2021 DoE Vehicle Technologies Office Annual Merit Review

V2G Electric School Bus Commercialization Project

Project ID: elt095

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Overview

Timeline

- Project start date: 1/19/17
- Project end date: 4/30/24
- Percent complete: 50%

Budget

- Total project funding: $9,804,528
  - DoE share: $4,902,237
  - Contractor share: $4,902,291

Partners

- Project lead: Blue Bird
- Charging system partners
  - Nuvve
  - Southern California Edison
- School bus host: Rialto USD
- Contributing funder: So. Coast AQMD
- Technology resource: NREL
- Project manager: National Strategies

Barriers

- Vehicle cost
  - Cost/performance trade-offs are inevitable but the best compromises for heavy-duty EVs have not been thoroughly mapped
- Preparedness for EV-grid integration
  - Many aspects of the systems needed to support advanced EV-grid integration remain partially or entirely undefined
  - Standards are still in development, cybersecurity protocols have not been applied, and metering and tariff schemes are wholly unaddressed

Relevance

Project is addressing VTO's core objective of reducing the cost of PEVs, and VTO's specific Electrification R&D objective of understanding the potential impacts of EV charging on the nation's electric grid – in both cases through pioneering V2G technology in heavy-duty vehicles

Overall Objectives

- Create a compelling value proposition for electric school buses based on a competitive total cost of ownership
- Advance the technical maturity of selected medium-duty electric drive components to achieve superior energy efficiency and reduce operating costs
- Enable V2G and V2B income-generating grid integration

Objectives this Period

- Advance the elements needed to enable electric school bus fleets to function as DERs that can provide active, compensated forms of grid support
  - Specification and procurement of high-power bidirectional EVSEs
  - Interconnection contracting for EV-based distributed energy resources (DERs)
  - Metering and tariffs to support service provision on utility and RTO networks

Collaboration and Coordination - 1

Active project participants

- Blue Bird (vehicle OEM)
- National Strategies (NSI) (project manager)
- Rialto Unified School District (school bus owner and DER host)
- A2Z Bus Sales (Blue Bird dealer and vehicle interface for Rialto USD)
- Nuvve (V2G integrator and project team member)
- Toyota Tsusho New Energy (technical advisor and financial integrator for Rialto USD)
- Southern California Edison (host utility)
- California Independent System Operator (host grid balancing authority)
- National Renewable Energy Laboratory (NREL) (technical expert on vehicle energy efficiency and energy system measurement)
- South Coast Air Quality Management District (project co-funder and technical advisor)
- Vehicle Technologies Office (lead project funder and technical advisor)

