
2019 DoE Vehicle Technologies Office Annual Merit Review

# Blue Bird V2G Electric School Bus Commercialization Project

***Project ID: EE0007995***

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BLUE BIRD
A heritage of looking ahead.

*This presentation does not contain any proprietary, confidential, or otherwise restricted information*

# Overview

## Timeline

- Project start date: 1/19/17
- Project end date: 8/31/21
- Percent complete: 40%

## Budget

- Total project funding: $9,804,528
  - DoE share: $4,902,237
  - Contractor share: $4,902,291
  - FY18 funding: $2,226,000

## Partners

- Project lead: Blue Bird
- Vehicle subcontractors:
  - Cummins Electrified Power
  - EPC Power
- 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
- Design of high-power charging system
  - Strong case for on-board inverter but size and weight are issues
  - Interface components for high-power AC charging are appearing slowly
  - Pathway to conform with existing and emerging standards is not well established

# 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
- ❖ Equip with V2G and V2B income-generating grid integration capabilities
- ❖ Advance the technical maturity of selected medium-duty electric drive components to achieve superior energy efficiency and reduce operating costs

**Objectives this Period**

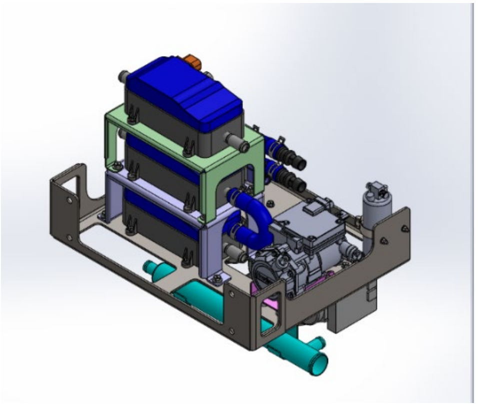
- ❖ Achieve energy efficiency of 1.32 kWh/mile or better for prototype bus P1' --halfway to the ultimate target of 1.10 kWh/mile from the initial P1 benchmark of 1.53 kWh/mile (note: climate control is excluded from efficiency benchmark)
- ❖ Initiate process of adapting high-power inverter platform to on-vehicle deployment
- ❖ Complete design of charging interface and specification of essential components

# Approach

- Technical approach is driven by the nature of the project's ultimate outcome:
  - A cost-competitive vehicle ready for immediate commercial offer
- Requires exploration of potential technology improvements and prioritization of those that deliver the best value
- Provides an opportunity to revisit the conventions of school bus design and see which ones need to be changed to meet the parameters of vehicle electrification
- Team started with three tightly defined technology improvement focuses. . .
  - Integrated thermal management
  - Advanced telematics
  - High-power charge/discharge capability
- . . . and one broad category: "smart design"
  - This grew into a list of >100 improvement ideas
  - Each was evaluated based on the ratio of efficiency improvement to required engineering effort as well as cost effectiveness
  - Top three subcategories with the most opportunity: traction energy budget; mass reduction (especially rotational mass); friction reduction

# Technical Accomplishments and Progress

## Integrated Thermal Management



**Starting point**

- Explore use of sensing, controls, and coolant loops to maintain batteries at optimal temperature and make beneficial use of surplus heat

**Accomplishments**

- Improved thermal management of batteries via high-performance heating/cooling loop and enhanced insulation
- Reduced "on time" for coolant pump and AC compressor for battery cooling by 30%
- Reduced "on time" for coolant pump and fan for motor and power electronics by 25%
- Fully implemented and refined variable speed control on all coolant pumps to further reduce energy consumption of 12V accessories
- Eliminated 10% of hoses and connections and removed all 3-way valves to simplify coolant routing; resulted in reduced pumping losses, less energy use by 12V pump
- Reduced overall weight of thermal management system by 16 kg

# Technical Accomplishments and Progress

## Telematics

**Starting Point**

- Adjust electric drive parameters in real time to anticipate conditions on the route ahead

