Medium and Heavy-Duty Vehicle Field Evaluations

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National Renewable Energy Laboratory
2016 DOE VTO Annual Merit Review
June 9, 2016

Project ID # VS001

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%)

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

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**

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)

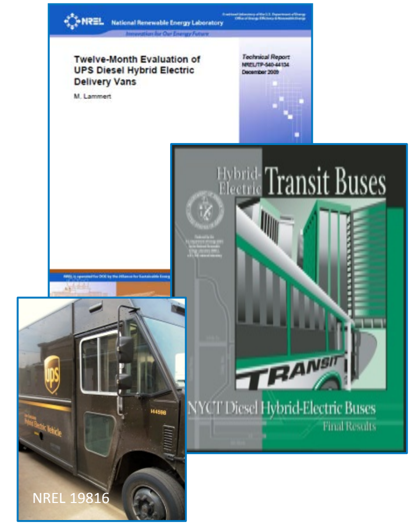
Partners

- **Industry collaboration required for successful studies. Past partners include:**
  New Flyer, Freightliner, Workhorse, International, Orion, Allison Transmission, Eaton, Enova, Azure, Cummins, International, FedEx Caterpillar, Coke, NYC Transit, Verizon
- **Current partners in FY16:**
  UPS, Eaton, Peloton, Parker Hannifin, Frito-Lay, Proterra, Foothill Transit, Odyne, Duke Energy, Miami-Dade, TransPower, PG&E, Efficient Drivetrains Inc., Altec, Clean Cities/National Clean Fleet Partnership
- **Project Lead:** National Renewable Energy Laboratory

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

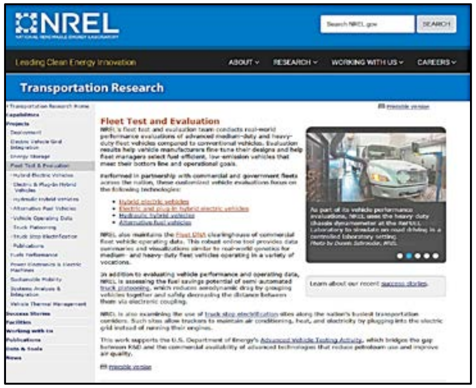


Milestones and Deliverables

Reports highlighting fleet data collection efforts and analysis of data:

Month / Year	Milestone or Go/No-Go Decision	Description	Status
FY15 Q3	Milestone	Status Report on all Projects	Complete
FY15 Q4	Milestone	Final Report & Data on all Projects	Complete
FY16 Q1	Milestone	Status Report on all Projects	Complete
FY16 Q2	Milestone	Status Report on all Projects	Complete

- ***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 Technical Report – December ’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

Fleets

UPS, FedEx, Coke, Frito-Lay, Foothill Transit, PG&E, Miami-Dade, Duke Energy, Walmart, Waste Management

+

Vehicle & Equip Mfg's

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, 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

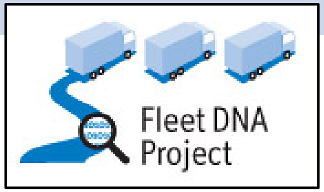
Capture, Store and Analyze

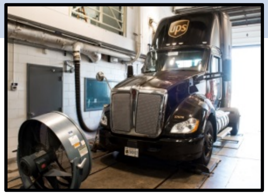
Laboratory Testing

Explore & Optimize

Communicate & Inform

Identify Barriers, New R&D Opportunities, Validate Efforts





NATIONAL Clean Fleets PARTNERSHIP
U.S. Department of Energy

21st CENTURY TRUCK PARTNERSHIP

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

Recent Interactions

DOE Programs

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

Industry Partners

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

Other Agencies

- US EPA
- National Park Service
- TARDEC
- SCAQMD
- CARB / CEC

Research Orgs

ORNL, INL, LLNL, ANL
Clemson, Ohio State, U of Michigan, Georgia Tech…

Approach: FY15/16 Projects and Selection Process

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 	

<u>FY16 Technical Accomplishment highlighted in this presentation include:</u>

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

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.

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

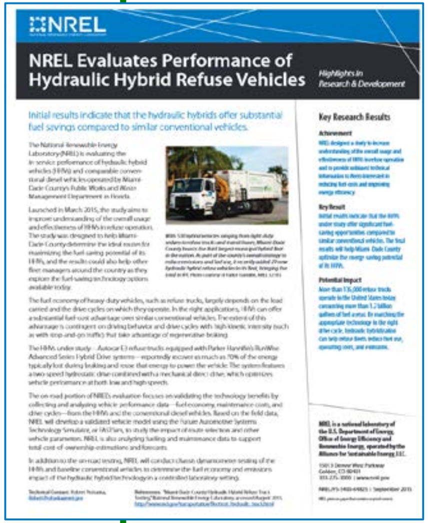
- Conduct objective, independent evaluation of hydraulic hybrid technology in refuse hauler application – including performance, fuel savings, emissions, total cost of ownership
- Contribute data to FleetDNA database & knowledge base on refuse hauler technology alternatives

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


NREL

NREL Evaluates Performance of Hydraulic Hybrid Refuse Vehicles

Highlights in Research & Development

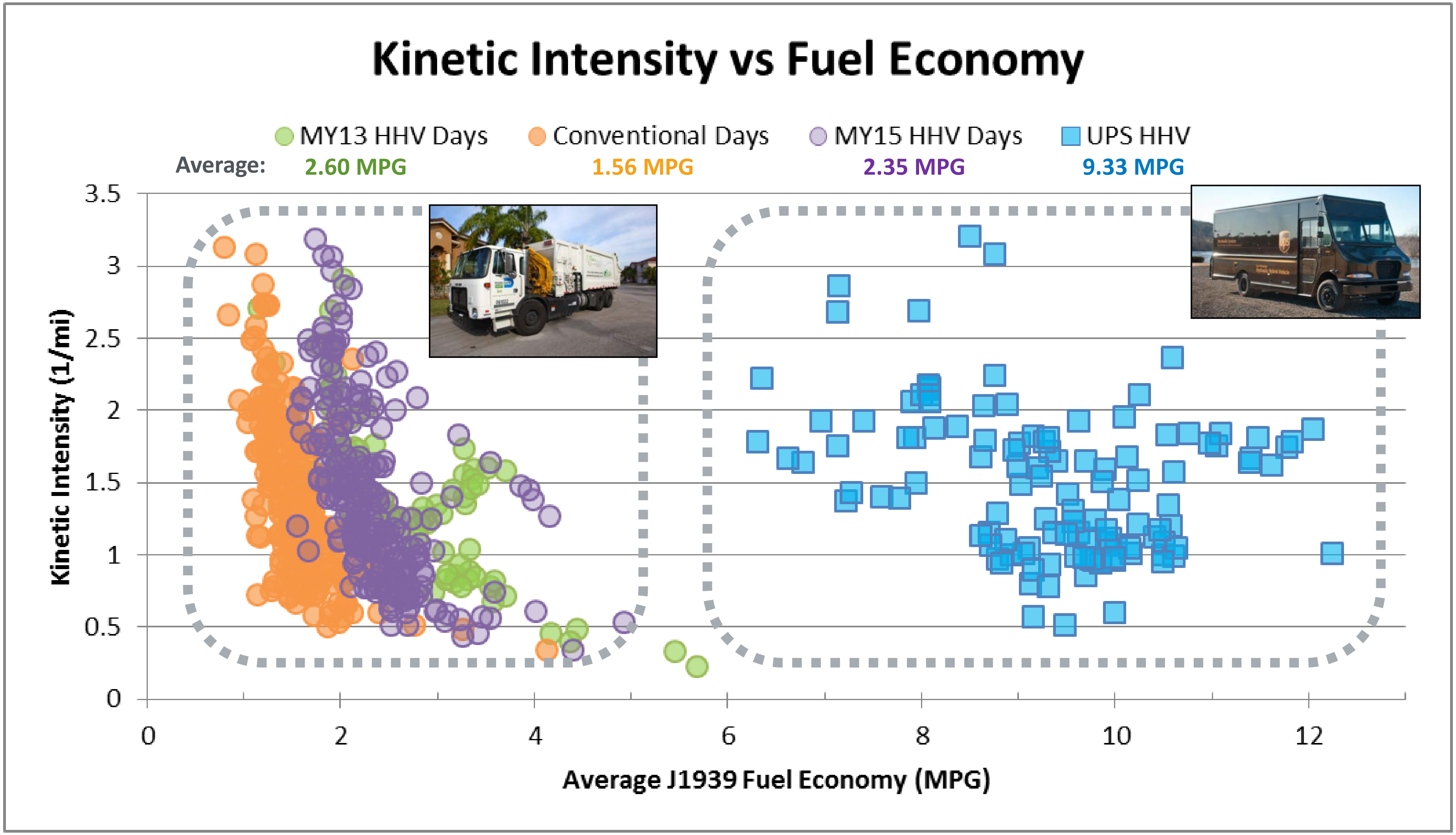
Initial results indicate that the hydraulic hybrids offer substantial fuel savings compared to similar conventional vehicles.

