Medium and Heavy-Duty Vehicle Field Evaluations

PI: Kenneth Kelly
NREL Team: Jon Cosgrove, Adam Duran, Mike Lammert, Bob Prohaska
National Renewable Energy Laboratory
2014 DOE VTO Annual Merit Review
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Project ID # VSS001

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

Timeline

- **Multiple Sites**: varies by project
- **Project Length**: typically 12–18 months start to finish (including startup and report)
- **For FY15**: Some "in-process," some "new"
- **Percent Complete**: ~50%

<table>
<thead>
<tr>
<th>Project</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS HHV</td>
<td></td>
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<td>Completed in FY15</td>
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<tr>
<td>Line-haul Platooning Phase 1</td>
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<td>Completed in FY15</td>
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<tr>
<td>Frito-Lay EV</td>
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<td>Planned FY15 completion</td>
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<tr>
<td>PG&amp;E PHEV Utility Trucks</td>
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<td></td>
<td>Planned FY15 completion</td>
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<tr>
<td>UPS Renewable Diesel Test</td>
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<td></td>
<td>Planned FY15 completion</td>
</tr>
<tr>
<td>Miami-Dade Refuse HHV</td>
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<td></td>
<td>Kicked off in FY15 – ending FY16</td>
</tr>
<tr>
<td>Foothill Transit Bus EV</td>
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<td></td>
<td></td>
<td>Kicked off in FY15 – ending FY16</td>
</tr>
<tr>
<td>EV V2G School Bus</td>
<td></td>
<td></td>
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<td></td>
<td>Kicked off in FY15 – ending FY16</td>
</tr>
</tbody>
</table>

Barriers

- **Unbiased Data**: Commercial users and original equipment manufacturers (OEMs) need unbiased, third-party new technology evaluations for better understanding of state-of-the-art technology performance to overcome technical barriers
- **Variable Commercial Vehicle Use**: Variable performance by technologies due to multiple and wide-ranging duty cycles (makes data and analysis of data valuable in overcoming this barrier)

Partners

- **Industry collaboration required for successful studies.**
  - Past partners include:
  - **Current partners in FY15:**
- **Project Lead**: National Renewable Energy Laboratory (NREL)

Budget

- **Total Project Funding FY14 w/industry cost share**: ~$700K
  - **DOE Share**: $600K in FY15
  - Participant cost share: in-kind support (vehicle loans, technical support, data access, data supplied to NREL); varies by individual project
- **DOE Funding Received in FY14**: $600K
This project provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

- **Third-party unbiased data**: Provides data that would not normally be shared by industry in an aggregated and detailed manner.

- Over 5.6 million miles of advanced technology MD and HD truck data have been collected, documented, and analyzed on over 240 different vehicles since 2002.

- **Data, Analysis, and Reports** are shared within DOE, national laboratory partners, and industry for R&D planning and strategy.

- **Results help**:
  - Guide R&D for new technology development
  - Help define intelligent usage of newly developed technology
  - Help fleets/users understand all aspects of advanced technology
## Milestones and Deliverables

Reports highlighting fleet data collection efforts and analysis of data:

<table>
<thead>
<tr>
<th>Month / Year</th>
<th>Milestone or Go/No-Go Decision</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY14 Q3</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
<td>Complete</td>
</tr>
<tr>
<td>FY14 Q4</td>
<td>Milestone</td>
<td>Final Report &amp; Data on all Projects</td>
<td>Complete</td>
</tr>
<tr>
<td>FY15 Q1</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
<td>Complete</td>
</tr>
<tr>
<td>FY15 Q2</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
<td>Complete</td>
</tr>
</tbody>
</table>

- In addition to the above reports, the following published (publically available) technical project reports have been completed since 2014 AMR:
  - Frito-Lay EV Implementation Report – September 2014
  - Peloton Truck Platooning Final Report – August 2014
MD & HD Field Testing Approach

Evaluate the performance of alternative fuels and advanced technologies in MD and HD fleet vehicles, in partnership with commercial and government fleets and industry groups vehicles.

Collect, analyze and publicly report data:
- Drive cycle and system duty cycle analysis
- Operating cost/mile
- In-use fuel economy
- Chassis dynamometer emissions and fuel economy
- Scheduled and unscheduled maintenance
- Warranty issues
- Reliability (% availability, MBRC)
- Implementation issues/barriers
- Subsystem performance data and metrics (energy storage system, engine, after-treatment, hybrid/electric vehicle (EV) drive focus)

Data stored in FleetDNA for security and limited public accessibility

Frequent interactions and briefings with stakeholders – fleets, technology providers, researchers, and government agencies

Fleets

Vehicle & Equip Mfg’s

Useful Data, Analysis and Published Reports
Data from field evaluations helps populate FleetDNA database

DOE Fleet Tools (DRIVE, FASTSim, AFleet, etc.) used to analyze and investigate impacts – data used to validate and improve tools

Published information and data used by fleets, industry, DOE and other research programs, and other agencies

Collect Lab and Field Data

Capture, Store and Analyze

Explore & Optimize

Communicate & Inform

Identify Barriers and New R&D Opportunities, Validate Efforts

Partnership with Fleets and Technology Providers = Relevant Results & Optimized Solutions for Real World Applications

NATIONAL RENEWABLE ENERGY LABORATORY
## Approach: FY15 Projects and Selection Process

