacement
  - Software integration
  - Driver errors when interconnecting EV bus to chargers
- Technician specialists were needed to perform on-site troubleshooting of V2G components
- Operator and site manager coordination was needed to ensure buses were available for scheduled V2G

Recommendations

- Performance issues should be remedied to assure operators there is reliable value associated with V2G
- Operator and bus component issues can be resolved through experience and wider school bus electrification
- V2G-specific equipment issues should improve with maturity of V2G industry

Battery Health Impacts

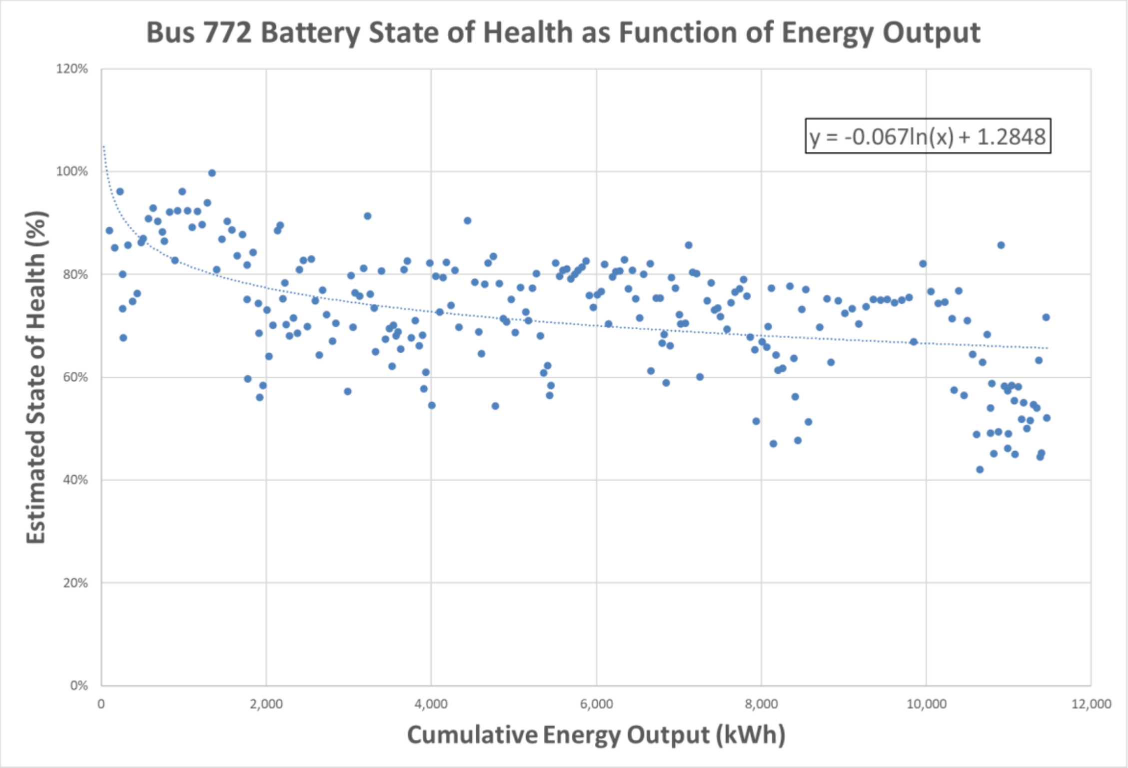
Battery health is important to understand for its effects on bus operations and its implications on warranty terms

- Batteries lose capacity to hold energy over time and as result of energy cycling
- Different operating conditions can also impact battery capacity, i.e., State of Health (SOH)
- Battery health impacts assessed by factors including energy transfer, temperature, depth of discharge, and low resting state of charge