Key Research Results

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



Fuel Economy based on Duty Cycle

Baltimore Custom
KI = 1.31
Avg Speed = 18.31 mph
Stops/mi = 3.4

- **Dyno Test on *'Baltimore Custom Cycle'***
  - HHV demonstrated **19.5% <u>FE</u> improvement** over diesel equivalent vehicle
    - Dyno HHV diesel: 10.18 MPG
    - Dyno diesel: 8.52 MPG
    - Dyno gasoline: 7.86 MPG_{de}

- **Initial Miami-Dade Field Data**
  - <u>Vehicle CAN data</u> indicates **67.8% <u>FE</u> improvement** with HHV over conventional.
    - 2007 conventional diesel: 1.55 MPG
    - 2013 HHV diesel: 2.60 MPG
    - 2015 HHV diesel: 2.35 MPG

Preliminary Results

Fuel Consumption based on Duty Cycle

Baltimore Custom
KI = 1.31
Avg Speed = 18.31 mph
Stops/mi = 3.4

- **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

Preliminary Results

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

Fast Charge Battery Electric Transit Bus In-Use Fleet Evaluation

Robert Prohaska, Kenneth Kelly, Leslie Eudy
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Abstract-The focus of this interim fleet evaluation is to characterize and evaluate the operating behavior of Foothill Transit's fast charge battery electric buses (BEBs). Future research will compare the BEBs' performance to conventional vehicles. In an effort to better understand the impacts of drive cycle characteristics on advanced vehicle technologies, researchers at the National Renewable Energy Laboratory analyzed over 148,000 km of in-use operational data, including driving and charging events. This analysis provides an unbiased evaluation of advanced vehicle technologies in real-world operation demonstrating the importance of understanding the effects of road grade and heating, ventilating and air conditioning requirements when deploying electric vehicles. The results of this analysis show that the Proterra BE35 demonstrated an operating energy efficiency of 1.34 kWh/km over the data reporting period.

Fig. 1. Proterra BE35 Fast Charge Battery Electric Transit Bus (NREL/Leslie Eudy)

I. INTRODUCTION

In March 2014, Foothill Transit began operating a fleet of battery electric buses (BEBs) in its service area in the San Gabriel and Pomona Valley region of Los Angeles County, California. These electric buses, produced by Proterra, Inc., are 35-foot long, composite body buses that are capable of being charged on-route via Eaton 500-kW fast chargers (Fig. 1). Foothill Transit is collaborating with the California Air Resources Board and the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) in Golden, Colorado, to evaluate the buses in revenue service [1]. NREL has extensive experience conducting fleet evaluations and has been evaluating advanced technology buses for several years under funding from the DOE's Vehicle Technology Office and the U.S. Department of Transportation's Federal Transit Administration.

This research report was sponsored by the Vehicle Systems Program's Advanced Vehicle Testing Activity within the DOE's Vehicle Technologies Office.

The objectives of these evaluations are to provide comprehensive, unbiased evaluations of advanced technology bus development and performance compared to conventional baseline vehicles. These evaluations help manufacturers improve their design requirements, test procedures, and ultimately their commercial success, while at the same time informing fleet managers to allow them to better select appropriate energy-efficient, low-emission vehicle technologies that fit their operational goals and requirements.

In 2013 Foothill Transit purchased 12 BEBs through a $10.2 million grant under the Federal Transit Administration's Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program. Foothill Transit's project goal was to fully electrify one route in its service area—Line 291, which is an approximately 26.8-km route between La Verne and Pomona as shown in Fig. 2—and to investigate the feasibility of BEB technology for other routes. The details of the Proterra BE35 are shown in Table I.

