# Project Final Report

**EERE award number: DE-EE0007995**
**Prime Recipient: Blue Bird Corporation**
**Title: Vehicle-to-Grid Electric School Bus Commercialization Project**
**Principal Investigator: Andy Moore, Blue Bird Corporation**
**Project Period: February 1, 2017 – March 31, 2022**
**Teaming Organizations:**

- **Blue Bird Corporation (prime contractor and vehicle OEM)**
- **National Strategies (program manager)**
- **Nuvve (V2G system developer)**
- **Rialto Unified School District (school district host)**
- **National Renewable Energy Laboratory (technical advisor)**
- **South Coast Air Quality Management District (technical advisor and project co-funder)**

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# Executive Summary

The Vehicle-to-Grid Electric School Bus Commercialization Project was chartered to advance the idea that the batteries in electric vehicles can play a valuable role in supporting the electric grid. As deployment of wind and solar generating resources accelerates to provide an ever-greater share of the nation's electricity, concurrent investment in solutions that can offset their inherent intermittency will be necessary. Many types of energy storage systems have been proposed, and more than one type will find an economic fit in the grid of the future. Electric vehicle batteries have the potential to provide grid support services in an advantaged manner.

The project's method of exploring this proposition called for development and demonstration of a fleet of vehicle-to-grid (V2G) electric school buses. School buses were chosen because their energy storage capacity is large relative light-duty vehicles; they are typically domiciled in fleet settings; and the number of hours per year they are available for grid support services is high on an absolute basis (generally 80-85% of the hours in a year) and relative to other categories of medium- and heavy-duty vehicles.

The project's efforts were applied on three fronts: 1) advancing the energy efficiency of electric school buses; 2) envisioning the different elements required for high-power, bidirectional charging, and overseeing their integration into a functioning system; and 3) serving as a catalyst for the creation of regulatory policy that would allow electric vehicle fleets to function as distributed energy resources (DERs).

The project met its overall goal of moving V2G school buses toward commercial realization. It fulfilled each of the milestones in its first budget period, and received approval to proceed through its first go/no-go point. And along the way it produced useful results in all three of its active fronts – with the benefit often coming from learning what was not possible rather than what is. In the case of vehicle energy efficiency, the project yielded a prototype vehicle that consumed 9% less energy per mile than a representative baseline vehicle -- while determining that its original target of a 28% reduction was not feasible for a commercial vehicle. In the case of the charging system, the architecture went through an extended period of evolution, ultimately migrating from a 200-kW system with an on-board inverter to a system based on an off-board inverter with a bidirectional power capacity of 125 kW. Finally, in the case of regulatory policy, the project was able to advance a concept for an electrical tariff that would support the vision of a fleet-based DER -- although discussions of this matter with the host utility never reached the point of fruition.

Over the course of the project's five years, numerous advances were made in the outside world in the development of the V2G school bus concept. Electric vehicles entered the mainstream school bus market. A project funded by the California Energy Commission provided an early demonstration of V2G function by electric school buses. The Energy Commission subsequently stipulated that all school buses funded through its $75 million "School Bus Replacement for California Public School Districts, County Offices of Education, and Joint Power Authorities" program would need to be "V2G-capable". A handful of utilities outside of California used electric school buses to demonstrate aspects of V2G functionality. Project team members were involved – often in key roles -- in each of these undertakings. Although the ultimate objectives of the project were not fully realized, there is no doubt that its influence was widespread and substantial.

# Contents



# Comparison of actual accomplishments with project objectives

The ultimate objective of the project was to develop, demonstrate, and commercialize electric school buses in a way that would allow them to function fully as dual-role assets, both meeting pupil transportation needs and serving as a vehicle-to-grid (V2G) distributed energy resource (DER) that can provide local and grid-oriented electricity support services. This ultimate objective was to be served through pursuit of three practical objectives.

**Practical objective 1:** Reduce the total cost of vehicle ownership, with special emphasis on operating energy efficiency. Quantitative target: Operating energy efficiency of $\leq$ 1.10 kWh/mile.

**Accomplishment:** An electric school bus baseline energy efficiency of 1.52 kWh/mile was established through dynamometer testing of an early prototype bus. An efficiency-oriented prototype subsequently achieved energy efficiency of 1.39 kWh/mile.

**Practical objective 2:** Deploy an on-board bidirectional inverter that could maximize revenues from vehicle-to-grid (V2G) services while minimizing incremental impact on total cost of ownership. Quantitative target: Charge/discharge power capacity of 200 kW.

**Accomplishment:** Both aspects of this objective were modified over the course of the project. The charging architecture ultimately chosen was based on use of an inverter in an off-board (curbside) charging station. The charging station selected for this role has a bidirectional power capacity of 125 kW. On-board charge/discharge power circuitry was capable of operating at this power level but was never rated for service above 60 kW.

**Practical objective 3:** Receive permission from relevant authorities to operate in the ancillary grid service markets managed by the California Independent System Operator (CAISO). Quantitative objective: Revenue realization > $0 from operating the school bus fleet as a DER.