### Active Fleet Evaluation Projects

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frito Lay EV with facility loads and battery testing</td>
<td><img src="image1.jpg" alt="Image 1" /></td>
</tr>
<tr>
<td>Miami-Dade Hydraulic Hybrid Refuse Trucks</td>
<td><img src="image2.jpg" alt="Image 2" /></td>
</tr>
<tr>
<td>EV School Bus With Vehicle to Grid Capability</td>
<td><img src="image3.jpg" alt="Image 3" /></td>
</tr>
<tr>
<td>PG&amp;E Electrified Utility Trucks</td>
<td><img src="image4.jpg" alt="Image 4" /></td>
</tr>
<tr>
<td>UPS-Solazyme Renewable Diesel</td>
<td><img src="image5.jpg" alt="Image 5" /></td>
</tr>
<tr>
<td>Battery EV Transit Bus with Fast Charging</td>
<td><img src="image6.jpg" alt="Image 6" /></td>
</tr>
</tbody>
</table>

### Projects Completed in FY15

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS Hydraulic Hybrid Package Delivery</td>
<td><img src="image7.jpg" alt="Image 7" /></td>
</tr>
<tr>
<td>Line-Haul Platooning</td>
<td><img src="image8.jpg" alt="Image 8" /></td>
</tr>
</tbody>
</table>

Typically 3–4 projects in process at any given time with some starting and some finishing.

### Project Selection Criteria

- New and emerging technology with active fleet demonstration
- Technology supports DOE program research and deployment mission and interests
- Fleet and industry partner as active participant, i.e., providing data, vehicles, technical data and information
- Fleet has adequate number of advanced vehicles, controls in similar service, and strong data collection processes.

### Project Selection Process

- NREL maintains awareness of fleet and industry trends through active participation in technical community and stakeholder relationships
- NREL identifies 8–10 possible evaluation projects annually
- NREL reviews candidate project with DOE technology managers to set priorities and down select projects.

### FY15 Technical Accomplishments covered in this presentation:

1. Miami-Data, Gen 2 Parker-Hannifin hydraulic hybrid refuse haulers
2. Update on Frito-Lay EV project progress
3. PG&E plug-in hybrid electric vehicle (PHEV) utility trucks
4. Foothills Transit – Proterra EV transit bus with Eaton 500-kW fast chargers
5. EV school bus with vehicle-to-grid (V2G) capability
Technical Accomplishments: Miami-Dade Hydraulic Hybrid Fleet Evaluation

NREL Lead: Bob Prohaska (PI)
Partners & Cost Share:

Miami Dade – access to hydraulic hybrid vehicles (HHVs) and baseline vehicles for instrumentation, fuel and maintenance data

Parker – data and technical information on Parker HHV system, demonstration vehicles for chassis dynamometer testing

Southeast Florida Clean Cities Coalition – coordination with the local Clean Cities partnership

Goals/Objectives

• Conduct objective, independent evaluation of hydraulic hybrid technology in refuse hauler application, including performance, fuel savings, emissions, total cost of ownership
• Contribute data to FleetDNA database and knowledge base on refuse hauler technology alternatives

Background and Value

• Miami-Dade is the 7th most populous county in the United States and the third largest municipal hybrid fleet (NYC, CA)
• Miami-Dade County currently operates 35 Autocar E3 refuse trucks with Parker Hannifin “Run Wise” Gen 1 hydraulic hybrid system and recently purchased an additional 29 Gen 2 HHVs
• Claimed 43% fuel savings needs to be evaluated by independent third party

FY15 Accomplishment Highlights

• Kick-off meeting held with Miami-Dade in January 2015
• Draft start-up fact sheet completed
• Fleet agreed to provide electronic maintenance, refueling and other operational data
• Parker NDA completed for vehicle-specific technical data
• Initial duty-cycle data collected on Gen 1 HHVs and conventional diesels: 2/25/2015 – 3/25/2015

FY15/FY16 Plan Forward

• Log data from 8–10 Gen 2 vehicles when deployed later this year
• Collect fuel and maintenance data from fleet – baseline, HHV-Gen 1 and Gen 2
• Calculate total cost of ownership, including reliability and maintenance on all projects
• Perform analysis to show optimal placement of new technology (i.e., route vs. benefit)
• Chassis dynamometer tests of HHV and baseline for controlled fuel economy and emissions using representative and standard drive cycles
• Final technical report FY16
Initial Duty-Cycle Data from Miami HHVs

HHV Technology Basics
The Miami-Dade test vehicles are Autocar E3 refuse trucks equipped with Parker Hannifin’s RunWise hydraulic hybrid drive. The HHVs are reported to recover as much as 70% of the energy typically lost during braking and reuse it to power the vehicle. The system features a two-speed hydrostatic drive combined with a mechanical direct drive, which optimizes vehicle performance at both low and high speeds.

Covanta Waste-to-Energy (WTE) plant
Refuse haulers deliver load from residential pickup to Covanta’s 77-megawatt WTE plant. Traces in the above image are from actual GPS data collected by NREL.

