NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Medium and Heavy Duty Vehicle Evaluations



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National Renewable Energy Laboratory
2012 Annual Merit Review
May 16, 2012

Project ID: VSS001

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

Overview

Timeline

- **Varies by project**
- **Typically 12-18 months per project start to finish**
- **Some "in-process," some "new"**
- **Percent Complete: ~50%**

Budget

- **Total Project Funding FY12 w/industry cost share: $1,300K [$1,050K Field Evaluations + $250K Medium Duty (MD) Electric Vehicle (EV) Data Collection]**
  - DOE Share: $1,150K
  - Participant cost share has been in-kind support (vehicle loans, technical support, data access and data supplied to NREL) and varies by individual project
- **Funding Received in FY11: $850K**

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 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)

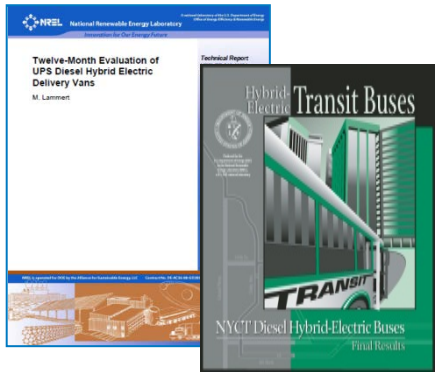
Partners

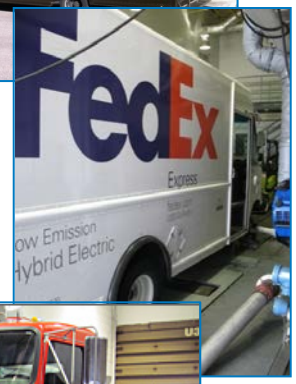
- **Industry collaboration required for successful studies. Partners (past and present) include:** New Flyer, Freightliner, Workhorse, International, Orion, Allison Transmission, Eaton, Enova, Azure, Cummins, International, Caterpillar, UPS, FedEx, Coke, NYC Transit
- **Current Partners in FY12:** FedEx, UPS, Coke, Eaton, Navistar Corporation, Smith Electric Vehicles, Parker Hannifin, TBD

Relevance

Recent & relevant MD and heavy-duty (HD) AVTA testing provides unbiased data & reporting:

- Hybrid EV (HEV) Transit Buses: 5 models of buses tested at 5 different fleet locations, 3.1 million miles of commercial operation documented
- HEV Delivery Vans: 3 models of HEV package delivery vans tested at 3 locations, 120,000 miles of commercial operation documented, with more planned for FY12
- HEV Delivery Tractors & Straight Trucks: 2 models tested to date at 2 locations, 75,000 miles of operation documented with another 120,000 miles currently accumulating





3.4 million test miles have been accumulated on 95 different electric drive vehicles since 2006.

More sites planned in for FY12& 13

Relevance/Objectives

Overall objectives of this project are as follows:

- **Test and analyze:** near-term advanced technologies (advanced prototypes or early commercial products) in-service and compare to conventional technologies in similar service
- **Provide data, analysis and feedback**: to the R&D community (including other offices and programs within DOE) to guide technology development that will lead to fuel-saving, commercially available products
- **Provide unbiased, 3rd party performance data:** to potential vehicle customers and OEMs as needed to make informed decisions on advanced technology vehicle purchases and fleet implementation
- **Supports the VT Program's strategic goal of:** *Support the laboratory and field evaluations of large-scale demonstration fleets of advanced commercial and passenger PHEVs and EVs.*

2 Specific Technical Objectives in FY12: Field Evaluations and MD EV Data Collection

- **In-Use Vehicle Evaluations:** Evaluate technology in 5 to 6 fleets (100 vehicles): UPS HEVs in two locations, Coca Cola HEVs in Miami, FedEx HEVs in California, UPS hydraulic hybrid vehicles (HHVs) in Maryland, TBD EV Fleet Implementation Studies, + 1 additional TBD fleet study

- **Data Collection from Commercial EVs**: Collect and analyze data and provide performance metrics from MD vehicles deployed across the United States: Smith EVs, Navistar EVs, Cascade Sierra Truckstop Electrification

Milestones

Milestone 1: Draft Interim report highlighting fleet data collection efforts and analysis of data (September 2012)

