Medium and Heavy-Duty Vehicle Field Evaluations

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National Renewable Energy Laboratory
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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)
- **Percent Complete**: ~95% previous FY funding
- **FY16-FY18 new competitive lab-call award (5%)**

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frito-Lay EV</td>
<td></td>
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<td>Completed in FY16</td>
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<tr>
<td>PG&amp;E PHEV Utility Trucks</td>
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<td></td>
<td>Completed in FY15</td>
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<tr>
<td>UPS Renewable Diesel Test</td>
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<td>Completed in FY15</td>
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<tr>
<td>Miami-Dade Refuse HHV</td>
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<td>Planned FY16 completion</td>
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<tr>
<td>Foothill Transit EV</td>
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<td>Planned FY16 completion</td>
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<tr>
<td>EV V2G School Bus</td>
<td></td>
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<td>Planned FY17 completion</td>
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<tr>
<td>Duke Energy / Odyne PHEV</td>
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<td>Kicked off in FY16 - ending in FY17</td>
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<tr>
<td>UPS / Workhorse range extended PHEV</td>
<td></td>
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<td>Planned kickoff FY16 - ending in FY17</td>
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<tr>
<td>Long Beach Transit EV with wireless charging</td>
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<td>Planned kickoff in FY16 - ending in FY17</td>
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Barriers

- **Unbiased Data**: Commercial users and OEMs need unbiased, 3rd-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

- **Project Lead**: National Renewable Energy Laboratory

Budget

- **Total Project Funding FY15 w/industry cost share**: ~$800K
  - **DOE Share**: $500K 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 FY16**: $1,100K
Relevance: Providing Unbiased Data and Analysis

This project provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

• **3rd 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:**
  o Guide R&D for new technology development
  o Help define intelligent usage of newly developed technology
  o 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>
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</thead>
<tbody>
<tr>
<td>FY15 Q3</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
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</tr>
<tr>
<td>FY15 Q4</td>
<td>Milestone</td>
<td>Final Report &amp; Data on all Projects</td>
<td>Complete</td>
</tr>
<tr>
<td>FY16 Q1</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
<td>Complete</td>
</tr>
<tr>
<td>FY16 Q2</td>
<td>Milestone</td>
<td>Status Report on all Projects</td>
<td>Complete</td>
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</tbody>
</table>

- In addition to the above reports, the following published technical project reports have been completed with data available through Fleet DNA:
  - Foothill Transit Implementation Report – June ‘15
  - EV School Implementation Report – June ‘15
  - Hydraulic Hybrid Refuse Truck Paper – September ‘15
  - Frito-Lay EV Final Conference Paper – April ‘16
  - Fast Charge Battery EV Bus Technical Report – May ‘16
  - Battery Standardization for MD HEVs – DOE Energy Storage Milestone
  - UPS / Solazyme result presented at NTEA Green Truck Summit
  - 17 technical papers and presentations completed since last AMR

http://www.nrel.gov/transportation/fleettest.html
MD & HD Field Testing Approach

Evaluate the performance of alternative fuels and advanced technologies in medium- and heavy-duty 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 & metrics (ESS, engine, after-treatment, hybrid/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


Proterra, Navistar, Smith EV, Eaton, TransPower, Allison, BAE, EDI, Altec, PACCAR, Oshkosh, Odyne, Parker-Hannifin, Cummins

Useful Data, Analysis and Published Reports
Approach: NREL Field Data, Testing, & Analysis Tools

Data from Field Evaluations helps populate FleetDNA database

DOE Fleet Tools (DRIVE, FASTSim, A Fleet, 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

Laboratory Testing

Explore & Optimize

Communicate & Inform

Identify Barriers, New R&D Opportunities, Validate Efforts

Partnership with Fleets and Technology Providers = Relevant Results & Optimized Solutions for Real World Applications
Approach: Data and Information Exchange

Evaluation Projects

Fleet DNA
DRIVE
FASTSim

DOE Programs

Industry Partners

Other Agencies

Research Orgs

Recent Interactions

Energy Storage
Power Electronics
Hydrogen and Fuel Cells
21st Century Truck
National Clean Fleet Partners
EV Everywhere

Extensive fleet and industry partners (e.g. see slide 5)

US EPA
National Park Service
TARDEC
SCAQMD
CARB / CEC

ORNL, INL, LLNL, ANL
Clemson, Ohio State, U of Michigan, Georgia Tech...
Approach: FY15/16 Projects and Selection Process

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 & 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.