Initial Duty cycle data
Images above show initial GPS route data collected from the Miami fleet. GPS data are used to develop duty-cycle statistics and are used in vehicle models. Data collected also include vehicle and engine operating parameters, including vehicle speed, fuel rate, engine speed/torque, NOx sensor, etc.
### Technical Accomplishments:
**PG&E – PHEV Utility Truck Data Collection and Analysis**

**NREL Leads:** Adam Ragatz & Jon Cosgrove

**Goals/Objectives**
- Quantify electric power take-off (ePTO) system benefits for jobsite and secondary auxiliary loads
- Collect and analyze duty-cycle information for trouble trucks and material handler vehicle use at a variety of locations throughout PG&E’s service area
- Contribute data to FleetDNA database and knowledge base on utility truck technology alternatives

**Background and Value**
- PG&E and the utility industry are interested in learning more about the fleet operations and measuring the value provided by an ePTO and Job-Site Energy Management System (JEMS)
- Altec is interested in optimizing field performance of the ePTO and JEMS systems
- Utility vocational data provided to FleetDNA

**Background and Value**
- PG&E and the utility industry are interested in learning more about the fleet operations and measuring the value provided by an ePTO and Job-Site Energy Management System (JEMS)
- Altec is interested in optimizing field performance of the ePTO and JEMS systems
- Utility vocational data provided to FleetDNA

**Partners & Cost Share:**
- **National Clean Fleet Partnership** – funding for data collection, analysis and reporting
- **PG&E** - access to PHEV and baseline vehicles for instrumentation;
- **Altec** – technical vehicle information/data on PHEV system
- **Efficient Drivetrain, Inc. (EDI)** – test vehicle, engineering hours, and technical vehicle information

**FY15 Accomplishments Highlights**
- Instrumented 20 PG&E Altec utility trucks
  - 10 AT JEMS “trouble trucks” (5 w ePTO/ 5 w/o)
  - 10 AM “material handlers” (5 w/JEMS + 5 diesel)
- 11 weeks of data collection at seven PG&E sites
  - Collecting data on:
    - Drive cycle / duty cycle
    - J1939 CAN (including fuel use and NOx sensor)
    - Battery charge/discharge power
    - Electric AC
    - Electric hydraulics
    - Electric auxiliaries
- Tech briefings on field data provided to DOE, fleet, and vehicle manufacturer
- Field data were used to develop chassis dyno test cycles

**Plan Forward**
- Complete analysis of jobsite operations to quantify impacts and potential of hybridization for the utility truck vocation
- Include analysis of component sizing opportunities using modeling tools in order to look for opportunities for best use cases for this technology type
- Deeper analysis of duty cycle operation to quantify loads added due to on road vs plug-in charging
- Final publication and report to interested parties, including PG&E and Altec

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Photo by Ragatz, NREL
Collaboration with PG&E and industry partners is helping develop a new generation of PHEV utility trucks with export power capability

### Field Data
- Data collected from 20 PG&E vehicles were used to characterize the driving behavior and jobsite energy usage profiles including:
  - Detailed drive cycle characteristics
  - Fuel economy
  - Jobsite idle fuel consumption on conventional vehicles vs. ePTO operation

### Chassis Dyno Testing of Prototype PHEV
- Duty-cycle data were analyzed using DRIVE to develop a representative chassis dynamometer drive cycle (see figure)
- Chassis dynamometer tests were performed on a PG&E prototype PHEV developed by Electric Drivetrains, Inc. (EDI) with export power capability
- Baseline conventional vehicle tests were conducted on a vehicle provided by Altec
- Results were used by PG&E to specify next generation vehicle requirements, by EDI to refine hybrid system, and by Altec to enhance understanding in-field vehicle operations
Technical Accomplishments: Frito-Lay Medium-Duty EV Fleet Evaluation

NREL Lead: Bob Prohaska (PI)

Partners & Cost Share:
Frito-Lay – access to EV and baseline vehicles, chargers, and facility for instrumentation; fuel and maintenance data
Smith EV – technical information/data on EV system, review and feedback on data analysis
Chateau – EVSE data

Goals/Objectives
- Conduct objective, independent evaluation of MD EV technology in delivery application as compared to conventional diesels
- Understand fleet’s experience with EV implementation and overall facility impacts
- Refine modeling & simulation tools using real world facility energy data to understand full potential of smart charging and the use of onsite renewables with EV implementation

Background and Value
- Frito-Lay is an active member of the National Clean Fleet Partnership currently operating 269 electric delivery trucks.
- MD EVs show considerable promise in commercial fleet applications in terms of both cost per mile and emission reduction.

FY15 Accomplishment Highlights
- Completed preliminary performance comparisons between EVs and conventional diesels.
- Installed main feed power meter at Frito-Lay facility with cellular data transfer
- Modified existing model of vehicle and facility electricity demand to simulate effects of vehicle charge management strategies on overall demand charges
- Conducted multiple battery degradation tests at three separate Frito-Lay locations (AZ, WA, NY)
- Conducted monthly technical briefings with Frito-Lay and Smith EV to review progress

FY15/FY16 Plan Forward
- Complete all data collection, analysis, and reporting in FY15
- Model impact of onsite integration of renewables (i.e., solar, wind) with building and vehicle electricity demands
- Investigate battery usage, sizing and performance in this delivery application.
- Final technical report expected Q4 FY15
Diesel vs. EV Metric Comparisons

Fuel Economy vs Average Speed

Fuel Economy vs Kinetic Intensity

Daily Distance vs Average Speed

Energy Consumed vs Distance Traveled

y = 1.1743x + 8.8848
R² = 0.6325
Final Technology Assessment Plans – FY15 Final Report

Capture Baseline
Conventional Gasoline/Diesel Trucks
+ Daily Facility Operations

Assess PEV Impacts
Fuel Savings
+ Facility Electricity Demand Increase

Develop Advanced Integration Business Case
Simulate V2G Peak Shaving
Integrate On-site Renewables
Model Battery Size/Life Impacts