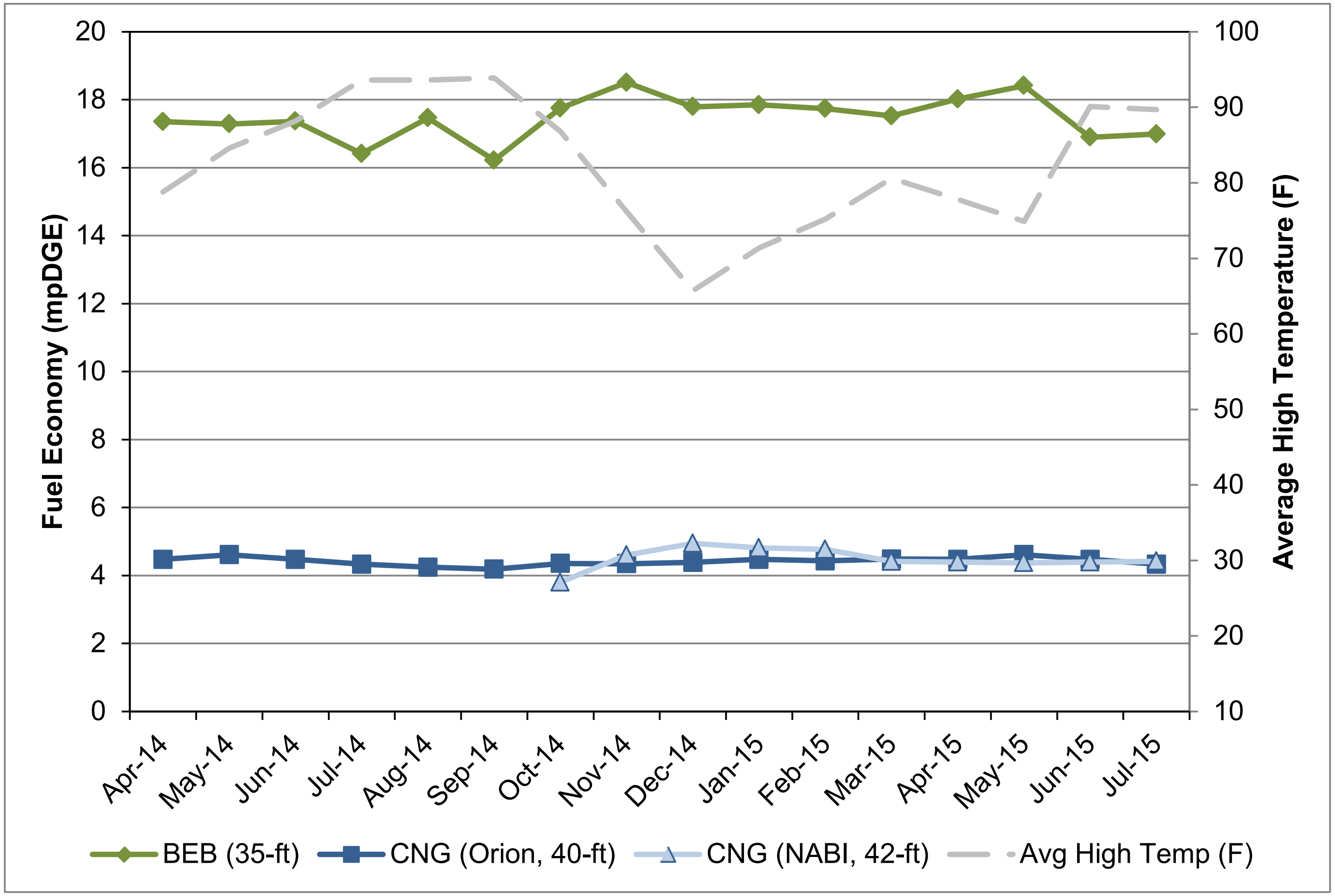
TABLE I.
PROTERRA BE35 BATTERY ELECTRIC BUS SPECIFICATIONS

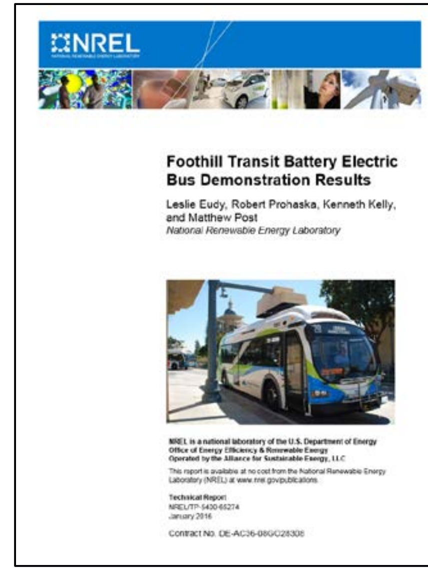
Bus manufacturer	Proterra
Bus model	BE35
Model year	2014
Total length	10.67 m (35 ft)
Total height	3.28 m (10.75 ft)
Wheelbase	6.02 m (237 in.)
Curb weight	12,555 kg (27,680 lb)
Gross vehicle weight rating	16,928 kg (37,320 lb)
Passenger capacity	35 seated / 18 standing
Battery manufacturer / model	Altairnano / TerraVolt 368
Battery type	368-V lithium titanate
Battery energy/capacity	88 kWh / 60 Ah
Number of packs	8 (6 floor, 2 roof)
Motor manufacturer / model	UQM / PP220
Motor power nominal	120 kW (161 hp)
Motor power peak	220 kW (295 hp)
Fast charging peak power	500 kW
Transmission gear ratios	3.53:1 and 1:1
Cabin air conditioning	Thermoking REH-M6
Cabin heater	11-kW electric resistance