- **Provides a year-end summary report on overall status and results of each project**
- **In addition to the Milestone Report, the following published (publically available) technical project reports will be completed:**
  - Coca Cola Class 8 HEV – final report published May 2012
  - UPS Gen I HEV (Phoenix) + UPS Gen II HEV (Minneapolis) – final reports published
  - FedEx Freightliner M2 box truck (Ontario, CA) – interim results published in August 2012
  - UPS Hydraulic Hybrid (Baltimore, MD) – startup and interim results published in 2012
  - EV Fleet Implementation Study - TBD – startup and interim results published in 2012

Milestone 2: Draft Interim Report on all projects (Sept 2012)

- **Smith EV, Navistar EV, Cascade Sierra Truckstop Electrification**
- **Usage data summarized, will include metrics such as charge characteristics, battery state of charge (SOC), driving characteristics, etc.**
- **In addition to Milestone Report above, the following quarterly updates will be completed in FY 12:**
  - Smith Quarterly Reports (Q4 2011 – completed in March 2012, Q1-Q2 2012 – June, September)
  - Navistar Quarterly Reports (Q1, Q2 2012) – planned for June & September

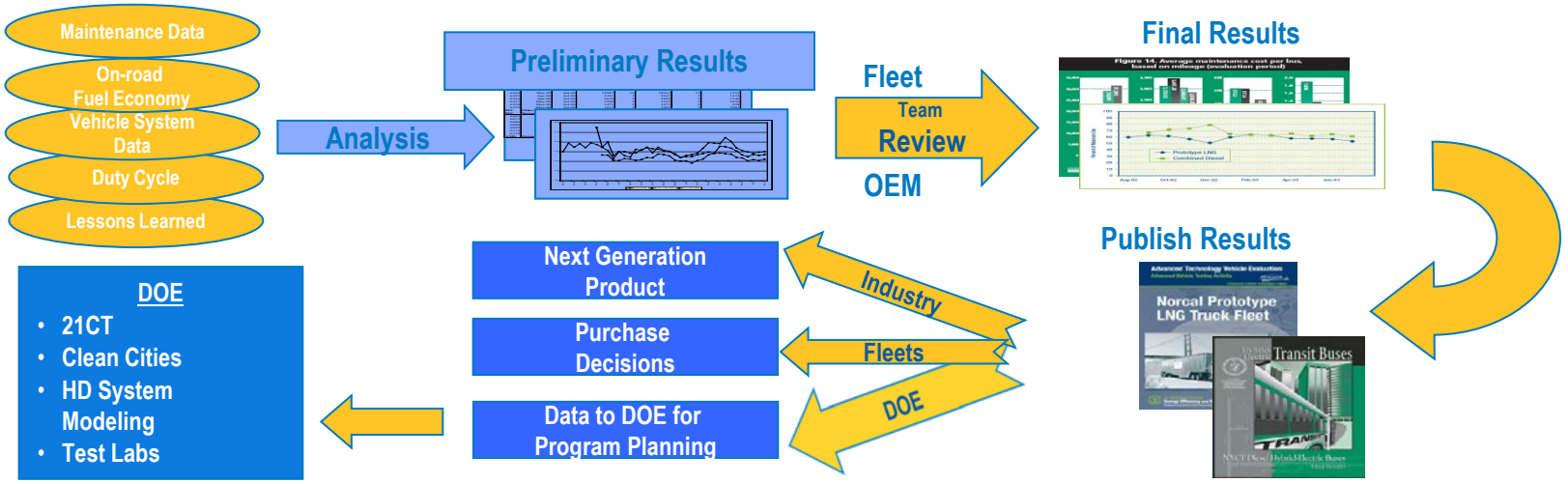
Approach – Selection & Data Flow

This project will collaborate with fleet and OEM partners to select, test and validate advanced technologies in commercial vehicle applications. Specific technologies are selected based on:

1. Their potential for reducing fuel consumption (current fuel usage and potential for reduction)
2. Their potential for widespread commercialization and availability to cooperate with deploying fleets
3. The interest of the DOE (including 21st Century Truck partners and other DOE program managers)

General Approach:

1. NREL collects data on sub-system and vehicle performance (varies by project), maintenance, reliability and warranty (if applicable) and/or operational costs relative to the new technology.
2. Data are analyzed and provided back to the DOE and project teams on the performance of the technology and its potential improvement in real-world service (by obtaining baseline data if a comparable conventional technology vehicle is available).
3. Reports are published that summarize the issues involved with integrating the new technology into operation, the overall performance of the new technology or what type of improvement in fuel economy or operational performance might be gained in the use of it.