Analyze Demand Management Potential
Assure Proper Charging
+ Reduce Facility Demand Charges
Technical Accomplishments:
Foothill Transit – Proterra EV Bus Fleet Evaluation

NREL Lead: Bob Prohaska (PI)

Partners & Cost Share:
Foothill Transit – access to EV and baseline buses and fast chargers for instrumentation; fuel and maintenance data
Proterra – technical information/data on EV system; detailed telematics data on buses
California Air Resources Board – $100K funding to NREL to conduct fleet study

Goals/Objectives
• Conduct objective, independent evaluation of EV bus and 500-kW fast-charger technology in transit bus operation, including performance, fuel savings, emissions, total cost of ownership
• Provide grid integration lessons learned transit fleets and EV technical community

Background and Value
• U.S. transit authorities are beginning to incorporate all-electric transit buses into their fleets at significant numbers
• Transit duty cycles may be well-suited to or exceedingly tough on lithium-ion batteries—unique requirements of heavy duty charging infrastructure further blurs the picture
• HD EV fast charging adds significant electricity demand to transit facilities

Accomplishments
• Project kicked off in FY15
• NDA signed with Proterra to provide vehicle detailed in-use, and component data (1 Hz)
• Vehicle detailed specs provided by Proterra
• EV data protocols defined and initial data received
• Planning three one-month 1-Hz data transfers from all 15 buses from the start of deployment.

FY15/FY16 Plan Forward
• Complete EV bus 1Hz data collection Q3 FY15
• Develop fast-charger data collection protocols and conduct Eaton 500-kW charger tests
• Develop in-use battery degradation test protocols with Proterra
• Coordinate with NREL/California Air Resources Board (CARB) project evaluation of maintenance and operations data
• Capability assessment of EV charge optimization strategies for transit fleets
• Assess opportunities for expanding EV routes
• FY16 final report documenting EV bus grid integration assessment

Photo by Eudy, NREL
Initial Duty-Cycle Data from Foothill EV Buses

The image above shows GPS traces of EV buses pulling into the charging depot near the center of the route. The depot includes two 500-kW fast chargers. Charger profile data and energy consumption metrics will be evaluated over the course of this study.

**Foothill Buses at Charging Depot**

The Foothill Transit EV route includes two 8-mile segments with an EV charging station near the center. The green line shown above is actual GPS data from one bus. Buses typically operate continuously along this route from 5 a.m. to midnight. The Foothill Transit depot is also shown.

**Initial EV Bus Duty-cycle Data**

<table>
<thead>
<tr>
<th>Vehicle Manufacturer</th>
<th>Proterra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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</tr>
<tr>
<td>Length, ft.</td>
<td>35</td>
</tr>
<tr>
<td>Passenger seats</td>
<td>35</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Altairnano</td>
</tr>
<tr>
<td>Energy storage type</td>
<td>Lithium Titanate</td>
</tr>
<tr>
<td>Nominal pack voltage</td>
<td>368</td>
</tr>
<tr>
<td>Total energy, kWh</td>
<td>88</td>
</tr>
<tr>
<td>Motor</td>
<td>UQM</td>
</tr>
<tr>
<td>Peak power, kW</td>
<td>220</td>
</tr>
</tbody>
</table>
Technical Accomplishments: 
EV Vehicle-to-Grid (V2G) School Bus Project

**Lead:** Mike Lammert, NREL

**Cost Share:**
EV V2G Partnership – $1.4M California Energy Commission (CEC) / $2.2M South Coast Air Quality Management District (SCAQMD) funding bus developments, deployment and evaluations

**Clinton Global Initiative Partners** – overall project management, technical review teams, and hardware providers

**TransPower** – EV school bus up-fits, technical information/data on EV system; 1-Hz data on EV school buses

**School Districts** – operating EVs at three California school districts, access to EV and baseline buses, chargers, and facilities for instrumentation / data collection

**Goals/Objectives**
- Demonstrate and document the total cost of ownership of all electric school buses with V2G capability
- Contribute TransPower bus conversion efforts through the duty cycle characterization of current conventional and hybrid vehicles in service

**Background and Value**
- Leverages investment of CGI technical and project team with funding from CEC and SCAQMD and many cost share elements
- Collaboration between Fleet Test and Vehicle Grid Integration, i.e., field data will support grid integration efforts and vice versa
- Contribute data to FleetDNA database & knowledge base on school bus duty cycles and electrification potential

**FY15 Accomplishment Highlights**
- Kicked-off project in Q2 FY15
- Reached agreement with Zonar Systems to provide telematics data on entire Torrance school bus fleet
- Worked with Napa Valley Unified School District to identify 10 buses as targets for data logger installation based on TransPower EV bus potential route operation
- Identified 10 additional buses as targets for data logger installation in the Kings Canyon Unified School District
- Completed initial round of vehicle instrumentation in Napa Valley Unified District.

