Blue Bird V2G Electric School Bus Commercialization Project

Project ID: EE0007995
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Presenter: Michael Boggess
Blue Bird Corporation
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## Overview

### Timeline
- Project start date: 1/19/17
- Project end date: 12/31/20
- Percent complete: 15%

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

### Partners
- Project lead: Blue Bird
- Vehicle subcontractors:
  - ADOMANI
  - Efficient Drivetrains, Inc.
  - EPC Power
- Charging system partners
  - Nuvve
  - Southern California Edison
- School bus host: Rialto USD
- Contributing funder: So. Coast AQMD
- Technology resource: NREL
- Project manager: NSI

### Barriers
- **Value Proposition**: Heavy-duty battery-electric vehicles must have performance, safety, and costs comparable to or better than advanced conventional vehicle technologies to gain widespread market uptake
- **Vehicle-Grid Integration**: Heavy-duty battery-electric vehicles should be supported by charging technologies and standards that can capture available vehicle-grid synergies
Electric school buses can blaze the trail to substantially increased deployment of electric medium- and heavy-duty vehicles by pioneering the integration of fleets as grid-integrated distributed energy resources.

**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 reduced operating costs

**Objectives this Period**
- Develop first two prototype buses (P1 and P2)
- Determine optimal drivetrain architecture (transmission; rear axle ratio)
- Investigate thermal management as a key to increased energy efficiency
- Use P1 to establish an energy efficiency benchmark
### Milestones

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Milestone</th>
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<th>Duration</th>
<th>End Mo.</th>
<th>Budget Period 1</th>
<th>Budget Period 2</th>
<th>Budget Period 3</th>
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<td>Performance Period 1 Component Development</td>
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<td>Task 1.2.2 Select best drivetrain option</td>
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<td>Task 1.9.3 Fabricate P2 drive train assemblies</td>
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<td>Task 1.9.7 Test and evaluate updated P1 at NREL</td>
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<td>Task 2.4.5 Other testing</td>
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<td>Performance Period 3 Vehicle Demonstration</td>
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<td>Task 3.2.3 Stage 1 commercialization</td>
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<td>Task 3.3.2 Long-term data archiving</td>
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- **Completed Milestone**
Approach

**Smart Design**
- Implement weight reduction; component right-sizing; drivetrain optimization (e.g., motor-specific rear axle ratio)

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

**Performance, safety, and costs comparable to or better than advanced conventional vehicle technologies**

**Integrated Thermal Management**
- Employ sensing, controls, and coolant loops to maintain batteries at optimal temperature and make beneficial use of surplus heat

**High-Power Charge/Discharge Capability**
- Employ 200 kW on-board inverter with grid-forming capability

**Use of charging technologies that can capture available vehicle-grid synergies**
Developed Efficient Drivetrain Architecture

Operational Simulation
- Direct drive (single speed) architecture was shown to have higher energy efficiency across three different duty cycles and vehicle loadings.

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<th>HD-UDDS</th>
<th>NREL</th>
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<tr>
<td>22000</td>
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Setting of Rear Axle Ratio
- TM4 Sumo traction motor was chosen based on its low-speed torque performance.
- The range of rear axle ratios was identified that could support the power required for a standing start on a grade of 20% and a top speed of 65 MPH.
- Operational simulation continues with the goal of identifying the ratio that will produce the best average motor efficiency at the most common motor speeds.
Designed Enhanced Thermal Management System

- Options for the bus's thermal management system were modeled and a design chosen that represents the best tradeoff between:
  - Optimization of thermal energy recovery and use
  - Cost and complexity
- The selected design integrates heating and cooling of the batteries, traction motor, and high-voltage system
Technical Accomplishments and Progress

Built and Benchmarked First Prototype Bus - 1

Development of Prototype P1
- Blue Bird and team member Efficient Drivetrains, Inc. (EDI) adapted EDI’s PowerDrive electric drive system for the requirements of a type C electric school bus
- The system was installed on a purpose-built Blue Bird glider

Duty Cycle Analysis
- NREL collected detailed duty-cycle data from buses in Rialto school district and combined with Fleet DNA data to select representative drive cycles for powertrain development and vehicle efficiency testing.
Dynamometer Benchmarking

- Prototype bus P1’s energy efficiency was benchmarked on NREL’s REFUEL dynamometer using an NREL duty cycle derived from ~1,000 hours of school bus operating data.
- The demonstrated efficiency of 1.53 kWh/mile serves as the initial “pre-improvement” benchmark that the subsequent prototypes will be measured against.

*P1 on NREL’s REFUEL dynamometer*
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**

**Prime Contractor**
- Blue Bird

**Core Team**
- ADOMANI
- EDI
- EPC Power
- NREL
- NSI
- Nuvve

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

**Vehicle Development**
- University of Delaware

**V2G Technology**
- Regional utilities
- School districts
Remaining Challenges and Barriers

Meet technology improvement objectives
- Energy efficiency of 1.10 kWh/mile
- Fully certified 200 kW bidirectional on-board inverter

Implement charging system
- Obtain interconnection agreement with Southern California Edison
- Specify and install all relevant 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
- Finalize production version of V2G bus (“design for marketability”)
- Develop bus financing tools (e.g., battery leasing scheme)
Remainder of FY18

- Pursue technology improvements
  - Thermal management
  - Telematics/drive parameters
  - High-power inverter
  - Incorporate improvements into P1 and P4

- Prepare for Go/No-Go Point #1 (Milestone M4) at end of F1Q19
  - Send P3 to NREL for energy efficiency evaluation
  - Must close 50% of gap between P1 benchmark (1.53 kWh/mile) and project target (1.10 kWh/mile)

Any proposed future work is subject to change based on funding levels
FY19
- Take stock of results from P3 and P4 energy efficiency evaluations
- Identify areas where further technology improvement will have biggest payoffs, for example:
  - Further refinements to the drivetrain control system
  - Aggressive light-weighting
  - Reduction in power circuitry energy losses
- Move into certification phase for high-power inverter

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

- The project is directly relevant to barriers identified in Vehicle Technology Office roadmaps – especially mutually beneficial vehicle-grid integration arrangements that can lead to competitive total cost of ownership and widespread deployment.
- The team is at an early stage of the project but has laid a strong foundation for the accomplishment of project goals.
- The next two quarters will be critical in determining the ultimate success of the project.

Summary of Key Technical Results in FY18

<table>
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<tr>
<th>Focus Area</th>
<th>Results</th>
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<tbody>
<tr>
<td>Prototyping and benchmarking</td>
<td>Designed, built, and formally benchmarked prototype bus P1</td>
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<tr>
<td>Drivetrain architecture optimization</td>
<td>Determined parameters of optimal application-specific drivetrain architecture</td>
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<td>Thermal management strategies</td>
<td>Developed an approach for integrating thermal management across key subsystems</td>
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<td>Telematics as an energy efficiency tool</td>
<td>Implemented a telematics platform with novel predictive capabilities</td>
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