**Progress**

- Experimentation and modeling indicate that real-time adjustment of electric drive parameters introduces significant complexity . . .
- But yields limited benefits beyond what can be gained from basic route planning (opportunity is to add an “EV layer” to the standard approach for school bus operations)
- Better is to focus on smarter onboard feedback control of acceleration and deceleration (addressed in Traction Energy Budget)

# Technical Accomplishments and Progress

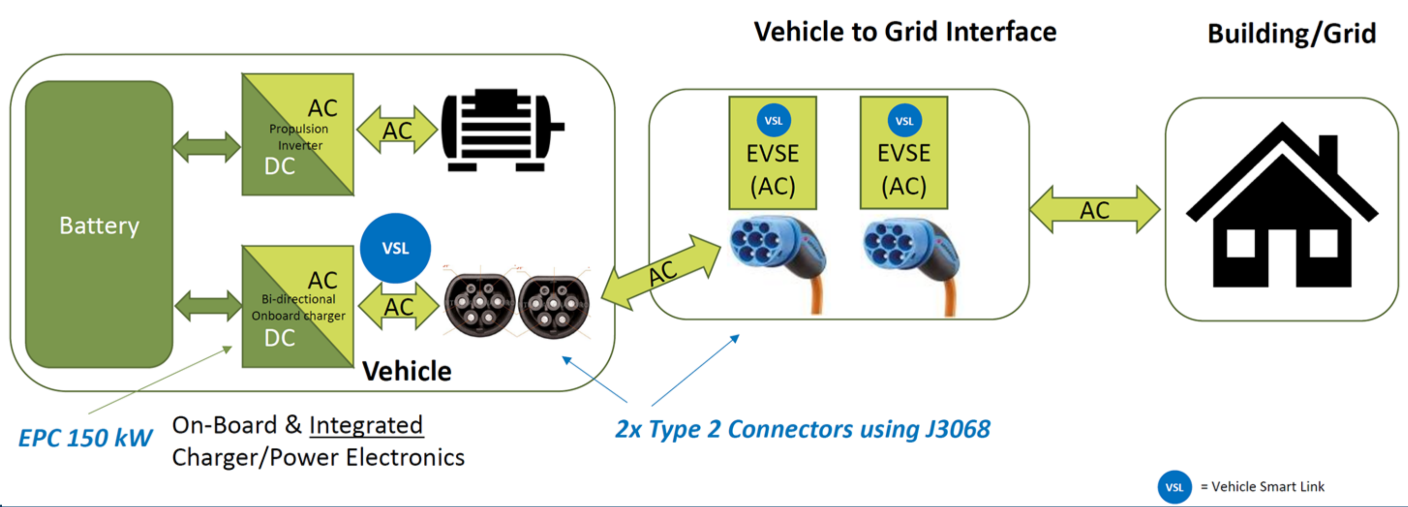
## Charging System Design: On-Board Inverter

**Starting Point**

- Maximize power inverter capacity (200 kW) in order to maximize revenue generation from provision of ancillary grid services
  - Drive speed and communication requirements and implement into a standard DBC file for power import and export

**Progress**

- Cost assessment and commercial interface availability led to the decision to reduce inverter power to 150 kW; still enough to allow favorable revenue/TCO for the buses
- **Team on track with software development/DBC file for rapid power import and export**



# Technical Accomplishments and Progress

**Smart Design: Traction Energy Budget**

**Accomplishments (completed)**

- Increased regen torque when not touching either pedal ("coasting regen") to maximum level consistent with safe operation without turning on brake lights
- Implement closed loop regen to make sure maximum regen is achieved in all loading conditions on all road grades

**Accomplishments (in process)**

- Implement two-stage brake pedal to achieve maximum regen torque when driver wants to stop bus without engaging friction brakes
  - Because this requires new brake pedal hardware and sensors, an alternative would be "single pedal" drive mode
  - This would apply enough brake regen when lifting off accelerator pedal that friction brakes are rarely needed and only when coming to a complete stop
  - Time and cost will determine method chosen