**FY15/FY16 Plan Forward**
- Scheduled to transition loggers to Kings Canyon in FY15 Q3
- Data logging completed
- Data analysis used to develop School Bus drive cycle using NREL DRIVE
- Construct vehicle model using FASTSim to investigate performance potential
- Collaborate with TransPower to collect and analyze EV Bus data
- Collaboration with DOE/NREL Grid Integration team to test V2G hardware and controls
- Contribute data to FleetDNA project
- Produce technical report of project status and outcomes
Response to Previous Year Reviewers’ Comments

Comment #1: This reviewer noted that the program provided valuable feedback on in-service technology use and effectiveness based on how vehicles are used. Numerous benefits are derived from these efforts including gaining an understanding of technology benefits in use, degree of fit between vehicle and application, real-world benefits in terms of fuel economy, and also identifying technical barriers such as demand charge penalties for an EV fleet. Regarding project planning, the project start/end dates were not clear. The reviewer concluded that it was hard to judge what was accomplished this year and in the past.

Response: Thank you for the positive feedback. With regards to timing of accomplishments, this is an ongoing project with multiple fleet evaluations. Each fleet study has its own planned start and end dates. The overview slide provides timelines for each fleet study. In this year’s presentation, we tried to highlight only those accomplishments that were achieved since last year’s AMR.

Comment #2: While most of the comments related to collaborations were positive (e.g., “the reviewer applauded the collaboration with numerous partners…”), a couple of comments encouraged expanding the collaboration and outreach “maybe seek out others who could utilize the data and be sure to make them aware of these results for a bigger impact.”

Response: This is a very helpful observation. We are addressing this in several ways. First, we are working closely with the National Clean Fleet Partnership (NCFP) and 21st Century Truck Programs (21CTP) both to help identify key areas of need and to serve as forums for getting information to stakeholders. We participate in the monthly 21CTP partnership calls, work directly with NCFP fleets, and present information at their annual events. We are also working with several government organizations, such as South Coast Air Quality Management District, California Air Resources Board, and the U.S. Environmental Protection Agency (EPA), to utilize data, information, and approaches to inform their programs. We try to present results from each project at multiple technical forums—SAE, Green Truck Summit, National Association of Fleet Administrators, Electric Vehicle Symposium, and others. We also hold “one-on-one” technical briefings with project participants, fleets, technology providers, and other stakeholders.
Response to Previous Year Reviewers’ Comments

Comment #3: Several reviewers’ comments asked the question about how data/results were being used; also one commenter found the platooning study to be in a different category than the other fleet evaluations.

Response: The platooning study was outside the normal fleet evaluation, and so follow-on work in that area has been broken out into a stand-alone project. The previous year’s platooning effort provides useful example of how data and results are being applied. The platooning test results showed significant improvements in fuel consumption, but also raised technical questions about the optimal spacing and control strategies. These results were communicated to the technology provider as constructive feedback that are being used to conduct follow-on testing and refine the technology. NREL is also collaborating with Lawrence Livermore National Laboratory (LLNL) to apply its expertise in vehicle aerodynamics modeling and wind tunnel testing.

Additionally, several large fleets have been briefed on the platooning fuel economy improvements and have indicated interest in demonstrated this technology within the real-world fleet service. Other recent examples of where data and results from this program are being used include feedback to UPS to place HHVs on routes with high kinetic intensity; data from PHEV dyno tests and duty cycles are being used by PG&E to refine specifications for next-generation vehicle procurement; and baseline school bus duty-cycle data are being shared with the EV manufacturer to inform the system design.
Collaboration and Coordination with Other Institutions

This project **absolutely requires** industry collaboration required for successful studies.

**Past industry partners included:**

<table>
<thead>
<tr>
<th>Partner</th>
<th>Relationship</th>
<th>Type</th>
<th>VT Program or Outside?</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>FedEx Corporation</td>
<td>Fleet Eval Partner</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
</tr>
<tr>
<td>UPS</td>
<td>Fleet Eval Partner</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
</tr>
<tr>
<td>Eaton Corporation</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided data access and hardware to enable testing</td>
</tr>
<tr>
<td>Peloton</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and hardware to test</td>
</tr>
<tr>
<td>Parker Hannifin</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles, data, and support for testing</td>
</tr>
<tr>
<td>Frito-Lay</td>
<td>Fleet Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles, data, and installed infrastructure (Servidyne/Chateau)</td>
</tr>
<tr>
<td>Momentum Dynamics</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing data and hardware to enable testing</td>
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<tr>
<td>XL Hybrids</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing data and hardware to enable testing</td>
</tr>
<tr>
<td>Smith Electric Vehicles</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing access to battery data and vehicle data</td>
</tr>
<tr>
<td>South Coast Air Quality</td>
<td>Funding Partner</td>
<td>Gov't Collaboration</td>
<td>Outside</td>
<td>Providing funding for projects to supplement DOE advanced vehicle technology testing (CARB = Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project [HVIP] assessment)</td>
</tr>
<tr>
<td>Management District / CARB</td>
<td></td>
<td></td>
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<tr>
<td>Clean Cities Program</td>
<td>Coordination</td>
<td>Gov't Collaboration</td>
<td>VT Program</td>
<td>Providing funding to assess fleet-specific technology options for National Clean Fleets Partnerships (Verizon, City of Indianapolis, PG&amp;E)</td>
</tr>
<tr>
<td>NTEA/GTA</td>
<td>Advisory</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing access and advisement on tools and protocols</td>
</tr>
<tr>
<td>Oak Ridge National</td>
<td>Coordination</td>
<td>Gov’t Collaboration</td>
<td>VT Program</td>
<td>Coordination of data analysis tools, captured data, and development of test protocol and procedures</td>
</tr>
<tr>
<td>Laboratory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Collaboration and Coordination with Other Institutions