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

Foothill Bus - Monthly Average Fuel Economy

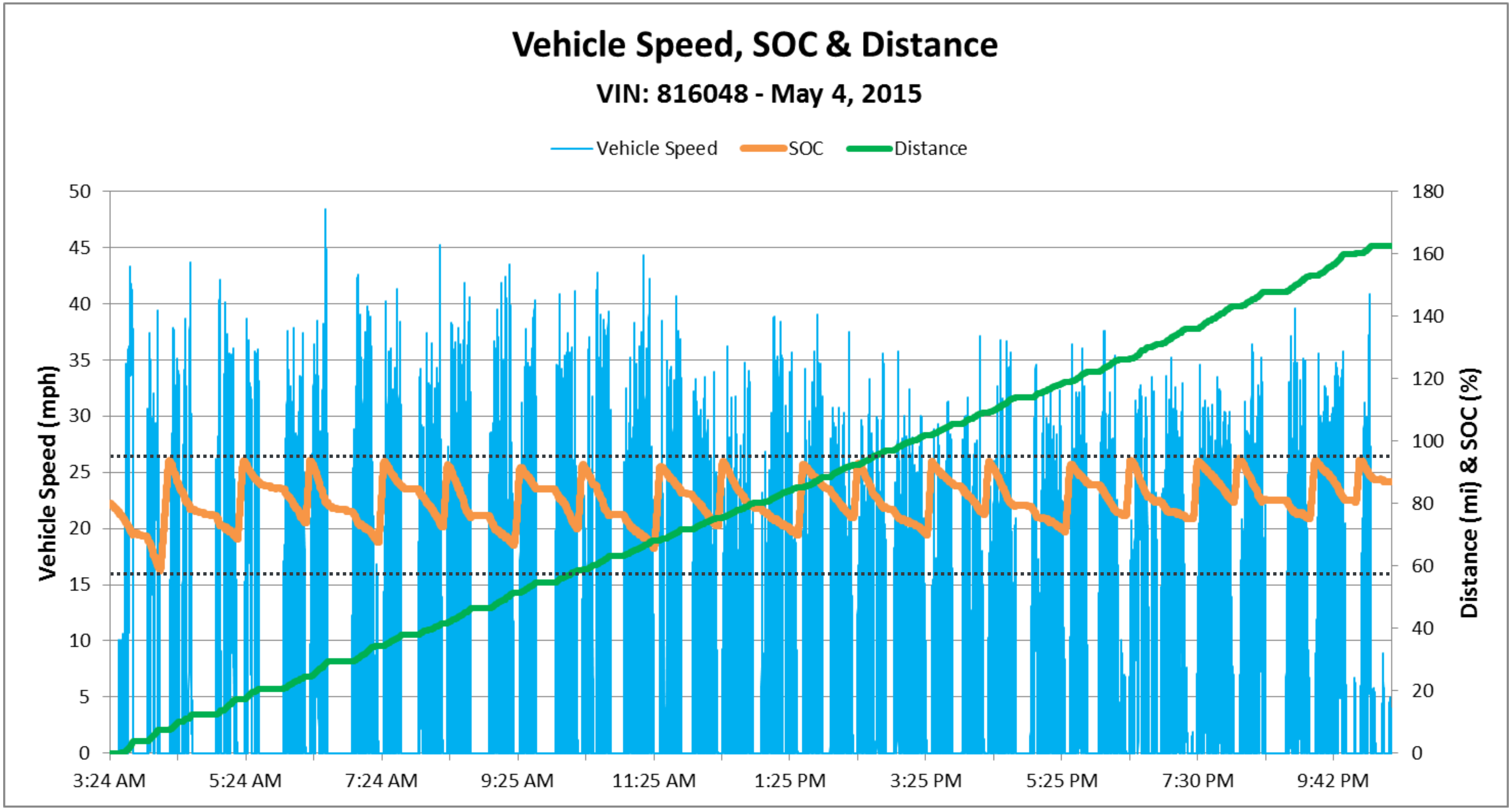




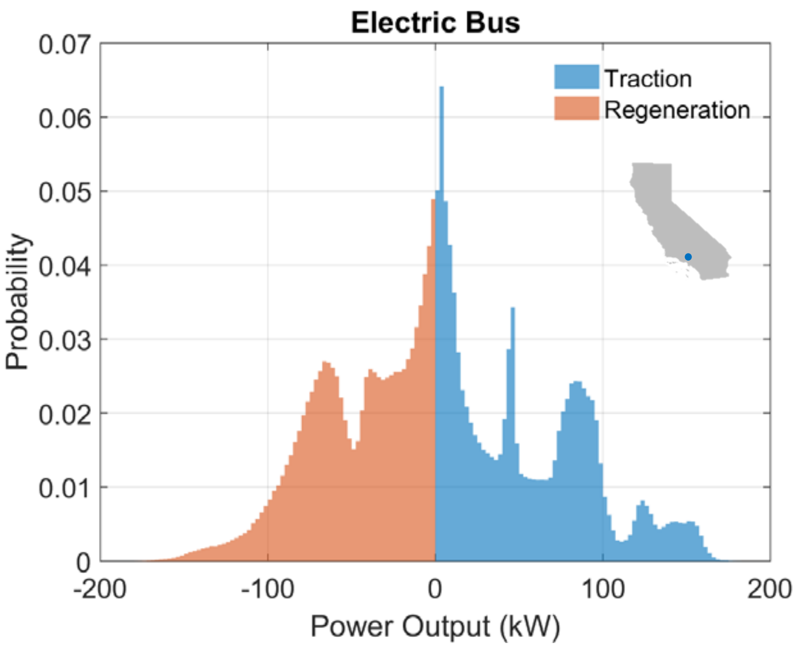
Overall Fuel Economy in Data Period BEB: 17.48 mi/DGE (2.15 kWh/mi)

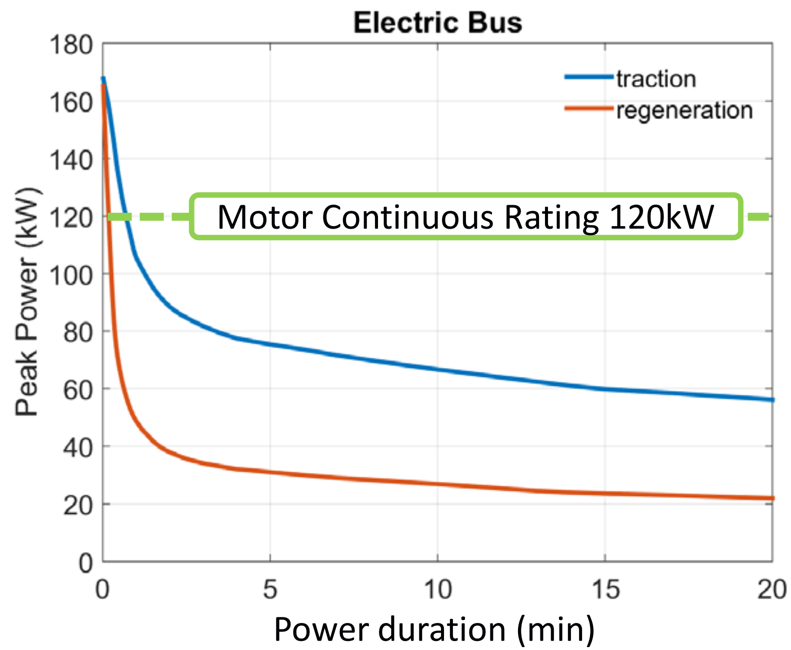
CNG: Orion 4.40 mi/DGE (3.93 mi/GGE) **NABI** 4.52 mi/DGE (4.04 mi/GGE)

Duty Cycle Data

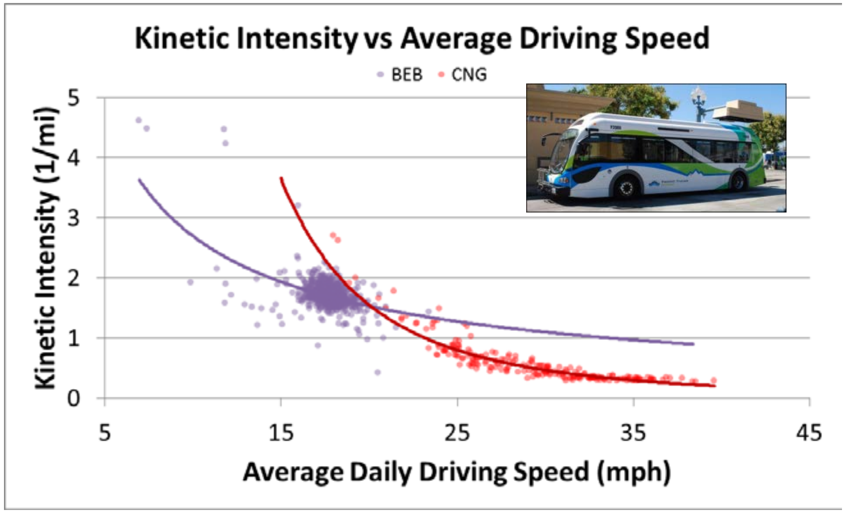


EV Bus In-Use Motor Power Characteristics





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



Technical Accomplishments:
UPS / Solazyme – Renewable Diesel Chassis Dynamometer Test

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

Accomplishments

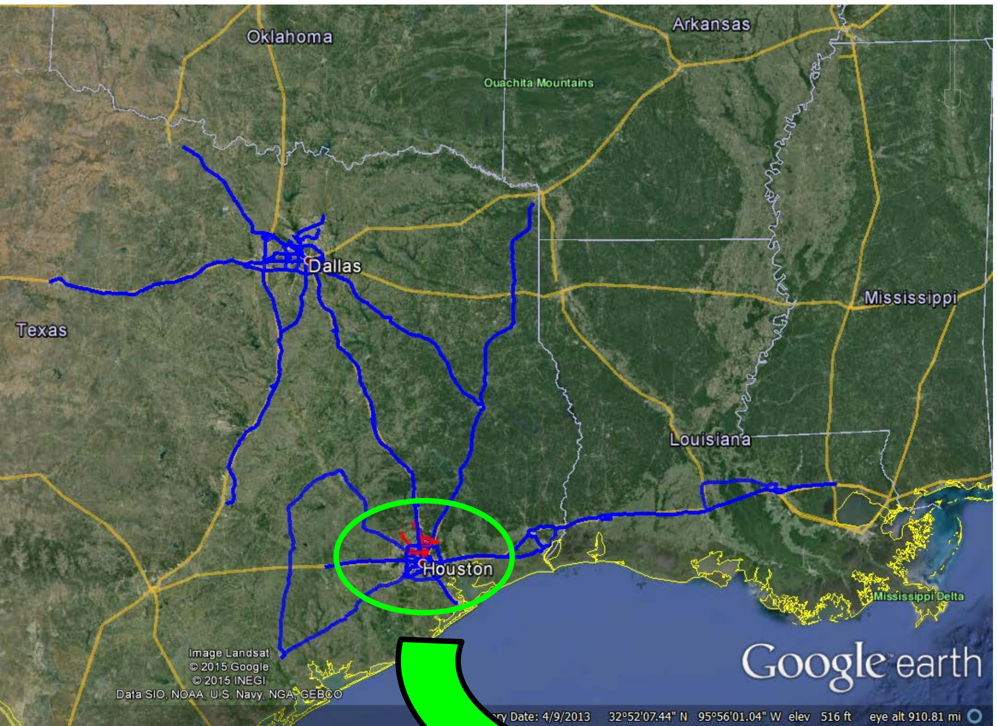
- Collected 2 weeks of 1Hz GPS and CAN data from 10 class 4 package vans and 10 class 8 tractors
- Completed analysis of field data including vehicle activity map, drive cycle statistics And representative drive cycle selection
- Completed chassis dynamometer testing of class 4 package van and class 8 tractor using Solazyme and low sulfur diesel
- Briefed industry partners and presented results at NTEA Green Truck Summit