# Technical Accomplishments and Progress

**Smart Design: Rotational Mass and Inertia Reduction**

**Accomplishments**

- Team selected the following based on value
  - Foundation brakes: take advantage of regenerative braking capacity to reduce bulk and mass
  - Seats: Reconceive all aspects of seat design (use aluminum for frames, track system for mooring)
  - Wheel size: reduce to take advantage of high-torque traction motor
  - Lightweight wheels: substitute aluminum for steel
  - Springs: substitute composite material for steel
  - Driveshaft: substitute hollow construction for conventional
  - Low friction paint and other drag reduction devices

  *[Target weight reduction estimate is > 2000 lbs]*

# Technical Accomplishments and Progress

## Smart Design: Friction Reduction

**Identify opportunities to reduce friction in all of its forms**

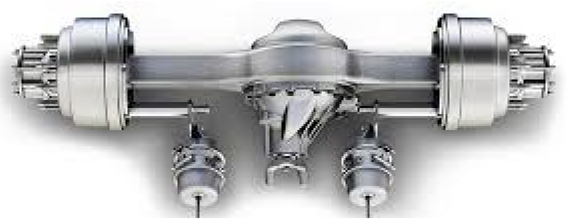
- Mechanical friction in axles, drive lines, wheels. wheel ends, tires, and brakes
- Aero (not a big contributor at school bus speeds but possibly significant)

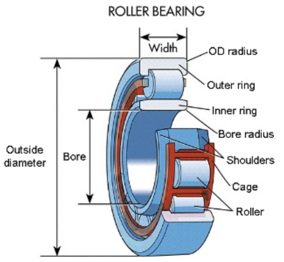
**Accomplishments (completed)**

- Low rolling resistance tires and bearings
- Aerodynamic enhancements: low-friction paint; belly pan; radiator orientation; close front cowl opening  (modeled only)

**Accomplishments (in process)**

- Low-friction rear axle / differential





# Milestones

| | Milestone | 1 | | | | | | | | 2 | | | | 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Milestone | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | J17 | A17 | S17 | O17 | N17 | D17 | J18 | F18 | M18 | A18 | M18 | J18 | J18 | A18 | S18 | O18 |
| **Task 1.2 Optimize Drivetrain Design** | | | | | | | | | | | | | | | | | |
| Task 1.2.2 Select best drivetrain option | M1 | | | | | | | | | | | | | | | | |
| **Task 1.8 Prototype Vehicle P1 Integration** | | | | | | | | | | | | | | | | | |
| Task 1.8.6 Test and evaluate P1 at NREL | M2 | | | | | | | | | | | | | | | | |
| **Task 1.9 Prototype Vehicle P1' Integration** | | | | | | | | | | | | | | | | | |
| Task 1.9.4 Test and evaluate P1' at NREL | M4, G/N-G#1 | | | | | | | | | | | | | | | | |
| **Task 1.10 Prototype Vehicle P2 Fabrication** | | | | | | | | | | | | | | | | | |
| Task 1.10.2 Fabricate P2 drivetrain assemblies | M3 | | | | | | | | | | | | | | | | |
| **Task 2.1 Prototype Bus P3 Integration** | | | | | | | | | | | | | | | | | |
| Task 2.1.2 Fabricate P3 drivetrain assemblies | M5 | | | | | | | | | | | | | | | | |
| **Task 2.2 Testing of Prototype Bus P3** | | | | | | | | | | | | | | | | | |
| Task 2.2.5 Inverter profiling and testing at NREL | M6, G/N-G#2 | | | | | | | | | | | | | | | | |
| **Task 2.3 Power2E Inverter Certification** | | | | | | | | | | | | | | | | | |
| Task 2.3.5 NRTL documentation | M7 | | | | | | | | | | | | | | | | |
| **Task 2.4 Prototype Bus P4 Efficiency Campaign** | | | | | | | | | | | | | | | | | |
| Task 2.4.8 Test and evaluate P4 at NREL | M8, G/N-G#3 | | | | | | | | | | | | | | | | |
| **Task 2.6 Production Bus (B1-B8) Integration** | | | | | | | | | | | | | | | | | |
| Task 2.6.9 B5-B8 delivery | M10 | | | | | | | | | | | | | | | | |
| **Task 2.7 Market Transformation Plan** | | | | | | | | | | | | | | | | | |
| Task 2.7.1 Battery lease development | M9 | | | | | | | | | | | | | | | | |
| Task 2.7.2 Stage 1 commercialization | M11 | | | | | | | | | | | | | | | | |
| **Task 3.2 Project Conclusion** | | | | | | | | | | | | | | | | | |
| Task 3.2.2 Long-term data archiving | M12 | | | | | | | | | | | | | | | | |