<table>
<thead>
<tr>
<th>Partner</th>
<th>Relationship</th>
<th>Type</th>
<th>VT Program or Outside?</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami-Dade County</td>
<td>Fleet Eval Partner</td>
<td>Local Gov’t Fleet</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
</tr>
<tr>
<td>Proterra</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
</tr>
<tr>
<td>Foothill Transit</td>
<td>Fleet Eval Partner</td>
<td>Transit Operator</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
</tr>
<tr>
<td>Parker Hannifin</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles, data, and support for testing</td>
</tr>
<tr>
<td>Clinton Global Initiative – EV School Bus Consortium</td>
<td>Funding Partner</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles, data, and installed infrastructure (Servidyne/Chateau)</td>
</tr>
<tr>
<td>TransPower</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing data and hardware to enable testing</td>
</tr>
<tr>
<td>US Hybrids</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing data and hardware to enable testing</td>
</tr>
<tr>
<td>Pacific Gas and Electric (PG&amp;E)</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing access to battery data and vehicle data</td>
</tr>
<tr>
<td>Con-Way</td>
<td>Fleet Partner</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing line-haul and regional-haul vehicle data</td>
</tr>
<tr>
<td>U.S. Environmental Protection Agency</td>
<td>Funding Partner</td>
<td>Gov’t Collaboration</td>
<td>Outside</td>
<td>Providing funding to analyze vocational vehicle data for Phase II Heavy-Duty Greenhouse Gas (GHG) Regulations</td>
</tr>
<tr>
<td>California Energy Commission (CEC)</td>
<td>Funding Partner</td>
<td>Gov’t Collaboration</td>
<td>Outside</td>
<td>Providing funding for fleet evaluation</td>
</tr>
<tr>
<td>Odyne</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing access to battery data and vehicle data</td>
</tr>
<tr>
<td>Altec</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles for chassis testing and field data collection</td>
</tr>
<tr>
<td>21st Century Truck Partnership</td>
<td>Coordination</td>
<td>Gov’t Collaboration</td>
<td>VT Program</td>
<td>Providing funding to assess fleet-specific technology options for National Clean Fleets Partnerships (Verizon, City of Indianapolis, PG&amp;E)</td>
</tr>
<tr>
<td>Solazyme</td>
<td>Fuel Provider</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing renewable diesel fuel for chassis testing</td>
</tr>
</tbody>
</table>
Remaining Challenges and Barriers

1. **Continuing need for information and analysis**
   o Fleets are faced with a long menu of alternatives, including propane, natural gas, electric, fuel cells, aerodynamics devices, low-rolling resistance tires, etc. Fleets need objective information on the performance of these technologies within the context of their operations.

2. **Availability of new technology solutions that are reliable and cost effective for fleets**
   o Fleets remain tentative in procurement based on return-on-investment projections: limited rollout of EVs, hybrid electric vehicles, and PHEVs, and fleets need suppliers that can provide reliable, long-term maintenance and support.

3. **Vehicle emissions performance requirements and changing GHG regulations may impact industry requirements and available technologies**
   o Focus on energy savings while relying on engine emissions certification may lead to in-use emissions challenges. Root-cause analysis and solutions are needed along with information on potential regulatory/process requirements
   o New EPA HD GHG rules likely to cause demand for new cost-effective energy-saving technologies and better un-biased data technology-specific fuel performance
Proposed Future Work

FY16 Proposed Work will Include:

1. Continued fleet analysis approach (3–4 new projects per year) of new emerging technologies based on highest potential for fuel reduction, need for data/information, and fleet interest. Emerging areas of interest include: MD/HD electrification, including grid integration technologies, wireless power transfer demo’s, validation of cost-effective HEV up-fits; autonomous vehicle technology in commercial fleet applications; latest natural gas technologies.

2. More “cross-cutting” vocational analysis rather than a single fleet, e.g., evaluate tradeoffs such as HHV technology in package delivery vs. refuse vocations; evaluate “best” vocations/duty cycles for MD/HD EVs

3. Better “deep dive” analysis approach to address issues discovered in assessments (i.e., root cause analysis of findings)

4. Continued coordination with 21st Century Truck and Clean Cities / National Clean Fleets Partners to align data and analysis

5. Better data coordination and data sharing to enable technology development across VTO offices (e.g., field battery data to inform VTO battery research efforts in MD/HD industry needs; field demonstrations of grid/building integrated EV; HD/MD accessory load requirements)
Summary

• MD and HD testing, data collection, and analysis are helping to drive design improvements, purchase decisions, and provide field data for researchers by:
  o Making data and analysis results publically available
  o Technical briefings conducted with fleet and industry stakeholders
  o Feeding vocational database for future analysis
  o Field data from vehicles and components feeds modeling and simulation efforts

• Key technical accomplishments in FY15 include:
  o Completed UPS Hydraulic Hybrid and Line-Haul Platooning studies with technical reports, presented to stakeholder community, with specific recommendations made to fleets and technology providers (e.g., UPS, Peloton, others)
  o Completed data collection activities and preliminary analysis on Frito-Lay EV project and scheduled CY15 project completion and reporting
  o Kicked-off new fleet evaluations, including HHV refuse haulers, Foothill Transit EV buses, EV School Bus, PG&E electrified utility trucks, and UPS renewable diesel projects, leveraging substantial fleet and industry participation
  o Published and presented results at key industry forums with data provided to FleetDNA database for public access
  o Close coordination with other DOE areas, including Clean Cities/National Clean Fleet Partnership members, 21st Century Truck partnership, DOE researcher programs
Technical Back-Up Slides
Acknowledgements and Contacts