Active Fleet Evaluation Projects

| Miami-Dade Parker Hydraulic Hybrid Refuse Trucks | Foothill Transit Proterra EV Bus with Fast Charging |
| EV School Bus with Vehicle to Grid Capability | Duke Energy - Odyne PHEV Utility Fleet |
| UPS / Workhorse extended range PHEV | Long Beach Transit EV Bus with Wireless Charging |

Projects Completed in FY16

| Frito-Lay EV with facility loads and battery testing | PG&E Utility Trucks With Job-site Electrification |
| UPS - Solazyme Renewable Diesel |

FY16 Technical Accomplishment highlighted in this presentation include:

1. Miami-Data, Gen 2 Parker-Hannifin hydraulic hybrid refuse haulers
2. Foothills Transit – Proterra EV transit bus with Eaton 500kW fast-chargers
3. UPS Solazyme, Renewable diesel
Technical Accomplishments:
Miami-Dade Hydraulic Hybrid Vehicle (HHV) Fleet Evaluation

NREL Lead: Bob Prohaska (PI)

Partners & Cost Share:

Miami Dade – access to HHV and baseline vehicles for instrumentation; fuel and maintenance data
Parker Hannifin – 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 & knowledge base on refuse hauler technology alternatives

Background and Value

• Miami-Dade is the 7th most populous county in the US and 3rd 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 independently evaluated

FY15/16 Accomplishment Highlights

• Kick-off meeting with Miami-Dade – Jan 2015
• Fleet Evaluation fact sheet completed
• Initial duty-cycle data collected on Gen 1 HHV’s and conventional Diesels: 2/25/2015 - 3/25/2015
• Additional duty-cycle data collected on Gen 1 HHV’s, Gen 2 HHV’s and diesels Nov ‘15 – Jan ‘16
• All data has been uploaded to Fleet DNA database
• Historic vehicle maintenance and fueling records obtained from fleet

FY16 Plan Forward

• Complete on data collection in FY16 – vehicle, maintenance and refueling data
• Conduct chassis dynamometer testing of HHV and baseline vehicles on representative drive cycles (FY16)
• Calculate total cost of ownership including reliability and maintenance
• Perform analysis to show optimal placement of new technology (i.e. Route vs benefit)
• Complete all analysis and publish Final Technical Report CY16
Comparison Miami HHVs w/ Baltimore UPS HHV’s

Kinetic Intensity vs Fuel Economy

- MY13 HHV Days: 2.60 MPG
- Conventional Days: 1.56 MPG
- MY15 HHV Days: 2.35 MPG
- UPS HHV: 9.33 MPG

Average: 2.60 MPG
Fuel Economy based on Duty Cycle

• Dyno Test on ‘Baltimore Custom Cycle’
  o HHV demonstrated **19.5% FE improvement** over diesel equivalent vehicle
    – Dyno HHV diesel: 10.18 MPG
    – Dyno diesel: 8.52 MPG
    – Dyno gasoline: 7.86 MPG

• Initial Miami-Dade Field Data
  o **Vehicle CAN data** indicates **67.8% FE improvement** with HHV over conventional.
    – 2007 conventional diesel: 1.55 MPG
    – 2013 HHV diesel: 2.60 MPG
    – 2015 HHV diesel: 2.35 MPG
Fuel Consumption based on Duty Cycle

• **Dyno Test on ‘Baltimore Custom Cycle’**
  - HHV demonstrated **16.3% FC improvement** over diesel equivalent vehicle
    - Dyno HHV diesel: 9.8 gal/100 mi
    - Dyno diesel: 11.7 gal/100 mi
    - Dyno gasoline: 12.7 gal_de/100 mi

• **Initial Miami-Dade Field Data**
  - **Vehicle CAN data** indicates **40.4% FC improvement** with HHV over conventional.
    - 2007 conventional diesel: 64.6 gal/100 mi
    - 2013 HHV diesel: 38.5 gal/100 mi
    - 2015 HHV diesel: 42.5 gal/100 mi
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 500kW 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 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 FY15
- Collected 2Hz vehicle and component data from 12 EV buses – including 775 vehicle days, 92,300 miles of operation
- Collected baseline performance data from 12 CNG transit buses operating over a period of 3 weeks, 37,800 miles.
- All data has been uploaded to Fleet DNA database
- Published EV In-used performance results at IEEE ITEC Conference – 2016

FY16 Plan Forward
- Planned final project wrap-up with final technical report in CY16
- Working with California Air Resources Board (CARB) to conduct chassis dynamometer emissions tests of EV and baseline vehicles
- Develop FASTSim
- Final analysis will include an evaluation of potential for expanding EV service to other routes
Overall Fuel Economy in Data Period  

