2018 DoE Vehicle Technologies Office Annual Merit Review

Blue Bird V2G Electric School Bus Commercialization Project

Project ID: EE0007995

Principal Investigator: Andy Moore
Presenter: Michael Boggess
Blue Bird Corporation

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DRAFT 7:00 a.m. 5/7/18

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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

Relevance

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

	Milestone	Start Mo.	Duration	End Mo.	Budget Period 1				Budget Period 2				Budget Period 3			
					1	2	3	4	5	6	7	8	9	10	11	12
Performance Period 1 Component Development																
Task 1.8.6 Test and evaluate P1 at NREL	M1	3	2	4												
Task 1.2.2 Select best drivetrain option	M2	1	5	5												
Task 1.9.3 Fabricate P2 drive train assemblies	M3	5	3	7												
Task 1.9.7 Test and evaluate updated P1 at NREL	M4, G/N-G#1	12	1	12												
Performance Period 2 Component, System, and Vehicle Testing and Production																
Task 2.2.2 Fabricate P3-P4 drivetrain assemblies	M5	13	2	14												
Task 2.4.5 Other testing	M6, G/N-G#2	16	2	17												
Task 2.5.5 NRTL documentation	M7	18	1	18												
Task 2.7.6 Test and evaluate B1 at NREL	M8, G/N-G#3	23	1	23												
Task 2.7.10 B5-B8 delivery	M9	25	1	25												
Performance Period 3 Vehicle Demonstration																
Task 3.2.2 Battery lease development	M10	24	5	28												
Task 3.2.3 Stage 1 commercialization	M11	28	5	32												
Task 3.3.2 Long-term data archiving	M12	35	2	36												

Completed Milestone

Approach

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

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

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

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

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

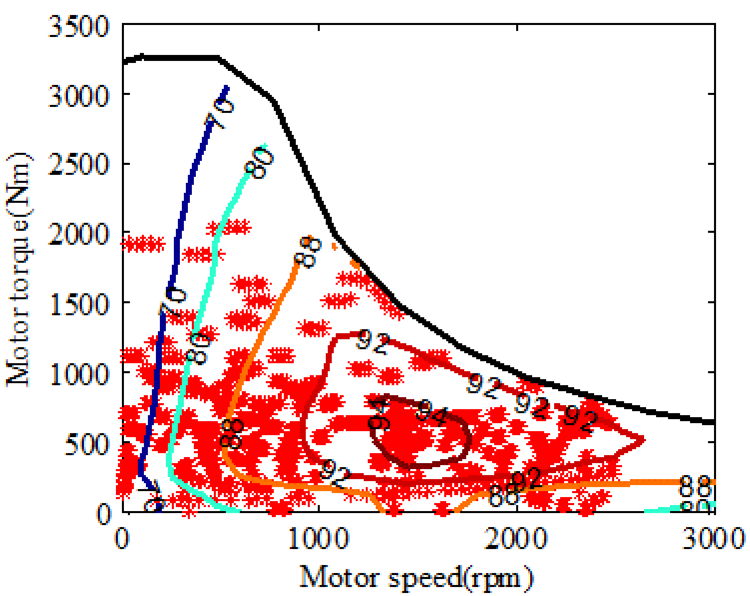
Technical Accomplishments and Progress

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

		HD-UDDS		NREL		Customer	
	Weight	Avg Motor Efficiency(%)	kWh/mile	Avg Motor Efficiency(%)	kWh/mile	Avg Motor Efficiency(%)	kWh/mile
TM4+Single speed	33000	87.2	1.82	86.2	1.84	87.8	1.81
	27000	87.3	1.61	86.5	1.67	87.8	1.61
	22000	87.2	1.43	86.7	1.44	87.7	1.43
		HD-UDDS		NREL		Customer	
		Avg Motor Efficiency(%)	kWh/mile	Avg Motor Efficiency(%)	kWh/mile	Avg Motor Efficiency(%)	kWh/mile
UQM+2 speed	33000	85	1.97	85	2.1	85.7	1.92
	27000	84.5	1.74	84.5	1.8	86	1.72
	22000	84	1.54	83.7	1.56	85.8	1.53