**Accomplishment:** The project was able to engage the host utility, Southern California Edison, in a productive process that had the potential to fulfill the objective.

# Project Activity Summary

## Total Cost of Ownership Modeling

Early in the project, Program Manager National Strategies integrated all of the pertinent parameters in a total-cost-of-ownership model that showed the relative importance of the factors in creating a competitive value proposition for electric school buses. (See Figure 1.) The model was based in part on current data from entities engaged in investigating or deploying electric school buses, and in part on National Strategies' own analysis of advanced topics including battery life and V2G revenue streams. It was updated several times, most recently at the end of 2020. The model was not intended to "prove" that V2G school buses could compete with diesel school buses, but rather to show the plausibility of circumstances under which such competitiveness might be achieved.

***TCO results from a representative scenario (one bus)***

| Comparative Cost Structure over 15-Year Life | | | |
|---|---|---|---|
| | EV | Diesel | Difference |
| Cap Ex | $ 380,000 | $ 100,000 | $ (280,000) |
| Fuel Cost | $ 37,354 | $ 80,044 | $ 42,690 |
| Maintenance | $ 25,739 | $ 102,954 | $ 77,216 |
| Battery Repl | $ 30,212 | $ - | $ (30,212) |
| Grid Services | $ (246,062) | $ - | $ 246,062 |
| LCFS Credits | $ - | $ - | $ - |
| 15-Yr Net | $ 227,243 | $ 282,998 | $ 55,755 |

**Scenario description:** Peak shaving for a distribution utility. Calculation based on probability-adjusted values of monthly demand charges.

**Figure 1.** *Total cost of ownership comparison between a V2G-deployed type C electric school bus and a diesel-powered school bus.*

## Energy Efficiency

Blue Bird initiated its technology development efforts in May 2018, with efforts focused on a short list of high-potential energy efficiency opportunities: drivetrain architecture, integrated thermal management, traction energy budget, and rotational and inertial mass reduction. Over the next year, engineering personnel from Blue Bird and Blue Bird's initial electric drivetrain subcontractor Efficient Drivetrains, Inc. (EDI) -- with invaluable contributions from the National Renewable Energy Laboratory (NREL) – made measurable progress in each of these areas.

As an early step, NREL installed telematics devices on buses in the current fleet of the project's school bus host, Rialto Unified School District in California. NREL used the collected route data to create a real-world school bus duty cycle (the "NREL School Bus Drive Cycle"). Blue Bird subsequently sent a prototype type C electric school bus that had been assembled at its factory in Georgia ("P1") to NREL's REFUEL dynamometer for energy efficiency profiling. The efficiency value recorded for a fully loaded bus, 1.53 kWh/mile, became the baseline against which subsequent improvements would be judged. (See Figure 2.)

| Cycle | Traction Energy (kWh) | Regenerated Energy (kWh) | Net Energy (kWh) | Distance (miles) | Energy Efficiency (kWh/mile) |
|---|---|---|---|---|---|
| NREL School Bus Cycle (27,000 lbs.) | -11.2 | 2.1 | -9.0 | 5.9 | 1.53 |
| NREL School Bus Cycle (22,000 lbs.) | -10.0 | 1.9 | -8.1 | 5.9 | 1.37 |
| Rialto Cycle | -17.2 | 3.7 | -13.5 | 7.6 | 1.80 |
| CARB HHDDTNC | -36.5 | 1.5 | -35.0 | 25.7 | 1.36 |
| Fort Valley Cycle (27,000 lbs.) | -25.1 | 3.2 | -21.9 | 20.6 | 1.06 |
| Fort Valley Cycle (22,000 lbs.) | -22.7 | 3.1 | -19.6 | 20.6 | 0.95 |

**Figure 2.** *Total energy efficiency results for P1 for various drive cycles from NREL's REFUEL Dynamometer (arithmetic deviations due to rounding).*

In the drivetrain architecture domain, modeling exercises were completed by both EDI and NREL. EDI's modeling was done on its proprietary simulation platform. NREL's used its FASTSim platform. In EDI's version of the modeling, the consistent indication was that direct-drive architecture produces better energy efficiency than a geared, two-speed configuration. (See Figure 3.)