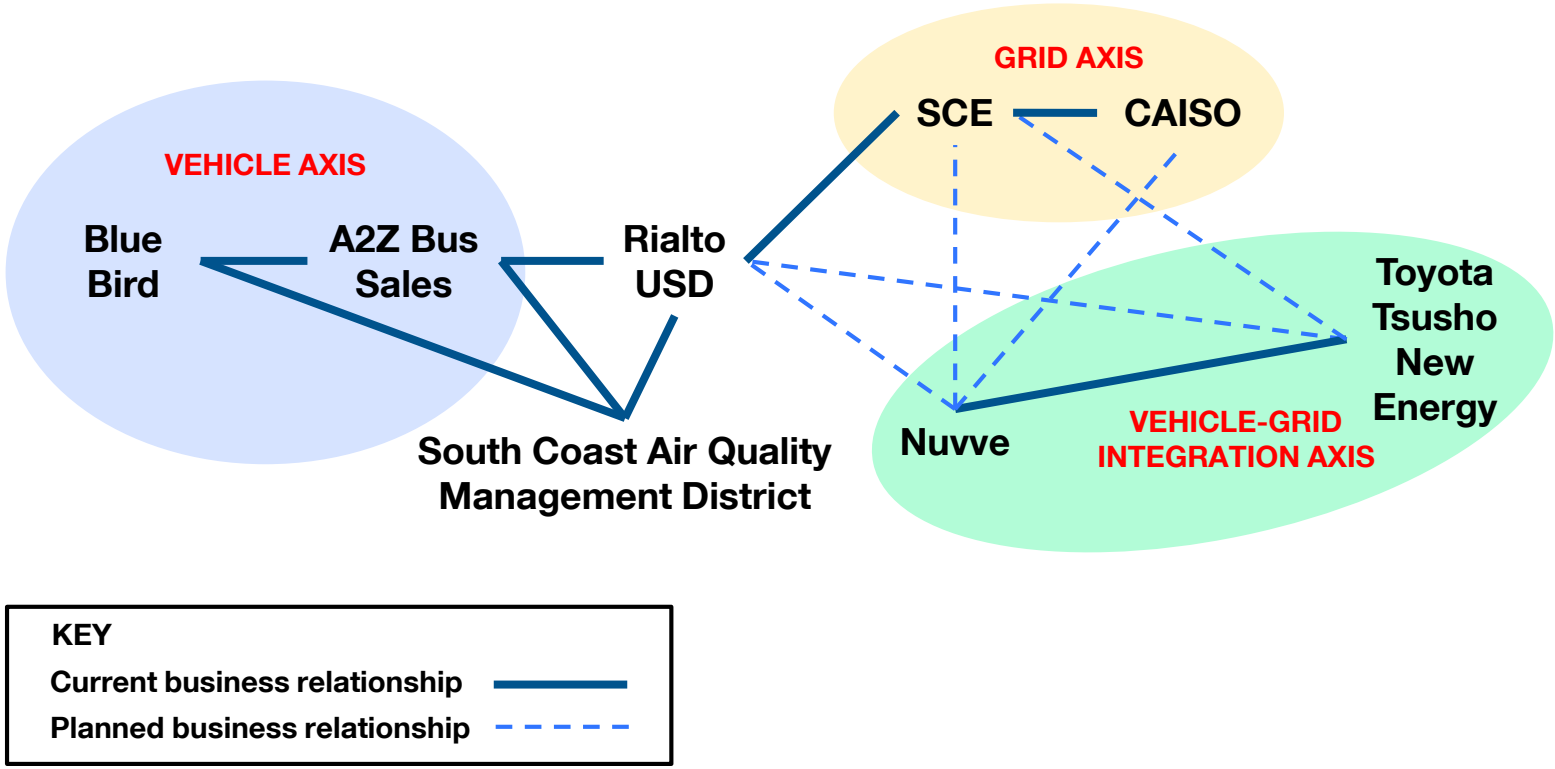
Collaboration and Coordination - 2

Collaboration and Coordination Modalities

- Primary collaboration and coordination occurs through recurring and ad hoc meetings involving project team members and participating stakeholders
  - NSI, as program manager, tracks all processes and facilitates communication and meeting scheduling across all relevant parties
- Collaboration and coordination are also occurring on tracks parallel to the project:
  - NREL draws upon its participation in the project to advance technical frontiers in selected areas (e.g., "Cost Reduction of School Bus Fleet Electrification With Optimized Charging and Distributed Energy Resources", conference paper, March 2020)
  - Blue Bird and Nuvve are participating in SCE's Vehicle-to-Grid Integration Project (2021-23, total funding of $3 million from the California Energy Commission's Electric Program Investment Charge (EPIC) Program)
  - "Make-ready" elements of Rialto USD's charging infrastructure will be funded and installed by SCE's Charge Ready Transport Program

Approach

- The current phase of the project involves development of the macro systems within which the V2G school bus fleet can function as a grid management tool and income-generating DER
- Requires high-intensity collaboration across a variety of stakeholders