**BEB**: 17.48 mi/DGE (2.15 kWh/mi)

**CNG: Orion** 4.40 mi/DGE (3.93 mi/GGE)  
**NABI** 4.52 mi/DGE (4.04 mi/GGE)
Duty Cycle Data

Vehicle Speed, SOC & Distance
VIN: 816048 - May 4, 2015

Vehicle Speed, SOC, and Distance chart showing fluctuations and trends over time.
EV Bus In-Use Motor Power Characteristics

Duty Cycle Statistics:

- Driving Days: 774
- Kinetic Intensity (1/mi): 1.71
- Stops per mile: 3.70
- Avg Acceleration (ft/s²): 1.44
- Average Speed (mph): 17.66

Motor Continuous Rating: 120kW
Technical Accomplishments: 
UPS / Solazyme – Renewable Diesel Chassis Dynamometer Test

<table>
<thead>
<tr>
<th>Accomplishments</th>
<th>FY16 Plan Forward</th>
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</table>
| - Collected 2 weeks of 1Hz GPS and CAN data from 10 class 4 package vans and 10 class 8 tractors  
- Completed analysis of field data including vehicle activity map, drive cycle statistics and representative drive cycle selection  
- Completed chassis dynamometer testing of class 4 package van and class 8 tractor using Solazyme and low sulfur diesel  
- Briefed industry partners and presented results at NTEA Green Truck Summit | - Project complete  
- Final technical paper to be published in FY16 |

**NREL Lead:** Adam Ragatz (PI)

**Partners & Cost Share:**
- **UPS** – access to package delivery van and class 8 tractor, provide test vehicles  
- **Solozyme** – provided renewable diesel fuel  
- **DOE Clean Cities / National Clean Fleet Partnership** - Funding to support chassis testing

**Goals/Objectives**
- Conduct an evaluation of fuel economy and emissions performance of Solazyme renewable fuel blend operating in UPS fleet application

**Background and Value**
- UPS announced purchase of up to 46 million gallons of renewable diesel over next 3 years  
- Renewable diesel is designed to be “drop-in” replacement fuel so it can offset petroleum use in existing fleet  
- Project provides independent evaluation of the fuel economy and emissions performance of renewable diesel
Baseline Duty Cycle – GPS Mapping

- Blue – Regional Tractor Trailers
- Red – Package Cars
Chassis Dyno Test Results – Fuel Economy

• Average measured over all cycles
  o Fuel consumption (mass based): 2.9% better
  o Fuel economy (volume based): -3.6% worse

• Expected from Solazyme fuel properties
  o Energy content (mass based): 3.1% higher
  o Energy content (volume based): -3.7% lower
**Chassis Dyno Test Results – Emissions**

**CO₂ - consistent 4.2% decrease tailpipe emissions**
- Higher mass based energy content
- Higher H:C ratio

**Estimated Annual Impact**
- Tractor VMT: 104,000 mi/yr
- Average FE: 6.49 mpg
- Displaced CO₂: 7.5 tons/veh/yr

**NOₓ Emissions Results**
- All cycles in compliance
- Tractor results were noisy likely due to low absolute levels and complex SCR interactions
- Package car averaged 4.1% reduction
Response to Previous Year Reviewers’ Comments

Approach:

Comment #1:  The reviewer stated that the approach of the medium- and heavy-duty field testing project has proved to be excellent. The fleet selection and the vehicle and equipment manufacturers in the project have provided very useful data analysis and published reports. The reviewer added that the data collected including drive cycle, operating costs, fuel economy and chassis dynamometer testing has provided an excellent data set to evaluate the fleets.

Response:  Thank you for the positive feedback.

Comment #2: The reviewer reported that the project addresses the barriers identified by generating unbiased data on technology usage, as well as drawing conclusions regarding the effectiveness of the technologies under real-world conditions. The result of this work is valuable knowledge of the strengths and weaknesses of each technology and their appropriateness in a given application. The reviewer added that this activity can be characterized as a support role, in collecting and interpreting the data. One suggestion would be to take a lead role to advise and engage with partners to define the parameters of the study up front. The reviewer suggested, for example, recommending the most appropriate technology based on the fleet and their operating characteristics. Over time, there should be enough data in Fleet DNA database to make recommendations for future studies.