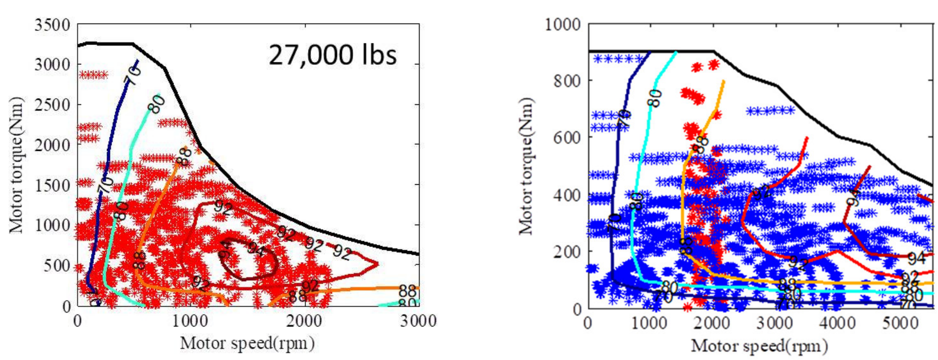


**Figure 3.** *Left: Efficiency map of TM4 3000 motor + single gear ratio on the NREL School Bus Drive Cycle. * = motor operating point. Right: Efficiency map of UQMHD 250 + Eaton 2-speed transmission. * = 1st gear motor operating point. * = 2nd gear motor operating point. Both cases: loaded vehicle weight of 27,000 lbs. Per EDI's proprietary simulation platform.*

In NREL's analysis, the indication is the opposite. (See Figure 4.) However, in NREL's case, the advantage for the geared configuration is modest. Hence, NREL concluded that "adding a transmission to the school bus does improve motor efficiency, but the impact is not significant to the extent that the current design should be revised."

| | | EDI Proprietary Simulation Platform | | NREL FASTSim Platform | |
|---|---|---|---|---|---|
| | Weight (lbs.) | Average Motor Efficiency | KWh per Mile | Average Motor Efficiency | KWh per Mile |
| TM4 motor + single speed | 33,000 | 86% | 1.84 | 84% | 1.95 |
| | 27,000 | 87% | 1.67 | 86% | 1.55 |
| | 22,000 | 87% | 1.44 | 87% | 1.31 |
| UQM motor + Eaton 2 speed gearbox | 33,000 | 85% | 2.10 | 90% | 1.76 |
| | 27,000 | 85% | 1.80 | 90% | 1.49 |
| | 22,000 | 84% | 1.56 | 91% | 1.27 |

**Figure 4.** *Motor efficiency modeling results for the NREL school bus drive cycle*.

In the thermal management domain, the original concept tagged for exploration was a system that would integrate selected vehicle functions in a series of interconnected thermal loops. Algorithms embedded within EDI's proprietary control module would receive and respond to data from an array of distributed sensors. In addition to the battery pack, the system would cover auxiliary systems such as steering and brakes whose energy consumption is influenced by the temperature of hydraulic motors and air compressors. The possibility of including the climate control function in the scheme was considered as well.

A first iteration of this system was developed and installed on an early version of prototype bus P1. The results were clear, if disappointing. Even with sophisticated controls in use, surplus heat could not be moved between on-board systems in an energy-efficient manner –and certainly not across the range of ambient conditions that school buses normally encounter.

In subsequent modeling, EDI concluded that the goal of maximizing energy efficiency could be best served by managing temperature via a series of heating-and-cooling loops dedicated to specific functions. This led to EDI's development and implementation of discrete coolant loops and sensing and control systems that could maintain batteries at prescribed temperatures; make beneficial use of surplus heat; and minimize energy consumption by associated pumps and compressors. (See Figure 5.)