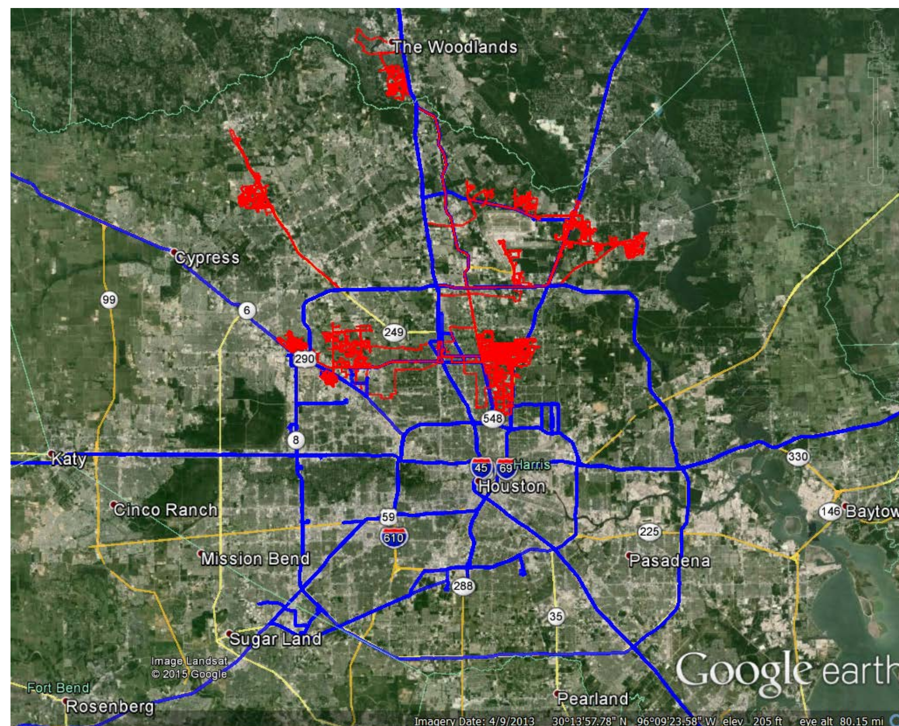
FY16 Plan Forward

- Project complete
- Final technical paper to be published in FY16

Baseline Duty Cycle – GPS Mapping

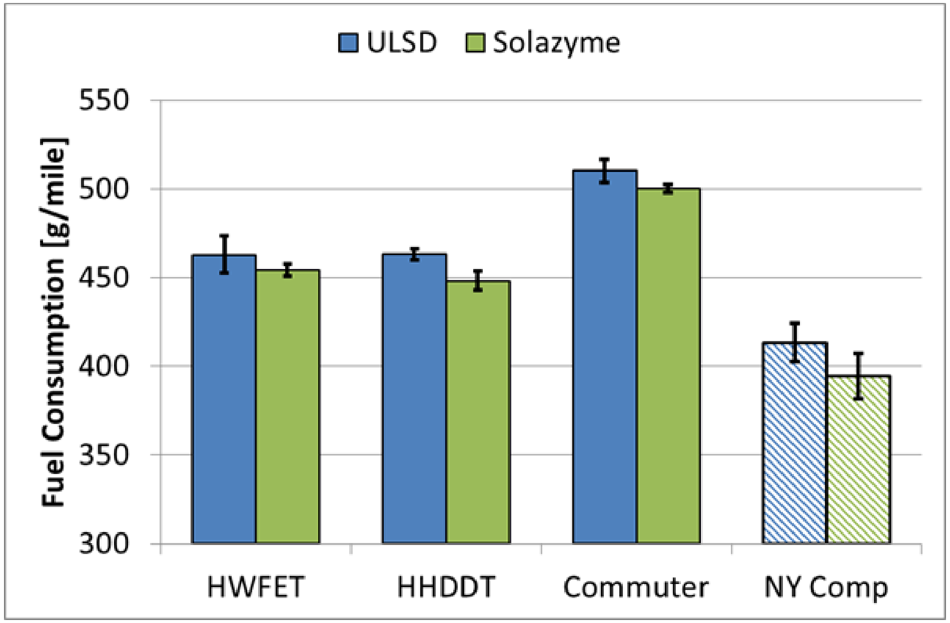
- **Blue – Regional Tractor Trailers**
- **Red – Package Cars**

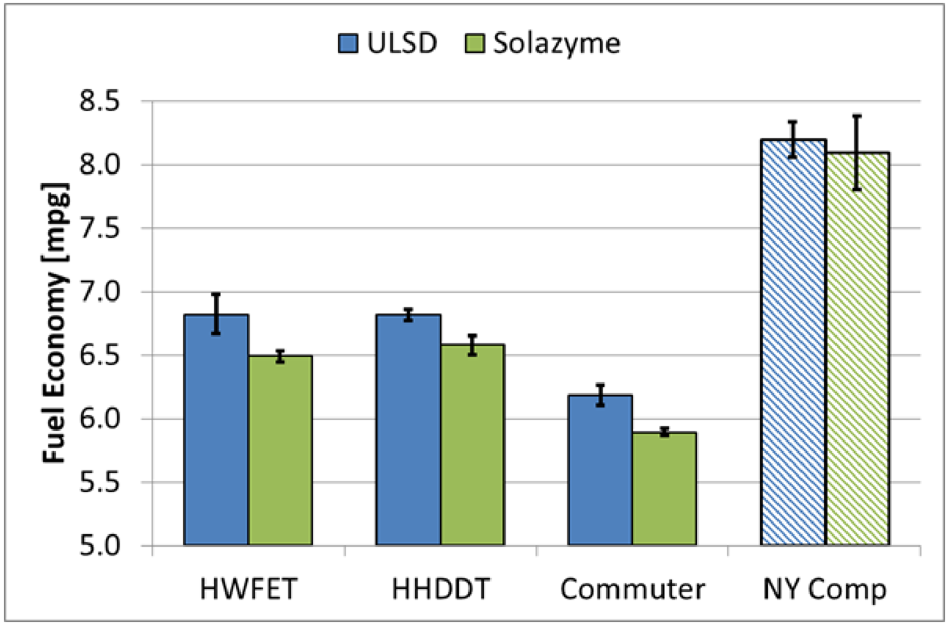




Chassis Dyno Test Results – Fuel Economy

- **Average measured over all cycles**
  - Fuel consumption (mass based): 2.9% better
  - Fuel economy (volume based): -3.6% worse
- **Expected from Solazyme fuel properties**
  - Energy content (mass based): 3.1% higher
  - Energy content (volume based): -3.7% lower