Technical Accomplishments and Progress - I

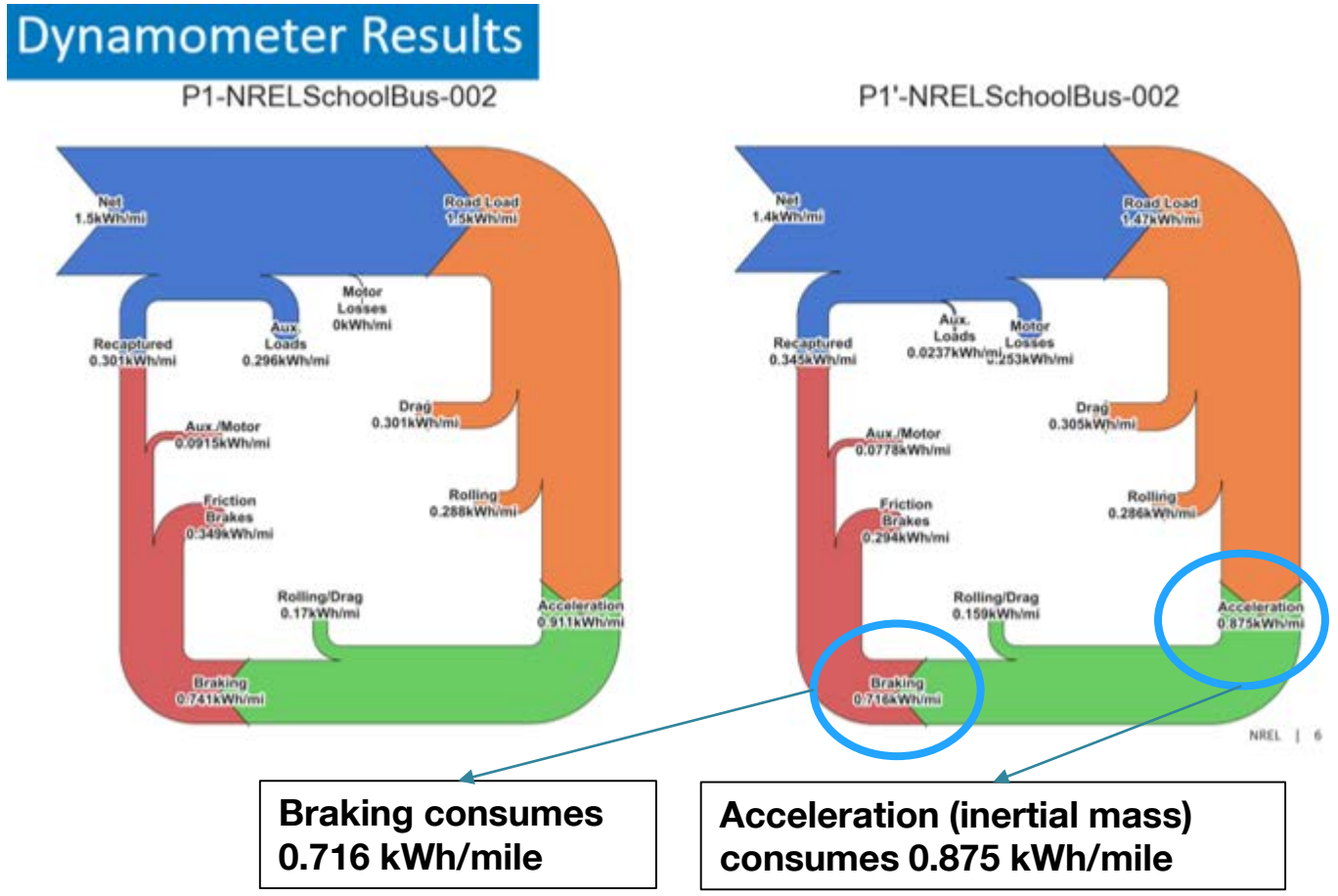
- Completed first energy efficiency campaign with testing and analysis at NREL's ReFUEL dynamometer
  - Improvement of 9% (to 1.39 from 1.53 kWh/mile) vs. the efficiency baseline, short of the 14% improvement target (1.32 kWh/mile)

Key takeaways

- "P1' has accomplished reduced energy consumption through lower rolling resistance tires, more aggressive regenerative braking, and light-weighting."

  -- NREL report

- Regenerative braking and weight reduction are the major opportunities for further efficiency improvements



Technical Accomplishments and Progress - II

- The primary focus of technical effort over the last 24 months has been on the charging and grid integration sides of the project
- Advances have been made in:
  1. Modeling the revenue generation opportunity from the provision of grid services
  2. Building the high-power bidirectional charging and communications chain
  3. Developing protocols under which a school bus DER can function as a node on a utility distribution circuit

Note: Based on stakeholder consultation, in 4QF19 the decision was made to change from an on-board inverter ("AC charging") to an off-board inverter ("DC charging")

Technical Accomplishments and Progress - II.1

Modeling the revenue generation opportunity from provision of grid services

- NSI led the creation of a comparative TCO model that draws on:
  - The world's first V2G school bus project (led by NSI in Torrance, CA, 2014-2019)
  - NSI's consulting work with a range of utilities interested in H-D fleet V2G
  - Experience from the first generation of electric school bus deployments

Key takeaways

- Annual V2G revenues can be substantial
- Variable and fixed costs can also be substantial
- In some cases, costs will depend on tariffs that have not yet been established
- In cases where costs can be reasonably estimated, V2G profits can play a meaningful role in the TCO equation

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.