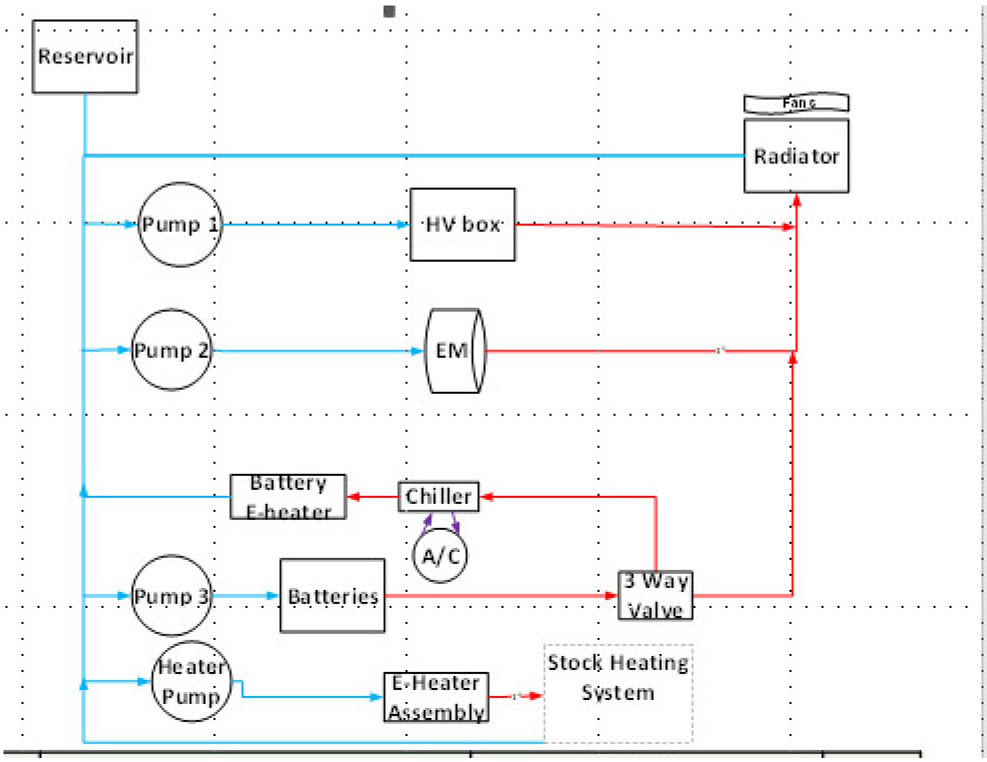


**Figure 5.** *Enhanced thermal management system based on discrete heating and cooling loops*.

In the traction energy domain, the focus was on the regenerative braking system's ability to convert a vehicle's kinetic energy back to stored electricity. Blue Bird increased regen torque when the vehicle is coasting to the maximum level consistent with safe operation without brake light activation; and implemented "closed loop" regen that is able to automatically adjust regen parameters as the vehicle encounters changing loading conditions and road grades.

In the mass reduction domain, all forms of mass were in scope even as special attention was paid to rotational mass. Inertial weight savings were obtained through foundation brake redesign that was enabled by the presence of the regenerative braking system, and the use of lightweight materials in a variety of applications. Major rotational targets included wheels (whose diameter could be reduced by virtue of the high-torque traction motor), and the driveshaft (where hollow construction could be substituted for solid construction). All told, the mass reductions removed approximately 2,000 pounds from a baseline curb weight of approximately 30,000 pounds.

In May 2019, Blue Bird sent a prototype bus that incorporated all of the energy efficiency measures developed thus far to NREL for dynamometer testing. The goal was to measure progress to date, with the primary purpose of determining the level of ambition that would be needed to achieve the ultimate goal of 1.10 kWh/mile. The team hoped the prototype would reach the halfway point of 1.32 kWh/mile.

In the event, the dynamometer testing showed an energy efficiency of 1.39 kWh/mile. Sankey diagramming revealed that the largest source of improvement came from energy regeneration in the course of braking. (See Figure 6.) Also contributing were mass reduction and lower energy consumption by pumps and compressors. (It should be noted that the beneficial effects of improved thermal management would be minimally expressed in the indoor conditions of the REFUEL facility.)

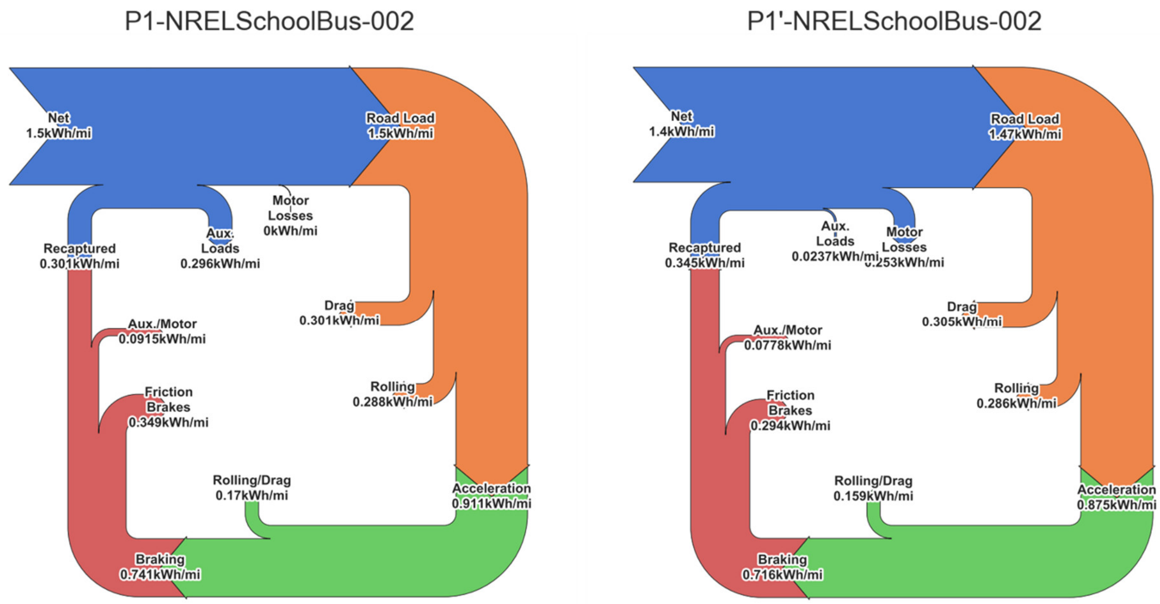


**Figure 6.** *P1 is the baseline vehicle tested in April 2018. P1' is the energy efficiency prototype tested in May 2019.*

With the prototype testing results in hand, Blue Bird conducted an analysis of the likely results from developing further energy efficiency measures. Team members used cost-benefit analysis to evaluate a list of approximately 100 potential improvements. Based on this work, Blue Bird reached two conclusions. The first was that while it would be technically possible to develop a bus that could achieve energy efficiency of 1.10 kWh/mile, the cost to produce this vehicle would be so high as to eliminate its commercial relevance. The second was that the area with the most potential for further energy efficiency improvements was higher-yield regenerative braking, and specifically redesign of the brake actuation system so that almost all deceleration would be accomplished through regenerative braking rather than friction brakes. The Blue Bird team consulted with the project's managers in the Vehicle Technology Office and agreed that the final energy efficiency target should be changed from 1.10 to 1.26 kWh/mile.