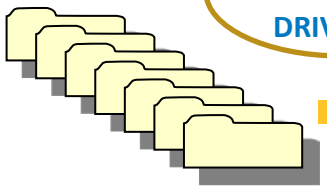
Approach – Data Acquisition and Analysis Tools

1. **Enhanced data collection capabilities:**
   - Controller Area Network (CAN) (standard and proprietary advanced technology parameters)
   - GPS route data collection and analysis for chassis dyno and simulation testing
   - Wireless capabilities – remote fleets

2. **Analysis Capabilities:** multiple methods to assess performance of new technology in service, automated processes

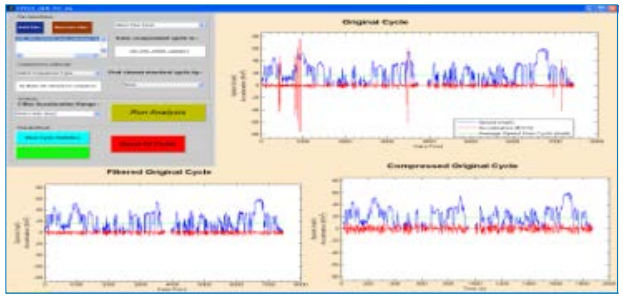
On-Board Data Collection

Enhanced capability in 2011+2012 (over 40 data loggers in use)



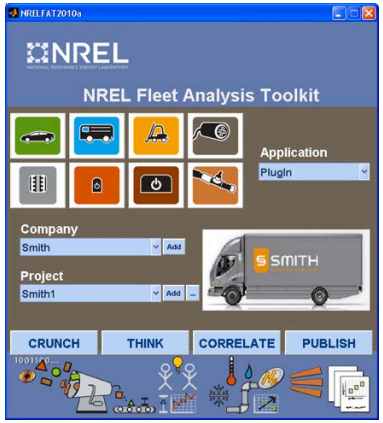
Collect sets of GPS, CAN & analog data (per day or per shift)

Drive cycle analysis tool = DRIVE



- Full understanding of supplied data: daily variation info; 150 stats for original, filtered and shortened data
- User-specific test cycle generated

Data Analysis



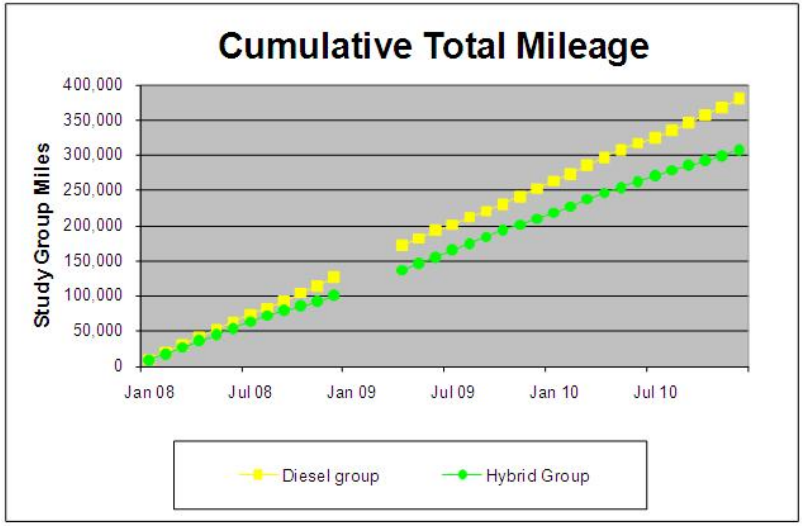
- Fleet Analysis Toolkit has unique algorithms developed for each set of variables from mfg.
- Displays graphs, tables, and histograms of data
- Automated production / common templates