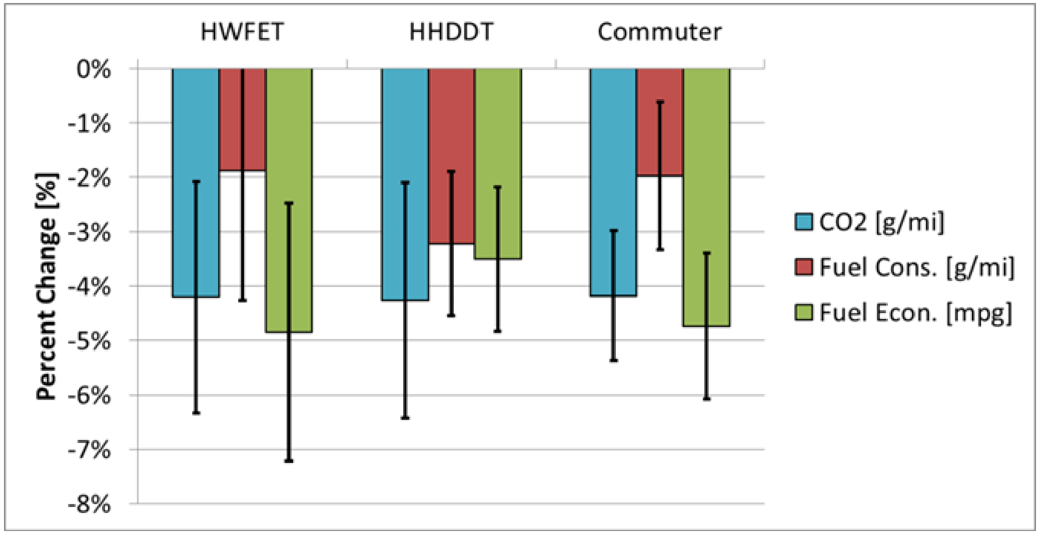




Chassis Dyno Test Results – Emissions

CO_2 - consistent 4.2% decrease tailpipe emissions

- Higher mass based energy content
- Higher H:C ratio

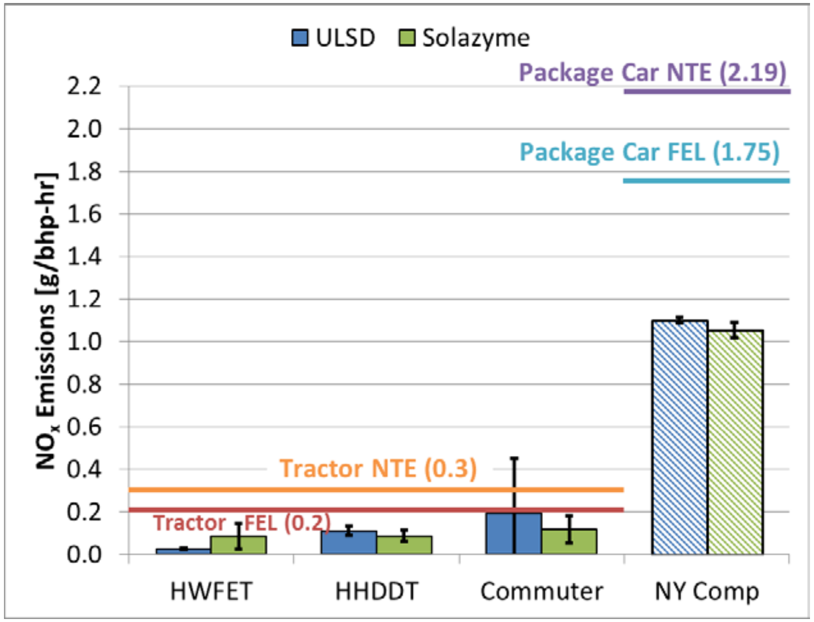


Estimated Annual Impact

- Tractor VMT: 104,000 mi/yr
- Average FE: 6.49 mpg
- Displaced CO_2: 7.5 tons/veh/yr

NO_x 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:

New Flyer, Freightliner, Workhorse, International, Orion, Allison Transmission, Eaton, Enova, Azure, Cummins, International, Caterpillar, Coke, NYC Transit, and Verizon

FY15 Collaborations & Coordination with Others				
Partner	**Relationship**	**Type**	**VT Program or Outside?**	**Details**
FedEx Corporation	Fleet Eval Partner	Industry	VT Program	Provided vehicles and data
UPS	Fleet Eval Partner	Industry	VT Program	Provided vehicles and data
Eaton Corporation	OEM Support	Industry	VT Program	Provided data access and hardware to enable testing
Peloton	OEM Support	Industry	VT Program	Provided vehicles and hardware to test
Parker Hannifin	OEM Support	Industry	VT Program	Provided vehicles, data, and support for testing
Frito-Lay	Fleet Support	Industry	VT Program	Provided vehicles, data, and installed infrastructure (Servidyne/Chateau)
Momentum Dynamics	OEM Support	Industry	VT Program	Providing data and hardware to enable testing
XL Hybrids	OEM Support	Industry	VT Program	Providing data and hardware to enable testing
Smith Electric Vehicles	OEM Support	Industry	VT Program	Providing access to battery data & vehicle data
South Coast Air Quality Management District / CARB	Funding Partner	Gov't Collaboration	Outside	Providing funding for projects to supplement DOE advanced vehicle technology testing (CARB = HVIP assessment)
Clean Cities Program	Coordination	Gov't Collaboration	VT Program	Providing funding to assess fleet-specific technology options for National Clean Fleets Partnerships (Verizon, City of Indianapolis, PG&E)
NTEA/GTA	Advisory	Industry	VT Program	Providing access and advisement on tools and protocols
Oak Ridge National Laboratory	Coordination	Gov't Collaboration	VT Program	Coordination of data analysis tools, captured data ,and development of test protocol and procedures

Collaboration and Coordination with Other Institutions

FY15/16 Collaborations & Coordination with Others				
Partner	**Relationship**	**Type**	**VT Program or Outside?**	**Details**
Miami-Dade County	Fleet Eval Partner	Local Gov't Fleet	VT Program	Provided vehicles and data
Proterra	OEM Support	Industry	VT Program	Provided vehicles and data
Foothill Transit	Fleet Eval Partner	Transit Operator	VT Program	Provided vehicles and data
Parker Hannifin	OEM Support	Industry	VT Program	Provided vehicles, data, and support for testing
Clinton Global Initiative – EV School Bus Consortium	Funding Partner	Industry	VT Program	Provided vehicles, data, and installed infrastructure (Servidyne/Chateau)
TransPower	OEM Support	Industry	VT Program	Providing data and hardware to enable testing
US Hybrids	OEM Support	Industry	VT Program	Providing data and hardware to enable testing
Pacific Gas and Electric	OEM Support	Industry	VT Program	Providing access to battery data & vehicle data
Con-Way	Fleet Partner	Industry	VT Program	Providing line-haul and regional-haul vehicle data
US Environmental Protection Agency	Funding Partner	Gov't Collaboration	Outside	Providing funding to analyze vocational vehicle data for Phase II Heavy-Duty Greenhouse gas regulations
California Energy Commission	Funding Partner	Gov't Collaboration	Outside	Providing funding for fleet evaluation
Odyne	OEM Support	Industry	VT Program	Providing access to battery data & vehicle data
Altec	OEM Support	Industry	VT Program	Provided vehicles for chassis testing and field data collection
21st Century Truck Partnership	Coordination	Gov't Collaboration	VT Program	Providing funding to assess fleet-specific technology options for National Clean Fleets Partnerships (Verizon, City of Indianapolis, PG&E)
Solazyme	Fuel Provider	Industry	VT Program	Providing renewable diesel fuel for chassis testing

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

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Lee Slezak and David Anderson

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Vehicle Technologies Office – U.S. Department of Energy