In the event, the project team never returned to the energy efficiency dimension of the project after the P1' dynamometer test. In July 2018, Cummins announced its intention to buy EDI. The sale closed later in the quarter. Over the next 30 months Blue Bird and Cummins conducted many rounds of discussion regarding Cummins' possible support for the project. Unfortunately, the companies were never able to reach an agreement.

## Charging System

The project team confronted several challenges related to its original charging concept. The team was motivated in its original goal-setting by the indication from financial modeling that revenue potential from provision of ancillary grid services is more typically driven by charging power capacity than by energy storage capacity. The 200-kW power capacity goal seemed to be high enough to generate a robust revenue stream, but not so high that it would challenge the technical capabilities of charging stations circa 2017.

Project partner EPC Power had joined the project with the stated intention of developing an inverter with the targeted bidirectional power capacity of 200 kW. Moreover, this inverter would have a form factor that would allow it to be included as an on-vehicle component. The latter capability was attractive to the team because it would lighten the burden of charging infrastructure development at host sites, both in terms of the bulkiness of curbside charging stations and their expense. (Price tags for "fast-charging" equipment went well into the five-figures). With this application in mind, project partner Nuvve developed a pole-mountable charging dispenser that they planned to price in the in the mid-four-figures. The inclusion of an on-board inverter would add to the cost of the vehicle, but EPC Power's projected pricing would result in a vehicle-plus-infrastructure cost well below that based on a standalone bus and curbside inverter. The relative affordability of the charging dispenser would also enhance the disaster resilience profile of buses by allowing municipalities to proactively install dispensers at critical sites that could be powered by electric school buses during grid outages.

This set of objectives proved to be ahead of its time. The first roadblock to appear was the notification from EPC Power that they had chosen not to proceed with development of a 200-kW on-board inverter. They arrived at this decision by weighing development cost (substantial) against likely market demand (not apparent for high-power on-board inverters). EPC Power indicated that they could feasibly develop a unit with power capacity of 150 kW by building off another of their products with that rating. The project team consulted with a variety of other inverter developers. Finding a dearth of products and interest, and after consulting with VTO representatives, the project team gave a green light to EPC Power's 150-kW proposal.

A short time after this resolution was reached another roadblock appeared. This was the notification from the project's host utility, Southern California Edison (SCE), that its willingness to allow a vehicle with a high-power on-board inverter to interconnect with its distribution system would come only after an extensive review process, the timeline for which was as yet undefined. The company's concern was that it would be difficult to ensure safety during unplanned grid outages with high-power DERs at large that could connect and export from a potentially wide variety of locations. While not a definitive refusal to entertain the project team's targeted charging architecture, SCE's hesitation put in motion a round of stock-taking. Two important considerations rose to the surface. One was that even though the on-board inverter would have a less massive form factor than a curbside charging station, it would still add approximately 600 pounds to the weight of the vehicle. Such a development would not be welcomed by the Blue Bird engineers who had worked hard to achieve 2,000 pounds of mass reduction in the recently tested prototype bus. The other consideration was that by this point (mid-2019), electric versions of many types of heavy-duty vehicles, including school buses, had appeared in the marketplace. Not one featured a high-power on-board inverter. The Blue Bird engineers took this as support for the argument that, whatever the merits of on-board inverter architecture, they were outweighed by the relative simplicity of the curbside solution: vehicle developers could optimize components core to vehicle functionality, and charging station developers could optimize components core to charging functionality. The decision to go with an off-board inverter was ratified after another round of consultation with VTO representatives.

The decision created one final hurdle for the project team: the lack of a bidirectional curbside charging station of appropriate specifications on offer from charging station developers. Nuvve had already launched its own search for a high-power bidirectional solution to meet its needs as a developer of broadly capable V2G systems. After making contact with a dozen companies, and engaging in substantive discussions with at least three, Nuvve was able to forge a partnership with Rhombus Energy Solutions. The highest Rhombus was willing to go in terms of power capacity, however, was 125 kW. The project team was called upon once more to seek and receive the concurrence of VTO representatives on a change in project specifications. Nuvve and Rhombus subsequently introduced their jointly developed apparatus to the market as the RES-HD125-V2G. (See Figure 7.)