Technical Accomplishments – UPS HEV Gen I

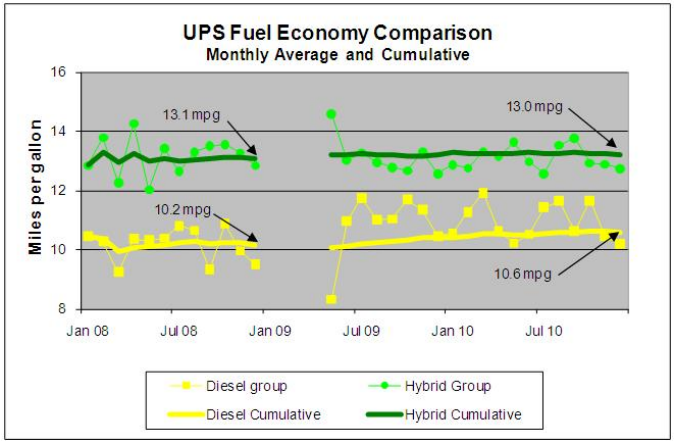
Accomplishment:
Completed on-road 36-month evaluation of Eaton hybrid electric system

Data collected:
- Fuel economy and maintenance records (~700,000 miles)
- Drive cycle characterization
- ReFUEL dynamometer testing

Details:
- Phoenix study location
- Six 2007 hybrid vans (pre 2007 emissions)
- Six 2006 conventional vans (pre 2007 emissions)



Usage and Fuel Economy
- Miles driven for the hybrids were 18% lower than miles driven for the diesels. The primary driver (about 16%) for the difference was a more dense/urban delivery route assignment, i.e., fewer miles per delivery day.

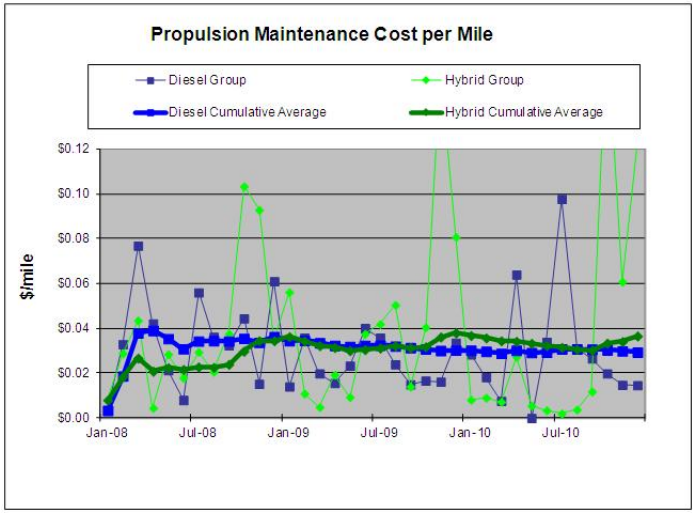


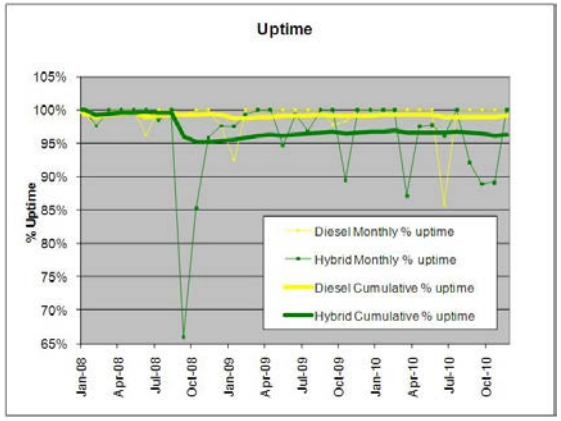
- Fuel economy of the hybrid group over these 3 years was 23.1% better than that of the diesel group. Larger improvement in mpg could be possible if hybrid and conventional vans were operated on the exact same routes.

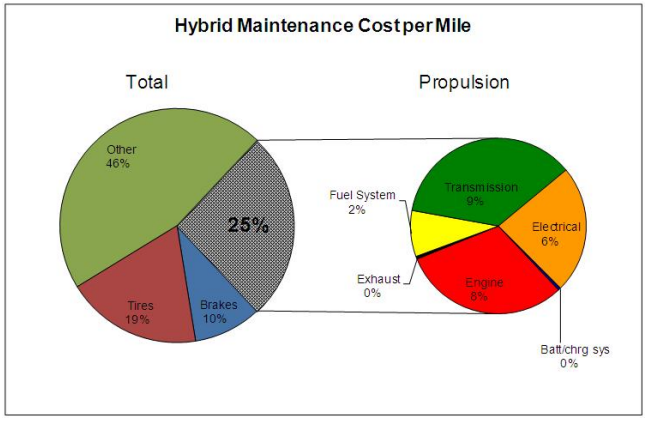
Technical Accomplishments – UPS HEV Gen I