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

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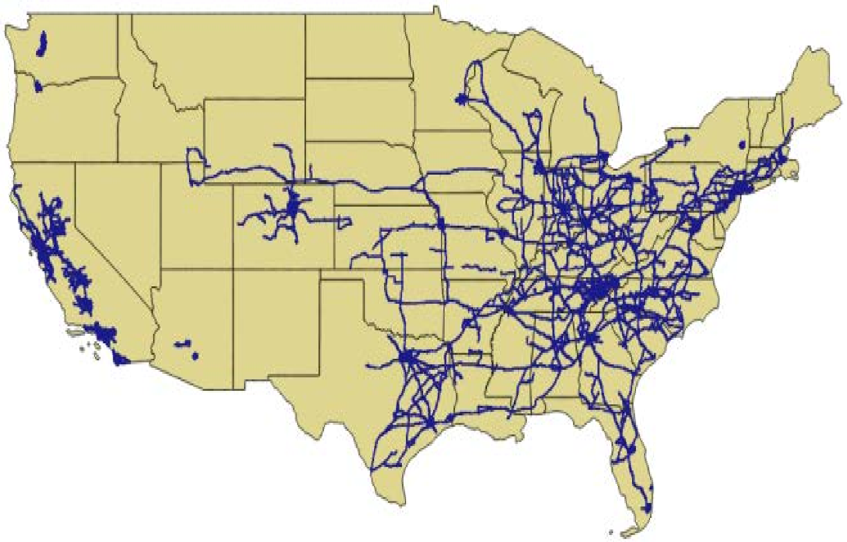
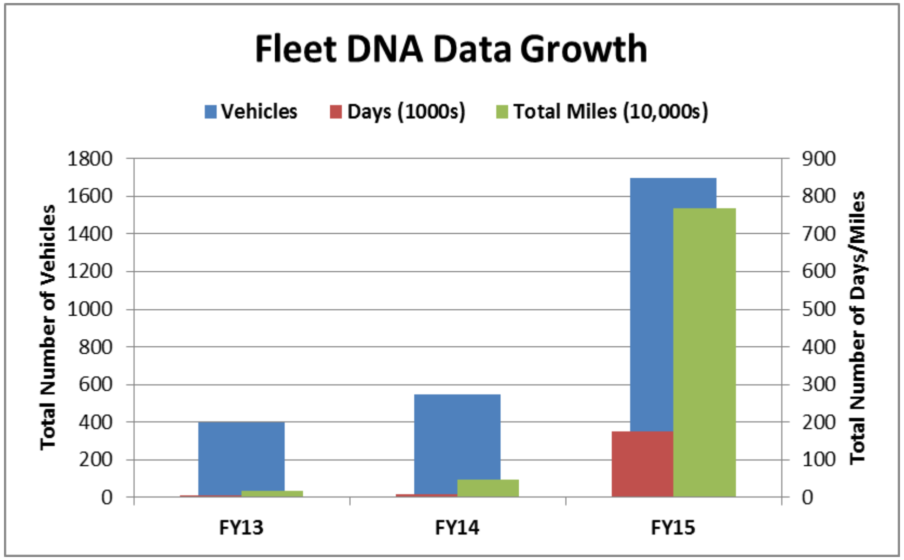
Technical Back-Up Slides

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).



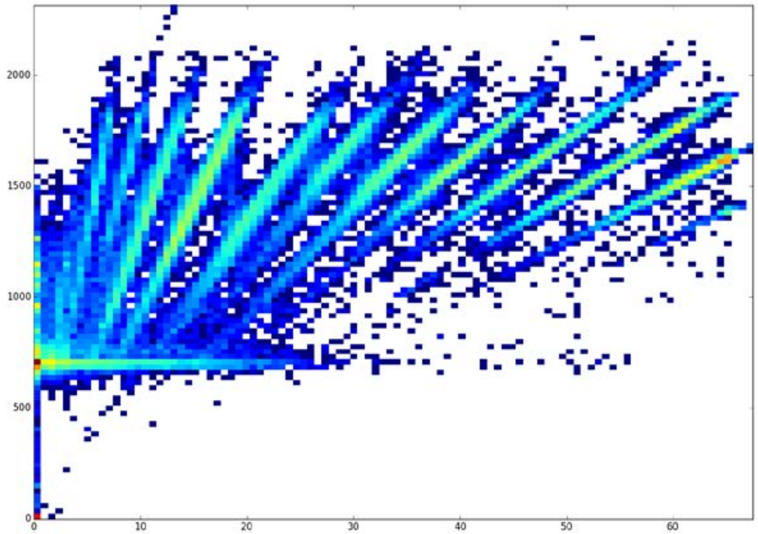


Fleet DNA – External Users and Support

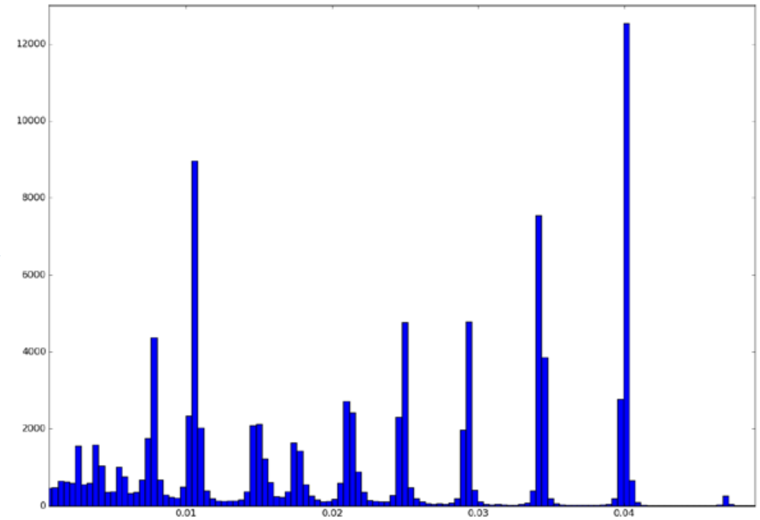
- **EPA Phase II Greenhouse Gas Regulations**
  - Grade Analysis
  - Vocational Vehicle Segmentation and Drive Cycle Analysis
- **SCAQMD**
  - Fleet DNA Roadmap – extensive new data and applications
  - ZECT I and ZECT II data
  - ComZEV Roadmap – upcoming application applying FleetDNA tools with Ricardo 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

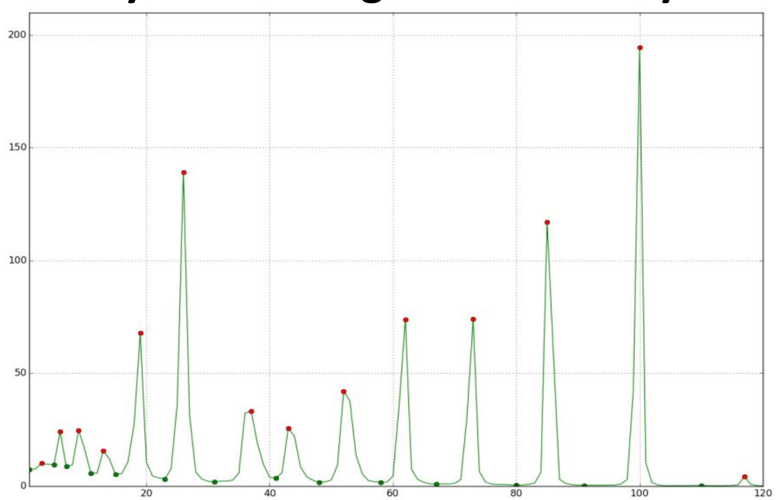
1) Staring with raw engine and vehicle data