| AC SPECIFICATIONS (POWER) | |
|---|---|
| Bidirectional Capable | Yes |
| Rated Power | 125 kW/kVA |
| Utility Grid Voltage | 480 Vac-3P |
| Max Rated Utility Current | +/-160A @ 480VAC (60 Hz) |
| Wiring | 3 phase WYE (L1, L2, L3, Neutral, Ground) or Delta (L1, L2, L3, Ground) |
| Utility Grid Frequency | 60 Hz |
| Power Factor Fange | +/- 0.5 |
| THD for Linear Loads | <5% |
| Charging Efficiency | >95% |
| Grid Isolation | Galvanic, Integrated |
| **DC OUTPUT** | |
| Maximum Power | 125 kW (625-800Vdc) |
| Voltage Operating Range | 530Vdc to 920Vdc |
| Maximum Current | +/- 200Adc (charging cable limited) |
| Connector and Cable | CCS1, up to 8m (25 ft) |

**Figure 7.** *Specifications for the Nuvve-Rhombus RES-HD125-V2G.*

Since the project guidelines issued by the Office of Energy Efficiency and Renewable Energy specifically stipulate that "Infrastructure investments must not be included in the project scope and will not be considered part of the projects funded under this area of interest", the project team had worked hard to formulate a three-part infrastructure funding plan that the partner companies could support. The on-site "make-ready" cost (i.e., installing electrical lines and related equipment up to the charging station) was the first. Here the team was able to enroll the project in SCE's Charge Ready Transport (CRT) program. SCE launched the program in May 2019 specifically to cover the make-ready costs of charging systems for heavy-duty electric vehicles. The second part was the purchase of the charging stations themselves. The price quoted by Rhombus for the 125-kW charging stations was $67,000 per unit, or $536,000 for the fleet. (Note that the figures in this and the following paragraph are estimates that were developed for various purposes in 2020 and 2021.) This was another area where Charge Ready Transport could provide financial support, but only up to $20,000 per charging station. The final part was the installation and commissioning of the charging stations, estimated at $20,000 per unit.

Toyota Tsusho America, Inc. (TAI), which had purchased an equity stake in Nuvve in 2017 and had been following the V2G school bus project ever since, now stepped forward as a financial backstop, indicating that it would be willing to fill the $536,000 gap that remained after the CRT contributions, plus cover the $40,000 per bus to which Rialto USD had committed at the project's proposal stage (well before COVID 19 wreaked havoc on school district budgets across the country). In exchange TAI asked for an undivided claim on income from credits earned in California's Low-Carbon Fuel Standard (LCFS) program and the potential profits from the provision of ancillary grid services. Nuvve estimated that LCFS credits would amount to $261,000 over the full 12-year life of the DER asset. The V2G profits, if any, would be the net of gross income from CAISO, estimated at $5,000 per bus per year; and the fees paid to Nuvve for the use of their V2G platform ($4,000 per year); fees paid to a scheduling coordinator (required by CAISO; estimated at $8,000 per year); and maintenance of the charging system (estimated at $211,000 over the asset's lifetime). When all cash in was netted against all cash out, TAI was looking at a negative (cash out of pocket) total of $470,000. (Indirect costs, e.g., for managerial and technical time, are not included in this balance.) This figure should be seen as the best-case scenario for TAI given the many risks and obstacles that would need to be overcome before the first dollar of V2G profits could be realized

## V2G Function – Regulatory Aspects

The current system for electric grid interconnections in California is based on a fundamental jurisdictional split between the California Public Utility Commission (CPUC) and the Federal Energy Regulation Commission (FERC). CPUC regulates utilities. FERC regulates the state's power market. CPUC is responsible for non-traditional generators whose output is managed within a utility's distribution system. FERC is responsible for generators who operate in parallel with traditional utilities. Rule 21, the main interconnection regulation on the CPUC side, covers all "CPUC-jurisdictional interconnections, which include the interconnection of all net energy metering (NEM) facilities, 'non-export' facilities, and qualifying facilities intending to sell power at avoided cost to the host utility".[1] The main regulation on the FERC side is the Wholesale Distribution Access Tariff (WDAT) which is defined as "the tariff through which open access transmission service and interconnection service are offered by SCE".[2] It should be noted that the role of both CPUC and FERC is to promulgate the interconnection framework and define application procedures. SCE is responsible for administering the application process for all parties looking to interconnect in its service territory. Neither of these regulatory frameworks, in their current states, are set up to accommodate DERs consisting of V2G-capable vehicles. The project team was aware of this circumstance from the outset, and was committed to pioneering a first-of-its-kind path through the interconnection application process in California.