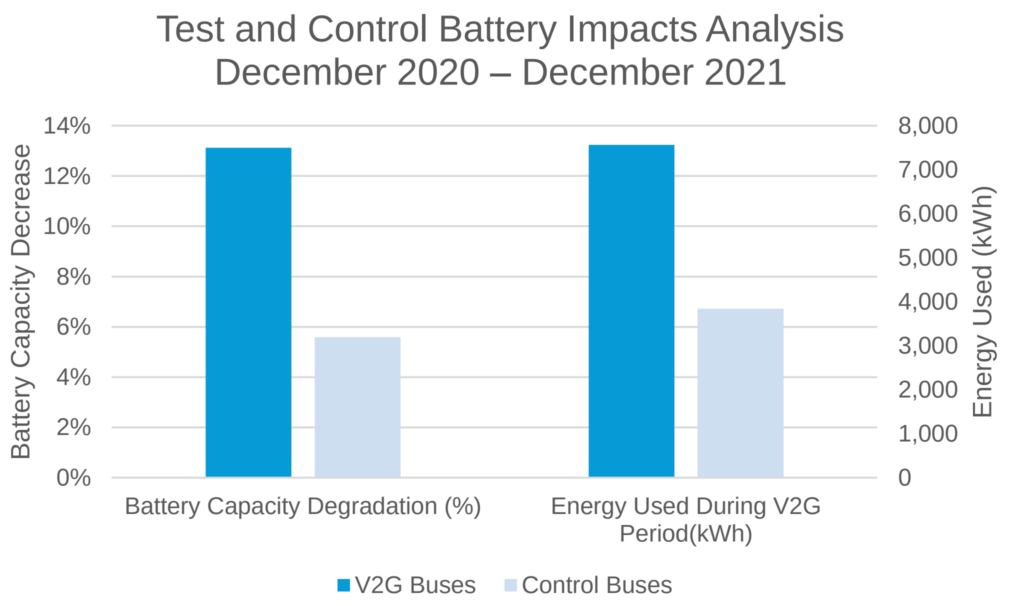
- Project questions for analysis:
  - What is estimated capacity of V2G and Control bus batteries following the test period?
  - What is forecast of battery SOH through bus expected useful life?

To understand how battery state of health (SOH) changed over time, we modeled the energy use by all buses during the project

- Analysis of energy use and corresponding change in battery state of charge for all five buses (V2G group and Control group)
- Battery SOH then derived over time:
  - $$Battery\ SOH(\%) = \frac{Current\ Available\ Battery\ Energy\ (kWh) * 100}{Initial\ Available\ Battery\ Energy\ (kWh)}$$
- Using logarithmic trendline, we forecast battery SOH for 8- and 12-year operating periods. This corresponds to standard and extended battery warranty terms



V2G buses showed higher battery capacity loss compared to control buses, attributed to incremental battery cycling



Capacity Degradation: Estimate is derived from change in state of charge and energy use during a trip or V2G discharge, expressed here as percentage of usable capacity

- Estimated battery capacity loss ~2x for V2G buses compared to Control buses after the V2G test period
- Energy transfer from V2G buses was ~2x during this period
- Energy transfer impacted battery capacity whether that energy is for transport or grid services
- Topics for further research: other factors such as depth of discharge, resting state of charge, and charge rate

Recommendations

- Operators should consider potential battery degradation impacts on transportation, e.g., shorter routes, charging management, battery replacements

V2G buses' capacity estimate implies challenge to meet standard warranty terms compared to EV bus

	kWh Used Over 8 Years	Remaining Battery Capacity After 8 Years	Estimated kWh Used Over 12 Years	Remaining Battery Capacity After 12 Years
V2G Buses	104,730	59%	155,781	56%
Control Buses	87,360	76%	131,040	73%