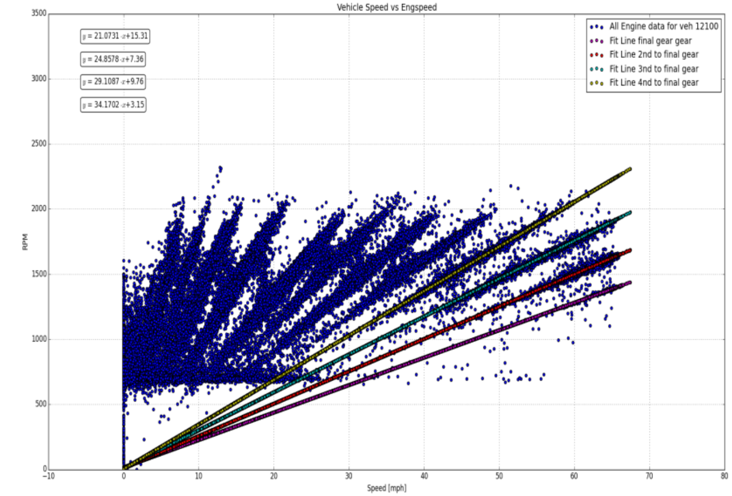
2) Convert to ratios and accumulate



3) Identify ratios using kernel-density methods

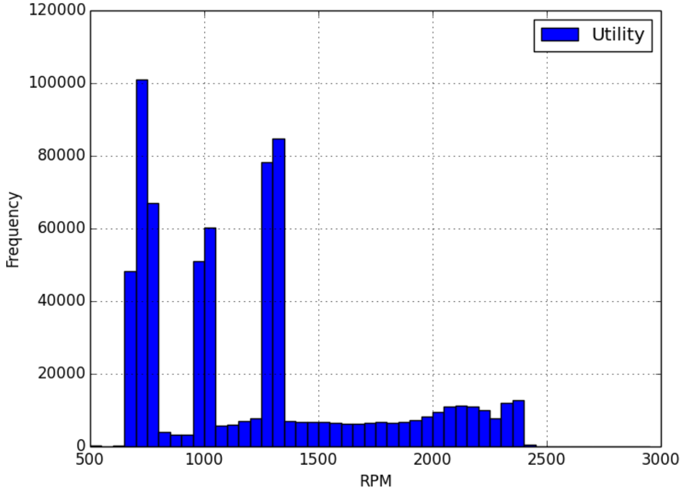


4) Confirm predicted ratios

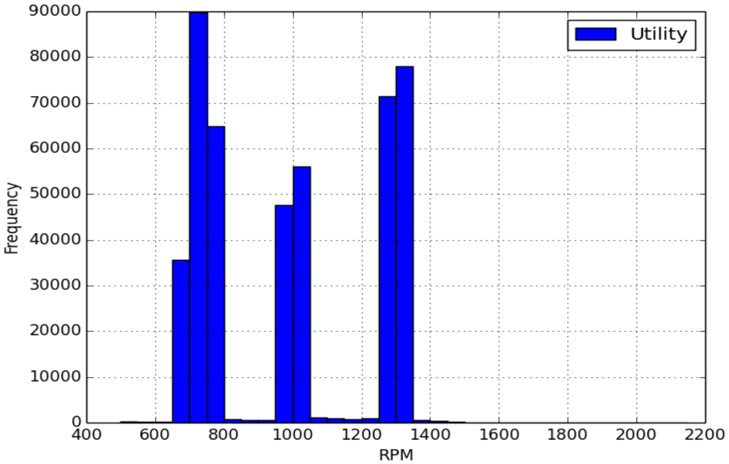


New Analysis – Idle & PTO Operations

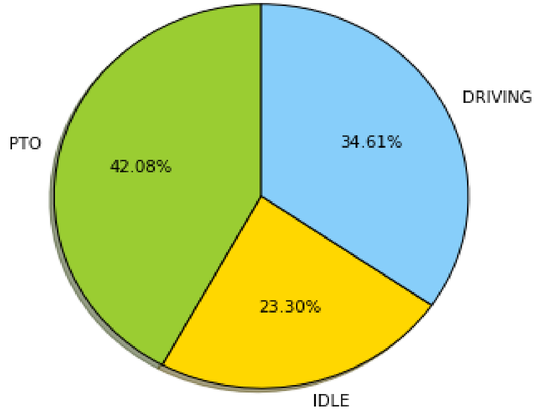
1) Distribution of Engine RPM



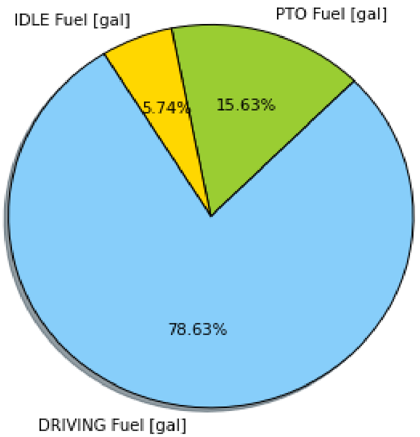
2) Distribution of Engine RPM with vehicle speed = 0 (idle + PTO)



3) Time Spent – Driving / Idle / PTO

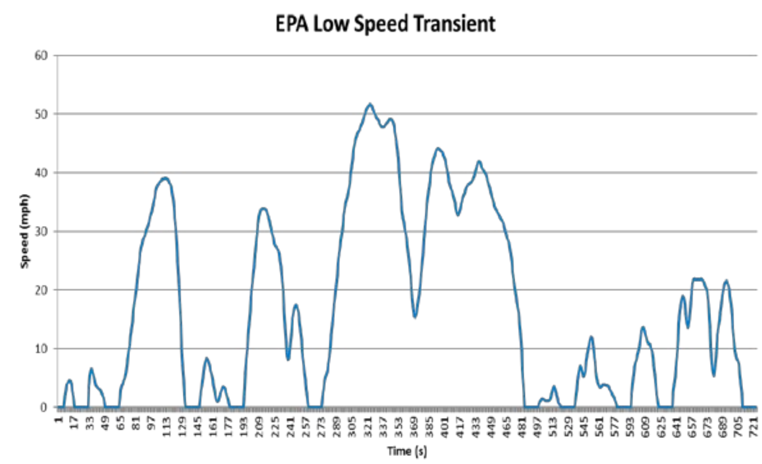


4) Fuel Consumption



EPA GHG MD/HD Phase 2 Regulations

- **Vocational Vehicle Categorization**
  - Identified 3 major operational clusters for vocational vehicles
- **Development of Custom Transient Drive Cycle and Weightings**
  - Generate representative cycle using Fleet DNA and DRIVE
  - Determined appropriate category weights using EPA criteria
- **National Road Grade Analysis**
  - Developed Custom Representative Road Grade Profile
- **PTO and Idle Characterization**
  - Characterized PTO and Idle usage for identified vehicle categories



Sample Data Protocol

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

Sample Data Protocol – EV/EVSE Data Collection

Type of Data	Frequency Recorded	Data Items
Vehicle Duty Cycle	On-board data loggers, one month of 1Hz duty-cycle data collection	On-board data loggers capture GPS/CAN data on vehicle duty cycle (time, location, speed, temperature, acceleration, battery/motor current, voltage, SOC, temperature)
Charging Profiles	EVSE power quality meters, monthly data collection – several times per year	Meters capture Voltage, Current, Power Factor, Harmonic Distortion at intervals as slow as one per minute (at each EVSE circuit if possible)
Facility Electricity Demand	Building level power quality meters, monthly data collection - several times per year to capture seasonal differences	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)
Battery Degradation Tests	One 7-hour battery test conducted every 6 months	NREL battery capacity test (conducted by NREL)
		Odometer reading at time of test
		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

EV Vehicle and Component Data – 1Hz

Vehicle Data Parameters

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

Component Data Parameters

Battery current
Battery voltage
Battery pack SOC
Battery pack min cell voltage
Battery pack max cell voltage
Battery pack balance mode state
AC charging current
AC charging voltage
Battery pack bulk temperature
Battery pack min cell temperature
Battery pack max cell temperature
Motor temperature
Power electronics/charger temperature
DC/DC voltage
DC/DC current
Motor speed
Motor torque
Motor power (electrical)