The lack of a fully fledged regulatory framework is not simply a case of regulatory inertia, where a common-sense solution is readily at hand for regulators to embrace. Rather, a legitimate regulatory conundrum is at play. The challenge originates in the two distinct roles that V2G school buses can play. In their role as transportation assets, the buses are conventional electric loads that draw energy from the grid. In this guise, it makes sense for the commercial relationship between customer and utility to be governed by one of the CPUC-approved retail electricity tariffs. In their use as DERs, the buses (in their collective identity as a fleet) either take on or export electricity pursuant to the provision of valuable services to the electric grid. Since the fleet is not acting as a load, a retail tariff by definition should not be applicable. (The fact that electricity is flowing in both directions would appear to give the fleet something in common with a net-energy-metered (NEM) resource, such as a rooftop panel installation, but key dissimilarities are clear: incoming electricity while the fleet is providing grid services is not being provided to support a load, and the outgoing electricity is not being generated on the buses.) The centrality of this challenge can be seen in its treatment in FERC Order No. 2222, which "directs the grid operators to allow DERs that participate in one or more retail programs to participate in its wholesale

[1] California Public Utilities Commission, "Rule 21 Interconnection", Web page consulted on May 2, 2022

[2] Law Insider, consulted July 1, 2022

markets and to provide multiple wholesale services, but to include any appropriate, narrowly designed restrictions necessary to avoid double counting."[3]

Project team members, with Nuvve and TAI in the lead, launched several strands of collaborative activity with designated units within SCE. The first was submission of a completed WDAT interconnection application at the end of March 2021. The application sought interconnection for a 1 MW DER, consisting of eight school buses, each with the capacity to import and export power at the rate of 125 kW.

The WDAT framework is set up to accommodate projects of differing scales and complexities, up to and including utility-scale generating stations. At the low end of the scale, it includes a "Fast Track" application path, which SCE defines as "an expedited process to evaluate a request to interconnect eligible new generation [which] is intended for projects up to 5 MW".[4] The Fast Track features lower application processing fees and a shorter timeline than the heavier-duty Independent Study Process. Since it is clear that interconnection affordability and timeliness will be important attributes for V2G fleet projects, the project team was disappointed when SCE determined that its application would not be eligible for the Fast Track. By way of explanation, SCE cited a restriction in its WDAT tariff that made any storage project that charged from the grid (as opposed to an on-site generating facility) categorically ineligible for Fast Track. (The restriction was ultimately eliminated in a settlement between interested parties and SCE, albeit after the project had been brought to a close.)

Over the ensuing year the project team navigated the steps stipulated by the Independent Study Process. One milestone came with SCE's completion of a System Impact Study (SIS). The SIS determined that the DER deployment would necessitate several upgrades to the distribution circuit that services the Rialto USD school bus fueling facility. Of note was the need for sensing and communications equipment at the circuit's substation that would be capable of handling the bidirectional flow of electricity. (SCE determined that power could flow "upstream" if the DER discharged at maximum capacity at the same time solar panels installed along the circuit were also generating at maximum capacity.) The cost for the upgrades was estimated at almost $1.1 million, all of which would need to be borne by TAI as the interconnection applicant. (Based on this indication, TAI paid in December 2021 the first installment of the required fees in the amount of $133,000.) The SIS also estimated the time required for SCE to complete its circuit upgrades at "approximately 11-12 months from the time the Interconnection Customer provides a complete Design Package".

A subsequent milestone was SCE's completion of a Facility Study Report (FSR), the purpose of which was to refine the estimated cost and timing for the system upgrades. On the cost side, the estimate was revised down to approximately $770,000. On the timing side, the estimate was revised up to approximately 20 months, exclusive of the time that would be required for the project team to complete its design and administrative items. Based on this input, the project team concluded that a realistic estimate for the in-service date would be sometime in the latter half of 2024.

While TAI was prepared to fill in the funding gap for the project's charging infrastructure, and probably would have been willing to absorb a few tens of thousands of dollars of SCE system upgrade cost, an additional $770,000 – for a net out-of-pocket cost well in excess of $1 million – was likely more than the

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[3] FERC, "FERC Order No. 2222: Fact Sheet", September 17, 2020

[4] SCE, "Frequently Asked Questions for SCE's Wholesale Generation Interconnection", 9/3/19; PDF p. 7

company would be able to shoulder. Further complicating TAI's calculus was the SCE timeline. The concern was that the further the timeline got extended, the more likely the project would lose the commitment of critical partners.

The other major strand of activity on the regulatory side was the project team's collaboration with SCE toward resolution of the questions that form the "split tariff" conundrum mentioned above: 1) what tariff should apply when a school bus fleet is providing grid services? And 2) how can each kWh be properly tracked and categorized as it passes through a meter on its way to or from a bus?

An SCE working group determined that the company's Station Power for Energy Storage Devices (SPESD) schedule may be the basis for an answer to the first question. The key aspect of the SPESD is its allowance of separately metered wholesale (for charging energy storage devices) and retail (for station power) electricity flows. The identification of this tariff seemed especially promising since it allows SCE to, "at its discretion accept alternative metering and measurement arrangements to the extent that the metering and measuring arrangement reasonably captures Station Power load and does not impose an administrative burden on SCE".[5] The project team was optimistic that SCE would recognize charging of the buses for transportation purposes as a form of station power that is functionally indistinguishable from station power used for premises lighting, cooling, etc.