Thanks to:

Vehicle & Systems Simulation & Testing Activity – Lee Slezak and David Anderson
Vehicle Technologies Office – U.S. Department of Energy

For more information:

Kenneth Kelly
National Renewable Energy Laboratory
kenneth.kelly@nrel.gov
phone: 303.275.4465
Electrified Utility Work Trucks
- Utility fleets expanding use of electrified vehicle alternatives
- Ability to provide off-board power for equipment or to power a small community
- Quiet and clean operation in neighborhoods or other noise-sensitive areas

EV and PHEV Delivery Vehicles
- Currently being demonstrated by large commercial fleets such as UPS, FedEx, Coke, Frito-Lay
- Opportunity to integrate EV with efficient fleet facilities (V2B)
- Large batteries have potential secondary-use applications

Electric Buses
- Clean and quiet operation in urban centers
- Federal funding opportunities promote clean, efficient transit solutions
- Fixed routes and centralized operations allow for innovative solutions such as fast charging, wireless charging, electrified roadways, and integration with transit facilities

Zero Emissions Cargo Transport
- Zero emission cargo transport and major ports, e.g., Port of LA / Long Beach
- Centralized operations – potential for catenary electrification
- Zero idle emissions
## Sample Data Protocol

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Frequency Recorded</th>
<th>Data Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Descriptions</td>
<td>Once, start of data collection</td>
<td>Bus OEM and model, bus size, engine, any other specification that could affect efficiency</td>
</tr>
<tr>
<td>Vehicle Operating Cycle</td>
<td>Once, start of data collection</td>
<td>General description of daily use of vehicles</td>
</tr>
<tr>
<td>Vehicle Usage in Service</td>
<td>At each time usage is measured</td>
<td>Odometer reading; hours of vehicle operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daily vehicle assignment</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>Each time a vehicle is fueled/charged</td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date</td>
</tr>
<tr>
<td></td>
<td>Each time the fuel price changes at a given site</td>
<td>Price per unit</td>
</tr>
<tr>
<td>Engine Oil Consumption and Changes (baseline buses)</td>
<td>Each time oil is added</td>
<td>Amount of oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date</td>
</tr>
<tr>
<td></td>
<td>Each time oil is changed as recommended by the engine manufacturer</td>
<td>Price per quart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount of oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date</td>
</tr>
<tr>
<td>Maintenance</td>
<td>For each work order</td>
<td>Type of maintenance: Scheduled, Unscheduled, Configuration Change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labor hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date of repair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of days out of service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts replaced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description of reported problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description of repair performed</td>
</tr>
<tr>
<td>Road Call or Road Service</td>
<td>For each occurrence</td>
<td>Same as maintenance</td>
</tr>
<tr>
<td>Vehicle Capital Costs</td>
<td>Start of data collection</td>
<td>Capital cost for test vehicles</td>
</tr>
</tbody>
</table>
## Sample Data Protocol – EV/EVSE Data Collection

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Frequency Recorded</th>
<th>Data Items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Duty Cycle</strong></td>
<td>On-board data loggers, one month of 1-Hz duty-cycle data collection</td>
<td>On-board data loggers capture GPS/CAN data on vehicle duty cycle (time, location, speed, temperature, acceleration, battery/motor current, voltage, state of charge [SOC], temperature)</td>
</tr>
<tr>
<td><strong>Charging Profiles</strong></td>
<td>Electric vehicle supply equipment (EVSE) power quality meters, monthly data collection – several times per year</td>
<td>Meters capture voltage, current, power factor, harmonic distortion at intervals as slow as one per minute (at each EVSE circuit, if possible)</td>
</tr>
<tr>
<td><strong>Facility Electricity Demand</strong></td>
<td>Building-level power quality meters, monthly data collection – several times per year to capture seasonal differences</td>
<td>Building meters capture voltage, current, power factor, harmonic distortion at intervals as slow as one per minute (at building level as well as a few dominant circuits such as HVAC, lighting, on-site PV, if possible)</td>
</tr>
<tr>
<td><strong>Battery Degradation Tests</strong></td>
<td>One 7-hour battery test conducted every 6 months</td>
<td>NREL battery capacity test (conducted by NREL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Odometer reading at time of test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery CAN data for enabling test, ensuring safety and post-processing of Ah and kWh capacity: (1) Pack-level: SOC, T, I, V, Ahcum, contactor status, (2) Cell-level: min/max V and min/max T</td>
</tr>
</tbody>
</table>
## Vehicle Data Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle ID</td>
</tr>
<tr>
<td>Vehicle weight or mass</td>
</tr>
<tr>
<td>Payload</td>
</tr>
<tr>
<td>Door Status</td>
</tr>
<tr>
<td>Timestamp</td>
</tr>
<tr>
<td>Operation state</td>
</tr>
<tr>
<td>Shifter position</td>
</tr>
<tr>
<td>Transmission gear state (if applicable)</td>
</tr>
<tr>
<td>Accelerator position</td>
</tr>
<tr>
<td>Brake pedal on state or applied pressure</td>
</tr>
<tr>
<td>Vehicle speed</td>
</tr>
<tr>
<td>Distance driven</td>
</tr>
<tr>
<td>GPS latitude</td>
</tr>
<tr>
<td>GPS longitude</td>
</tr>
<tr>
<td>GPS elevation</td>
</tr>
<tr>
<td>Ambient temperature</td>
</tr>
<tr>
<td>Air conditioner state</td>
</tr>
<tr>
<td>Air conditioner compressor power</td>
</tr>
<tr>
<td>Heater state</td>
</tr>
<tr>
<td>Air compressor status / pressure</td>
</tr>
</tbody>
</table>