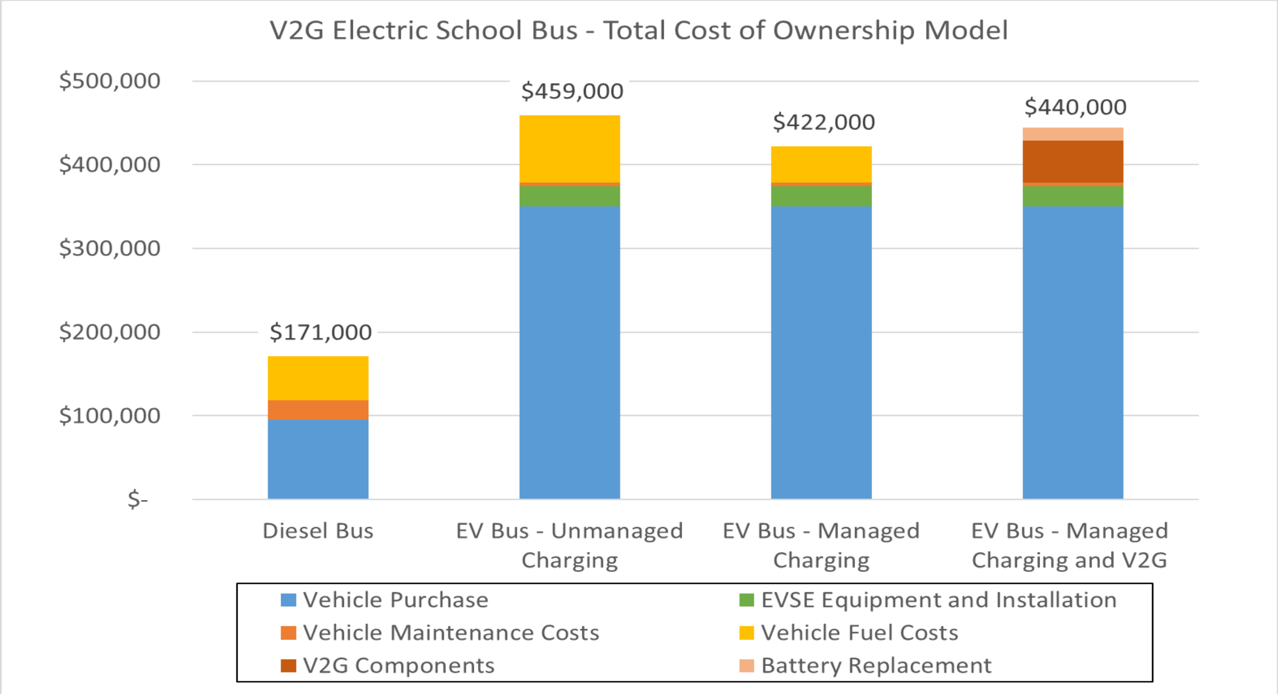
Remaining Battery Capacity: Based on reported change in state of charge and energy use during a session, expressed as percentage of original capacity

- Battery warranty guarantees 65% capacity after 8 years and extended warranty guarantees after 12 years
- But warranties do not cover V2G energy cycling as "normal conditions"

Recommendations

- Bus manufacturers and operators should consider amendment to warranty terms to cover V2G
- Operators should manage other battery hygiene factors to extend battery longevity and asset life

Bill credits provide value but do not overcome costs of the hardware and software components enabling V2G



- V2G includes ~$50k for bi-directional OBC and network protector
- Also assumes ~$15k battery replacement during bus operating life
- Utility bill credits from V2G offset energy costs in EV Bus + V2G case

Total Cost of Ownership (TCO): Model includes unsubsidized actual project capital costs and assumed operating costs for buses over 12-year operating life. Does not include assumptions for capital maintenance on diesel bus. V2G assumes off-peak charging and participation in Con Edison Value Stack Tariff (Rider R). All costs in nominal dollars. Battery replacement assumes $150/kWh.

Recommendations

- Further testing needed to evaluate performance and cost improvements of V2G business case
- Economic case for V2G can improve with technology improvements and integration standardization

Summary Results & Recommendations

Positive experience with EV buses while V2G technology needs more testing and experience to confirm reliable value

	Project Questions	Summary Results	Recommendations
EV School Bus Operations	What are the financial and operational benefits of EV compared to diesel?	• Satisfactory vehicle performance compared to diesel • Cost remains a barrier	• Continue public policy and incentive support to encourage EV adoption • Operator training and an on-site EV Fleet Manager can help
Vehicle-to-Grid Operations	Is V2G technically and operationally viable?	• Successful V2G design, installation and operations	• V2G technology should seek required certifications to simplify project implementation
	Does V2G perform and dispatch as expected?	• V2G reliability was challenged but energy transfer met expectations	• Fully integrated systems should mitigate technology integration issues
Battery Health Impacts	Is battery degradation from V2G significant?	• Battery capacity loss correlates with energy use regardless of end use	• Operators should practice battery hygiene to maintain useful life
	Is V2G cost-prohibitive?	• V2G adds cost to EV bus including additional battery degradation	• Further integration standards to improve economic case

Questions?