Working with energy industry consultant Better Energies, the project team developed a potential "split tariff" concept that features simplicity in design, ease of implementation, and both accuracy and fairness in its allocation of electricity flows to the relevant tariffs. (See Figure 8.) The key to the concept is the separate measurement of inbound and outbound kWhs. The difference between the two quantities (after accounting for round trip efficiency losses) is labeled "driving kWhs". The electricity customer would pay for driving kWhs under the applicable retail tariff. The customer would pay for the remaining inbound kWhs under the applicable wholesales tariff. For example (ignoring losses for simplicity), if a bus took on a total of 100 kWh of electricity in a given 24-hour period, and exported a net of 30 kWh while providing ancillary grid services in that same period, 70 kWh would fall into the "driving" category and be billed at the retail rate. The remaining 30 kWh of imported electricity would be billed at the wholesale rate.

[5] SCE, "Schedule SPESD Station Power for Energy Storage Devices", 5/26/17

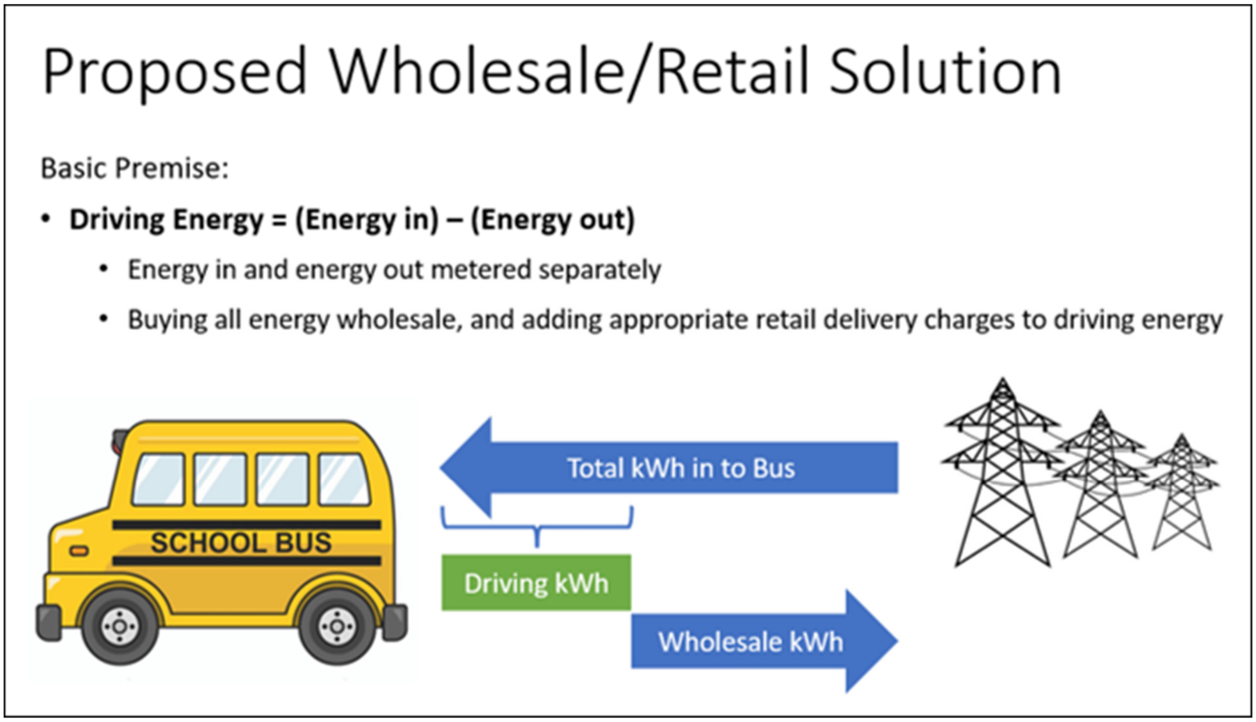


**Figure 8.** *Better Energies' proposed resolution to the wholesale/retail "split tariff" conundrum.*

The project team acknowledged that further work would be needed on the concept in at least one area. This is its application when time-of-use (TOU) tariffs are in play. In this case, since a bus could charge and provide grid services over two or more time-of-use bands, it would be impossible to give each driving kWh a definitive time stamp.

Discussions of this proposal with SCE went on for more than year. The company's working group expressed interest in the concept and pledged to study it. The group did not communicate any conclusions before the project was brought to an end.

Although the project team did not reach its goal of operating a school bus fleet on a dual-use basis, it did highlight the specific hurdles that stand in the way of DERs based on heavy-duty vehicle fleets in California. At the top of the list is the lack of a regulatory framework that has been designed for the particular attributes of such DERs. Today there is a framework for utility-scale generators; one for large-scale energy storage deployments; and one for net-energy metered solar installations; but nothing that corresponds with the unique characteristics of a DER in the 1-10 MW range whose energy storage devices are also able to do useful work in another context. Interested parties in the regulatory establishment should take note, given the state's ambitious goals for achieving a clean, resilient electricity grid.

# Products Developed under the Award

National Renewable Energy Laboratory conference paper:

Becker, W., et al., "Cost Reduction of School Bus Fleet Electrification With Optimized Charging and Distributed Energy Resources", Conference Paper NREL/CP-7A40-74187, March 2020