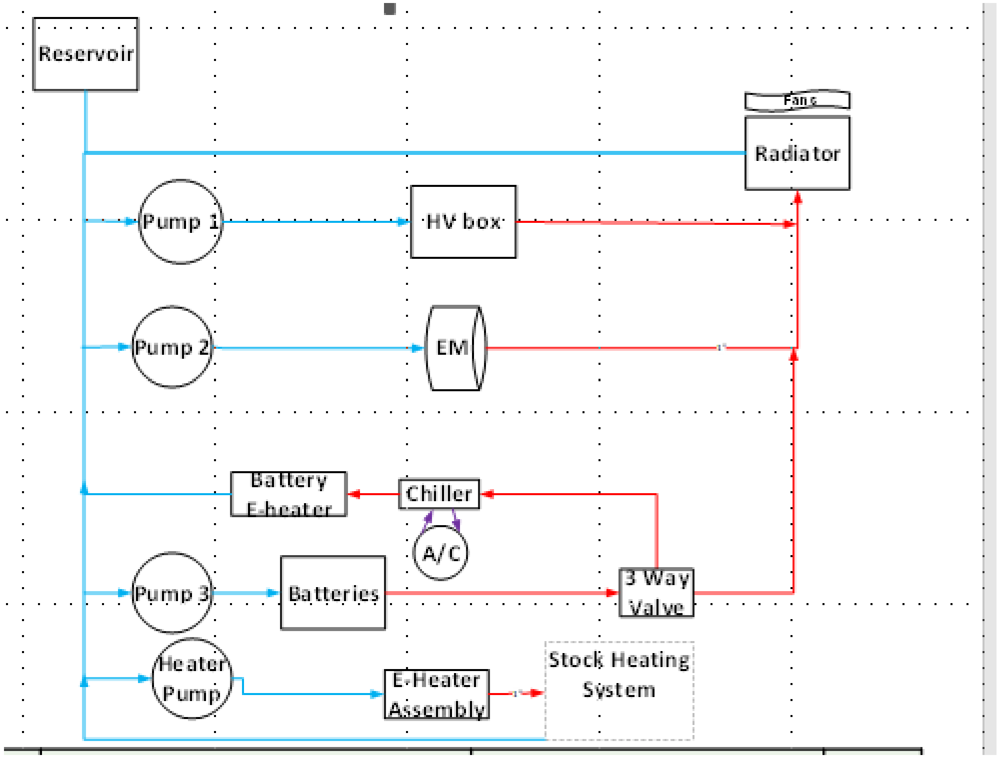
Setting of Rear Axle Ratio

- 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.

Technical Accomplishments and Progress

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

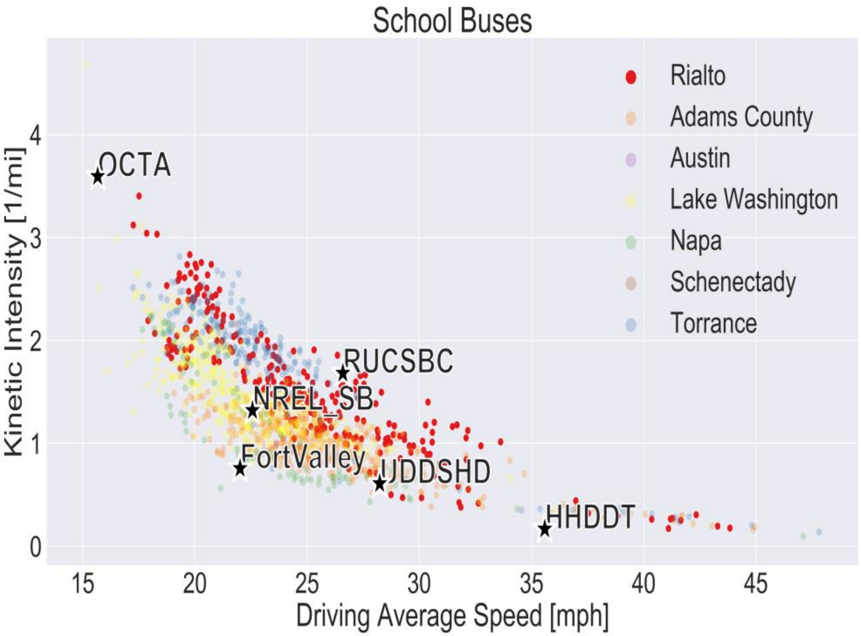
Built and Benchmarked First Prototype Bus - 1

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.



Technical Accomplishments and Progress

Built and Benchmarked First Prototype Bus - 2

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

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

Prime Contractor
- Blue Bird

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

Vehicle Development

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

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)

Proposed Future Research - 1

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

Proposed Future Research - 2

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

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