## Component Data Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery current</td>
</tr>
<tr>
<td>Battery voltage</td>
</tr>
<tr>
<td>Battery pack SOC</td>
</tr>
<tr>
<td>Battery pack min cell voltage</td>
</tr>
<tr>
<td>Battery pack max cell voltage</td>
</tr>
<tr>
<td>Battery pack balance mode state</td>
</tr>
<tr>
<td>AC charging current</td>
</tr>
<tr>
<td>AC charging voltage</td>
</tr>
<tr>
<td>Battery pack bulk temperature</td>
</tr>
<tr>
<td>Battery pack min cell temperature</td>
</tr>
<tr>
<td>Battery pack max cell temperature</td>
</tr>
<tr>
<td>Motor temperature</td>
</tr>
<tr>
<td>Power electronics/charger temperature</td>
</tr>
<tr>
<td>DC/DC voltage</td>
</tr>
<tr>
<td>DC/DC current</td>
</tr>
<tr>
<td>Motor speed</td>
</tr>
<tr>
<td>Motor torque</td>
</tr>
<tr>
<td>Motor power (electrical)</td>
</tr>
</tbody>
</table>
UPS Hydraulic Hybrid Delivery Van Study (completed Q4 FY14)

NREL Lead: Mike Lammert (PI)

Partners & Cost Share:
- UPS – access to vehicles, chassis dyno test vehicles, operational cost data, refueling records and maintenance
- Parker-Hannifin – hydraulic hybrid technical information

Goals/Objectives
- Conduct objective, independent evaluation of hydraulic hybrid technology in package delivery application, including performance, fuel savings, emissions, total cost of ownership
- Contribute data to FleetDNA database & knowledge base on refuse hauler technology alternatives

Background and Value
- UPS is a member of the National Clean Fleet Partnership and has been active in demonstrating various advanced vehicle technologies
- UPS operating 40 Parker HHVs in Baltimore and Atlanta
- 20 HHVs in Baltimore area are currently being studied
- Being compared to gasoline conventional vehicles

FY15 Accomplishment Highlights
- Project completed in Q4 – FY14
- The hydraulic hybrid parcel delivery van demonstrated 19% – 52% better fuel economy than conventional diesel on cycles
- The hydraulic hybrid parcel delivery van demonstrated 30% – 56% better fuel economy than conventional gasoline
- Recommendations provided to UPS: Hydraulic hybrid parcel delivery vans could maximize their fuel saving potential if deployed on more kinetically intense routes
- Field data incorporated into FleetDNA
- Results published SAE COMVEC, October 2104

FY15/FY16 Plan Forward
- Project is complete with publications and data available
- Results from this study will be incorporated into a cross-cutting analysis comparing several technologies across the package delivery vocation
- This hydraulic hybrid study will be compared against the Miami-Dade refuse hauler application to see how the technology performs in different vocations
Line Haul Truck Semi-Autonomous Platooning Study (completed Q4 FY14)

NREL Lead: Mike Lammert (PI)

Goals/Objectives
- Define fuel savings for a large fleet that adopts platooning technology
  - Geospatial analysis of current platooning opportunity
  - % of miles platooning capable for one large fleet acting independently.
- Estimate fuel savings if large national trucking fleets adopted platooning independently or cooperatively and achieved savings similar to studied fleet
- Demonstrate optimized configuration fuel savings on track and field tests

Background and Value
- Technology shows potential to reduce fuel use by 6+% (truck pair average)
  - Opportunity exist to further optimize the fuel savings
- Supports development and adoption of connected/automated vehicle (CAV) technology
- High level of interest from fleets and industry

Partners & Cost Share:
- Peloton – vehicle platooning hardware and controls, technical data and information
- Intertek (DOE contract) – vehicle procurement and track testing
- PACCAR – test truck CAD files
- Con-Way – fleet data
- LLNL – CFD & Wind Tunnel testing (DOE funded follow-on study)

FY15 Accomplishment Highlights
- Project completed in Q4 FY14
- Tests showed fuel savings for the lead (up to 5.3%) and trailing (up to 9.7%) trucks
- The demonstrated “team” savings of 6.4% could be an attractive return on investment for a fleet
- Remaining questions:
  - Engine coolant temperature needs to be monitored/addressed for the trailing vehicle
  - Optimum following distance may depend on ambient temperature and vehicle load (absent some aerodynamic aid for radiator air flow)
- Results published SAE COMVEC, October 2104, transferred lessons learned/recommendations to Peloton
- Follow-on study initiated with LLNL

FY15/FY16 Plan Forward
- Collaboration with LLNL computational fluid dynamics (CFD) and wind tunnel (WT) testing to answer aerodynamic questions raised during FY14 track tests.
- Geospatial analysis of in-use fleet logistics data to define “Big Picture” fuel savings potential at fleet and national levels.
- Track testing to confirm WT and CFD findings
- Fleet testing to validate savings under real world conditions.