Response:  Thank you for the positive feedback. One way that NREL is expanding the use of this data/information with industry partners is through participation in DOE-sponsored FOA awards with industry. For example, NREL is providing Fleet DNA duty-cycle data and tools to inform the following DOE industry led FOA awards: Eaton multi-speed gearbox; Cummins medium-duty range-extended hybrid; Bosch-led medium-duty urban range-extended powertrain. We are also working on non-DOE programs such as SCAQMD Commercial Zero Emissions Vehicle Roadmap to apply Fleet DNA data and analysis techniques to select appropriate technologies for key vocations. We will continue to seek opportunities to apply the existing data and information earlier in the vehicle development process.
Response to Previous Year Reviewers’ Comments

Accomplishments:
Comment #1: The reviewer commented that technical accomplishments in fiscal year (FY) 2015 have been excellent. Close coordination with DOE including Clean Cities and 21st Century Truck Partnership has helped to get information out to the public about the project. The reviewer added that several new fleet evaluation efforts have been kicked off this year and data collection and reports of ongoing activities have provided technical reports that were published and presented to the industry.
Response: Thank you for the positive feedback. This year we expanded our use of the data and information to other programs within DOE including Energy Storage, Power Electronics and Fuel Cell program areas, and will continue to work closely with Clean Cities and 21st Century Truck Partnership.

Collaboration:
Comment #1: The reviewer stated that the collaboration and coordination in this project is outstanding. Without support from the industry partners this project would not be very successful. The reviewer added that the industry partners are absolutely necessary to the success of this project.
Response: Thank you for the positive feedback, we greatly value industry participation – the scope and quantity of fleet evaluation projects would be cost prohibitive without the in-kind support provided by fleet and industry partners.

Future Plans
Comment #1: The reviewer commented that continued funding of these efforts to include other fleets and other technologies is highly recommended to support Vehicle Technology Office objectives. The reviewer deemed this work to have provided a great return on investment.
Response: Thank you for the positive feedback.
Collaboration and Coordination with Other Institutions

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

Past industry partners included:

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<th>Relationship</th>
<th>Type</th>
<th>VT Program or Outside?</th>
<th>Details</th>
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</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>
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<td>UPS</td>
<td>Fleet Eval Partner</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and data</td>
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<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>
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<tr>
<td>Peloton</td>
<td>OEM Support</td>
<td>Industry</td>
<td>VT Program</td>
<td>Provided vehicles and hardware to test</td>
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<td>Parker Hannifin</td>
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<td>VT Program</td>
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<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>
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<td>Momentum Dynamics</td>
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<td>Industry</td>
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<td>Providing data and hardware to enable testing</td>
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<td>Gov't Collaboration</td>
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<td>Providing funding for projects to supplement DOE advanced vehicle technology testing (CARB = HVIP assessment)</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>
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<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>
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<tr>
<td>Oak Ridge National Laboratory</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>
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## Collaboration and Coordination with Other Institutions

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<td>VT Program</td>
<td>Provided vehicles, data, and support for testing</td>
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<td>VT Program</td>
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<td>Altec</td>
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<td>21st Century Truck Partnership</td>
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<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>
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<tr>
<td>Solazyme</td>
<td>Fuel Provider</td>
<td>Industry</td>
<td>VT Program</td>
<td>Providing renewable diesel fuel for chassis testing</td>
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</tbody>
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Remaining Challenges and Barriers

1. **Continuing need for information and analysis**
   - 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**
   - Fleets remain tentative in procurement based on ROI projections – limited rollout of EVs, hybrid electric vehicles, plug-in hybrid electric vehicles, and fleets need suppliers that can provide reliable, long-term maintenance and support.

3. **Vehicle emissions performance requirements and changing greenhouse gas regulations may impact industry requirements and available technologies**
   - 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 potential regulatory/process requirements;
   - 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-FY18 Proposed Work will Include:
During the FY16 year, the Fleet Evaluations work is transitioning to a collaborative effort with Idaho National Lab and Argonne National Lab, funded under the DOE Lab Call Vehicle Technology Evaluations. Under this activity, NREL will:

1. Coordinate with DOE’s VTO technology managers, medium and heavy-duty industry, and fleet partners to identify and select high-priority vehicle technologies for evaluation
2. Coordinate medium and heavy-duty evaluation activities with other DOE program activities (such as 21CT, NCFP, and energy storage) and laboratory partners (e.g., INL, ANL, ORNL, and LLNL)
3. Conduct medium and heavy-duty vehicle technology testing, data collection, and evaluation activities
4. Report on results from all medium and heavy-duty vehicle technology activities.