Technical Accomplishments and Progress - II.2 - 1

High-power bidirectional charging and communications chain

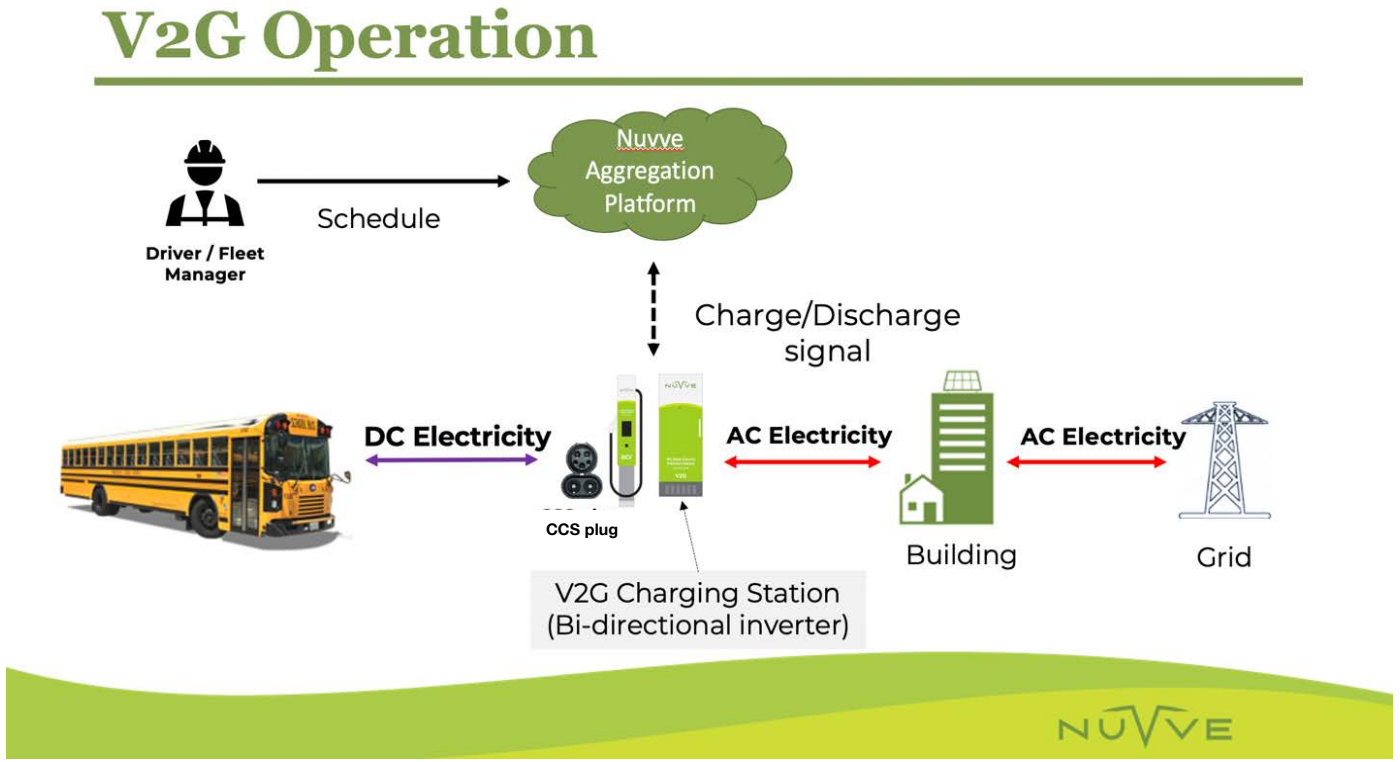
- Nuvve engaged in a year-long process of
  - Cultivating vendor interest in the development of high-power bidirectional charging equipment
  - Negotiating terms of engagement with most promising vendors
  - Concluding an agreement for a 125 kW bidirectional EVSE
  - Co-developing the hardware and software elements of the product
  - Receiving IEEE 1547, IEEE 2030.5, UL 1741, UL 2202, CSA 22.2 certifications for the EVSE
- Developed a paired set electric vehicle communication controller (EVCC) and supply equipment communication controller (SECC) and demonstrated with 60 kW EVSE and standard Blue Bird bus utilizing a Cummins drivetrain