**Completed Milestone**

# Responses to 2018 Reviewer Comments

| Comments | Responses |
| --- | --- |
| The economic case for the high-power bidirectional charging and provision of ancillary grid services was not made | Team member experience and desk modeling indicate the strong likelihood that the economic case will be favorable; demonstrating the economics in the real world is an explicit project objective |
| The research plan does not address key cost barriers to adoption or state and federal certification issues | Over the last year, the research plan has increasingly focused on reducing the cost of EV school buses; state and federal certifications are always critical for school buses |
| Strategies for achieving the core energy efficiency target were not adequately described, including the role of the energy storage system, power electronics, thermal management, cabin climate control, and weight reduction | Over the last year, the team's allocation of effort has shifted from 3 main efficiency areas (including thermal management) to a broader list of targets that has considerable overlap with the DoE's Super Truck program |

# Collaboration and Coordination

**The effort is supported by a multi-disciplinary project team and supportive group of stakeholders**

**STAKEHOLDER GROUP**

Interested Parties
- Clean transportation NGOs
- California Public Utility Commission

**PROJECT TEAM**

Vehicle Development

Prime Contractor
- Blue Bird

Core Team
- Cummins EP
- EPC Power
- NREL
- NSI
- Nuvve

Deployment Team
- Rialto USD
- Scheduling coordinator TBD
- So Cal Edison
- South Coast AQMD

V2G Implementation
- CAISO

V2G Technology
- University of Delaware

Early Adopters
- Regional utilities
- School districts

# Remaining Challenges and Barriers

**Achieve technology improvement objectives**

- Cover the energy efficiency distance from 1.32 to 1.10 kWh/mile
- Package and certify the150 kW bidirectional on-board inverter

**Implement charging system**

- Obtain interconnection agreement with Southern California Edison
- Install high-power charging equipment
- Commission V2G charging stations

**Demonstrate buses as both transportation assets and distributed energy resources**

- Operate in daily pupil transport service
- Participate in CAISO’s wholesale power markets
- Document total-cost-of-ownership parameters (e.g., electricity expense, revenue generation)

**Commercialization**

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

# Proposed Future Research

## Energy Efficiency

- Determine methods to maximize energy recapture
- Determine methods to minimize energy consumed by auxiliaries
- Determine final selection of lightweighting measures
- Incorporate improvements into P4 to prepare for Go/No-Go Point #3 (Milestone M8) in 2QFY20

## High-Power Charging System

- Profile control and fault characteristics of on-board inverter and obtain all applicable certifications
- Prepare for Go/No-Go Point #2 (Milestone M6) in 1QFY20
- Collaborate on the development of interface components for high-power charging

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

# Summary

### Relevance

- The project is directly relevant to barriers identified in VTO roadmaps
  - Electrical and Electronics: cost and weight reduction for heavy-duty electric drive trains
  - Grid Interaction: standards compliance for all aspects of the vehicle charging system

### Approach

- Achieve technology improvements in key systems
- Augment with range of smart design elements
- Work within a cost/benefit framework appropriate for immediate commercialization
- Learn and refine

### Technical Accomplishments

- Refinement of original concepts for thermal management and high-power bidirectional charging
- Attainment of interim energy efficiency target of 1.32 kWh/mile based on measures in four areas
  - Traction energy budget
  - Rotational mass and inertia reduction
  - Friction reduction

### Future Research

- Final selection and realization of measures to achieve final energy efficiency target of 1.10 kWh/mile
- Attainment of all applicable certifications for high-power bidirectional charging system