Separate to this activity, NREL will continue to seek opportunities to expand and apply existing data and expertise to support government, industry, and research partners in the development of advanced vehicle technologies through DOE-sponsored industry awards, DOE VTO programs, other government state and federal agencies, and “Work-for-others” with industry.
Summary

• MD and HD testing, data collection, and analysis is helping to drive design improvements, purchase decisions, and provide field data for researchers

• Key Technical Accomplishments in FY15/FY16 include:
  - Published or presented 17 technical papers / presentations resulting from Fleet Evaluation activities including key forums such as SAE Commercial Vehicle Engineering Congress, IEEE Transportation Electrification Conference, International Workshop on China Automotive Test Cycle Development, and NTEA Green Truck Summit;
  - Completed data collection activities, testing and analysis on Frito-Lay EV, UPS Solazyme renewable diesel, and PG&E PHEV utility trucks – and made significant technical progress on Foothill Transit EV bus, Miami-Dade HHV refuse hauler fleet evaluations;
  - Applied results of Fleet Evaluations and Fleet DNA to DOE R&D programs including – Energy Storage Battery, Hydrogen and Fuel Cells, Power Electronics, National Clean Fleet Partnership, and EV Everywhere
  - Hosted joint meeting of 21st Century Truck Partnership and National Clean Fleet Partnership bringing together fleets, truck industry, and government agencies (DOE, EPA, DOD, DOT).
  - Kicked-off new fleet evaluations with Duke Energy fleet evaluation of Odyne PHEV utility trucks, and established potential new evaluations of UPS / Workhorse extended range EVs, and Long Beach Transit BYD EV transit bus with wireless power transfer;
  - Completed vocational duty cycle analysis for EPA Phase II Greenhouse Gas proposed rulemaking and published report on “The Development of Vocational Vehicle Drive Cycles and Segmentation”
Acknowledgements and Contacts

Thanks to:

Lee Slezak and David Anderson
Vehicle Systems Program’s Advanced Vehicle Testing Activity
Vehicle Technologies Office – U.S. Department of Energy

Additionally to all the fleet and industry partners without whom this work would not be possible

For more information:

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Technical Back-Up Slides
Fleet DNA Accomplishments

- Significantly increased volume of data stored in Fleet DNA database; Fleet DNA now houses data on more than 1,600 unique vehicles.
- Performed analysis and published results examining impact of road grade on simulated commercial vehicle fuel economy.
- Examined methods to estimate vehicle fuel economy based on drive cycle metrics. Results of the research were released as an SAE publication.
- Performed a sweep study exploring the effects of vehicle parameters such as aerodynamic drag, rolling resistance, and mass on heavy-duty vehicle fuel consumption. Results were published and presented at SAE Commercial Vehicles Congress.
- Fleet DNA’s unique capabilities and data were leveraged to support multiple project partners including the California Air Resources Board, the South Coast Air Quality Management District, and the U.S. Environmental Protection Agency (EPA).
Fleet DNA – External Users and Support

• **EPA Phase II Greenhouse Gas Regulations**
  o Grade Analysis
  o Vocational Vehicle Segmentation and Drive Cycle Analysis

• **SCAQMD**
  o Fleet DNA Roadmap – extensive new data and applications
  o ZECT I and ZECT II data
  o ComZEV Roadmap – upcoming application applying FleetDNA tools with Ricardo vehicle penetration and Total Cost of Ownership models

• **DOE VTO Battery Standardization Strategy Assessment**

• **Applied Power Electronics (APEC) – Motor Power Requirements**

• **National Clean Fleet Partnership**

• **21st Century Truck Program**

• **DOE Fuel Cell Technologies Office Technical Targets**
New Capabilities – Identifying Gear Ratios

1) Starting with raw engine and vehicle data

2) Convert to ratios and accumulate

3) Identify ratios using kernel-density methods

4) Confirm predicted ratios
New Analysis – Idle & PTO Operations

1) Distribution of Engine RPM

2) Distribution of Engine RPM with vehicle speed = 0 (idle + PTO)

3) Time Spent – Driving / Idle / PTO

4) Fuel Consumption
EPA GHG MD/HD Phase 2 Regulations

• Vocational Vehicle Categorization
  o Identified 3 major operational clusters for vocational vehicles

• Development of Custom Transient Drive Cycle and Weightings
  o Generate representative cycle using Fleet DNA and DRIVE
  o Determined appropriate category weights using EPA criteria

• National Road Grade Analysis
  o Developed Custom Representative Road Grade Profile

• PTO and Idle Characterization
  o Characterized PTO and Idle usage for identified vehicle categories
## 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 &amp; 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>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>Date</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts replaced</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>
<tr>
<td>Type of Data</td>
<td>Frequency Recorded</td>
<td>Data Items</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vehicle Duty Cycle</td>
<td>On-board data loggers, one month of 1Hz 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, SOC, temperature)</td>
</tr>
<tr>
<td>Charging Profiles</td>
<td>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>Facility Electricity Demand</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>Battery Degradation Tests</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>
# EV Vehicle and Component Data – 1Hz

## 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>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>