Note: The process of vendor cultivation led to the decision in 3QF20 to move from bidirectional charging power capacity of 150 kW to 125 kW

Technical Accomplishments and Progress - II.2 -2

High-power bidirectional charging and communications chain

Key takeaway: The V2G fleet concept is dependent on high-power bidirectional charging; this aspect of the project has created an indispensable part of the complete solution



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Technical Accomplishments and Progress - II.3

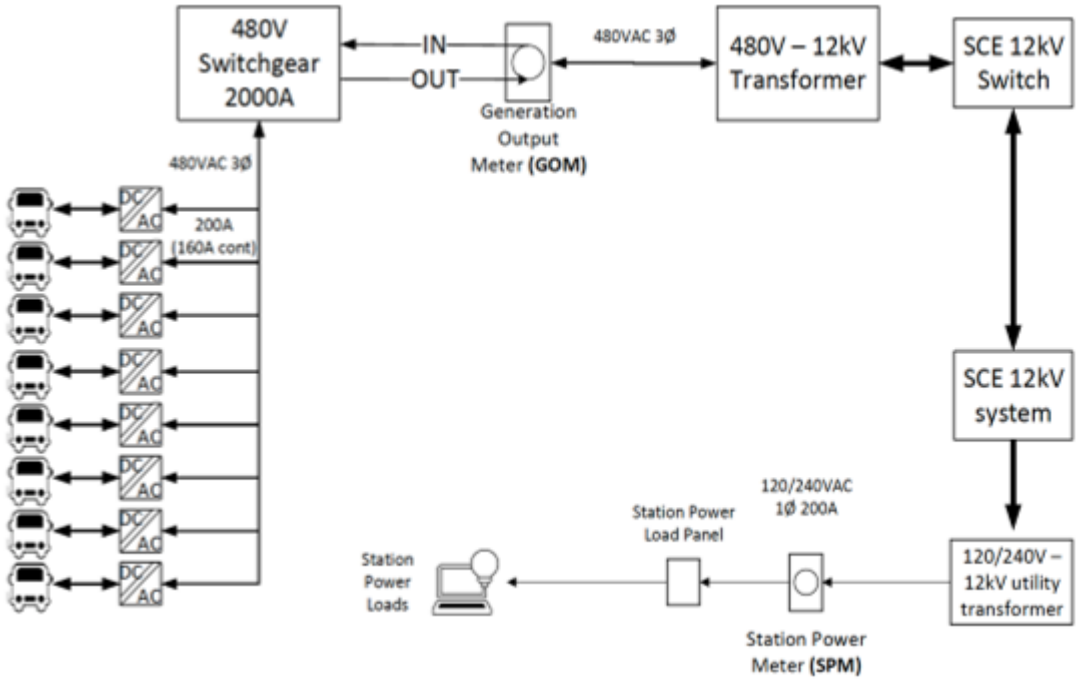
School bus DER as a node on a utility distribution circuit

- The project team is collaborating with Southern California Edison to profile, lab test, and on-site pilot a bidirectional school bus + EVSE system within SCE's first-generation distributed energy resource management system (DERMS)

Key takeaways

- The process will involve major ground-breaking on the regulatory front
  - SCE has determined that Toyota Tsusho's WDAT interconnection application must be evaluated in an Independent Study Process
  - The metering and tariff proposal will need to go before the CPUC

Toyota Tsusho New Energy's metering proposal



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Responses to 2019 Reviewer Comments - 1

Comments	Responses
"There should have been an itemized energy analysis to show how each accomplishment contributed incrementally to the goal of achieving an energy efficiency of 1.32 kWh/mile)"	With bus development occurring in Georgia and dynamometer testing in Colorado, it was not feasible to measure the incremental contribution of each improvement. The team was able to draw high-level conclusions based NREL's Sankey analysis of the dynamometer results. (See slide 7.)
"The V2G contribution is questionable – the technology is still in its infancy."	Project partner Nuvve has been engaged in commercial V2G operations using light-duty vehicles since 2016. The V2G School Bus Commercialization Project is the pioneering effort for heavy-duty fleets, and is showing that DER-related contractual and regulatory arrangements are the constraining factors, not technology. Definitive conclusions about V2G's economic contribution can not be made until the contractual and regulatory arrangements have been established, but modeling to date points to favorable prospects. (See slide 9.)

Note: The project was not reviewed in 2020

Responses to 2019 Reviewer Comments - 2

Comments	Responses
"DC bidirectional charging could offer the overarching target of vehicle weight and packaging."	The project team confronted this point after experiencing the difficulty of reducing bus weight while developing prototype bus P1'. When SCE stated that AC charging (on-board inverter) would complicate the process of bringing a V2G school bus fleet on line as a DER, the team made the decision to move to DC (off-board) architecture. (This is noted on slide 8.)
"The design of the high-power charging systems is lagging where components for high-power AC charging are only appearing slowly and the pathway to conform with existing and emerging standards is not well established."	This comment was entirely accurate in describing the situation in 2019 for high-power bidirectional charging, AC or DC. Shortly after the comment was made, the project team initiated a multi-faceted work program to bring into being components that would support the project's objectives. Great progress has been made in this regard, not least in the area of the applicable existing and emerging standards. (See slide 10.)

Note: The project was not reviewed in 2020

Remaining Challenges and Barriers

Achieving energy efficiency objectives

- The challenge will be to cover the energy efficiency distance from 1.39 to the revised end goal of 1.26 kWh/mile
  - . . . With measures that will make a positive contribution to the vehicle's economic value proposition

Completing arrangements for Rialto USD's electric school bus fleet to function as a DER

- While the process for applying for an interconnection agreement is well defined, it remains to be seen how a DER consisting of heavy-duty electric vehicles will fare in that process
  - . . . And the process for establishing the terms of DER participation within SCE's distribution grid is currently undefined

Proposed Future Research (through FY22)

Dig more deeply into selected energy efficiency measures

- Renew focus on weight reduction and regenerative braking

Develop an approach for authorizing a vehicle-based DER

- Obtain interconnection agreement with SCE
- Negotiate terms of DER participation within SCE distribution grid

Explore commercialization options

- Define optimal business model based on convergent interests of potential partners (school districts, utilities, renewable energy developers, financial institutions . . .)

Progress in each of these research areas is required if the project is to achieve its core objectives

Any proposed future work is subject to change based on funding levels

FY21 and FY22 Milestones

Milestone	Description	Completion Date	Status
M5. Interconnection application deemed "adequate and complete" by SCE (sub-task 2.4.3)	SCE will determine if the submitted interconnection application contains all of the information necessary for processing by its interconnection department.	March 2021	Complete
M6-G/NG #2. On-board electrical system equipped for high-power charging (sub-task 2.6.5)	Blue Bird will complete and test the on-board circuits and components that will allow high-power charging and discharging.	September 2022	On track
M7-G/NG #3. Prototype P3 commissioning (sub-task 2.11.5)	P3 is built and commissioned for testing in advance of the B1-B7 builds.	September 2022	On track

Source: Statement of Project Objectives, revision 4/9/21

Summary

- Over the last 24 months the project team has made strides on the “V2G” part of the V2G Electric School Bus Commercialization Project
  - Most of the necessary elements have been brought into existence
  - Those remaining are the most challenging, but the project team is bringing a sharp focus to bear on them
- Over the rest of FY2021 and FY2022, the project team will:
  - Return to the vehicle dimension of the project and the quest for an economically optimized energy efficiency package
  - Seek to complete the necessary V2G-related arrangements

Achievement of the project‘s objectives will meaningfully advance VTO’s objectives related to electric vehicle technology