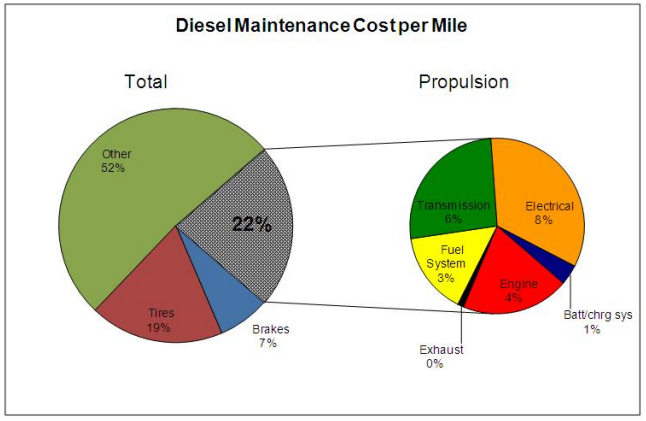
Propulsion Maintenance Cost, Overall Cost, Reliability

- No statistically significant difference between the diesel and hybrid groups for total maintenance cost per mile (P value = 0.46) and propulsion maintenance cost per mile (P value = 0.33)
- Total cost of operation : $0.38 - 0.42 mile (no statistical significant difference)
- The hybrid group had a cumulative average uptime of 96.3% over the 36-month study period, less than the diesel group's cumulative average uptime of 99.0%. The hybrids experienced troubleshooting and recalibration issues related to prototype components, which were primarily responsible for the lower uptime figures.









Technical Accomplishments – UPS HEV Gen II

Project Background & Accomplishment:

On-road evaluation of Eaton's latest next-generation hybrid electric system in package delivery application at UPS. Final report in May 2012.

Data collected – 18 months of operation:

- Fuel economy and maintenance records
- Engine control unit (ECU) records downloaded regularly
  - Miles traveled
  - Fuel consumed
  - Percent idle time
  - DPF regenerations
- GPS route data logging
- ReFUEL dynamometer testing

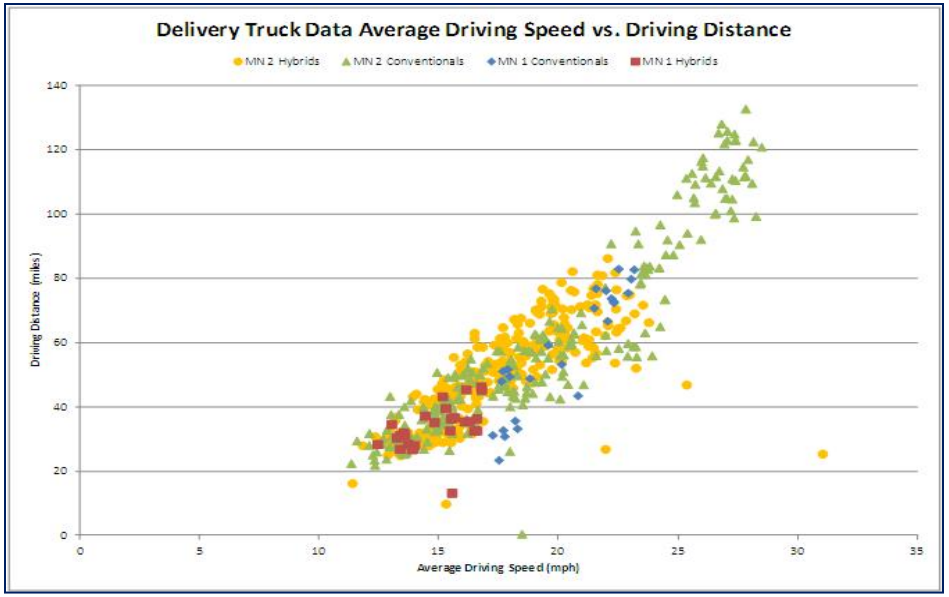
Details:

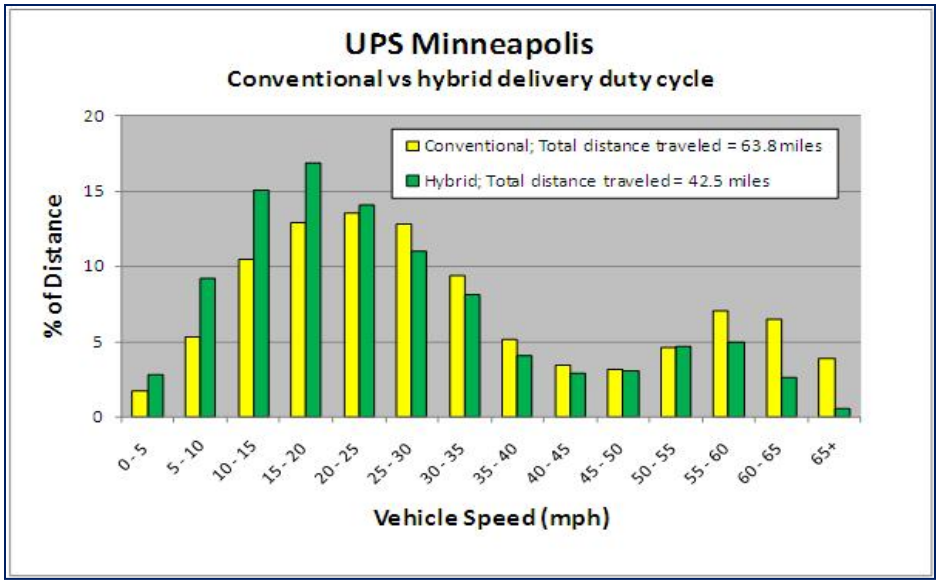
- Minneapolis location
- Eleven 2010 hybrid vans (2007 emissions)
- Eleven 2010 conventional vans (2007 emissions)
- Groups switched assigned delivery routes midway through study for a better comparison

Technical Accomplishments – UPS HEV Gen II

Using DRIVE, route analysis illustrated the need for a route switch for a balanced comparison. Initial data showed:

- The hybrid vans drove 44% of their miles below 20 mph while the conventional vans drove only 30.5% of their miles at those slow speeds
- The van groups drove a similar percentage of their miles at the intermediate speeds of 20-50 mph: 47% for conventional and 43% for hybrids
- The hybrid vans drove only 13% of their miles above 50 mph while the conventional vans drove 22% of their miles at those highway speeds.

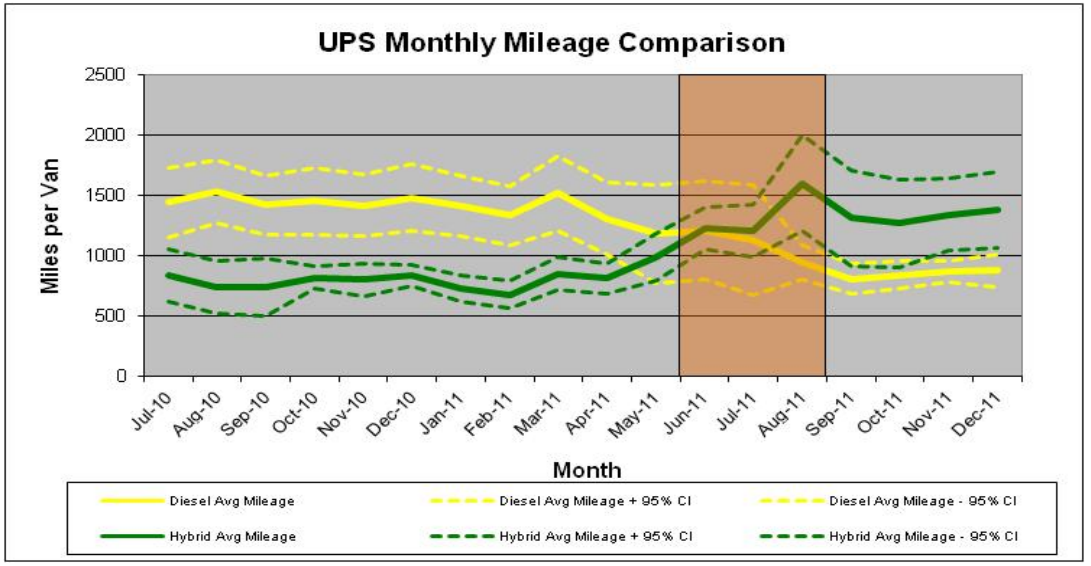


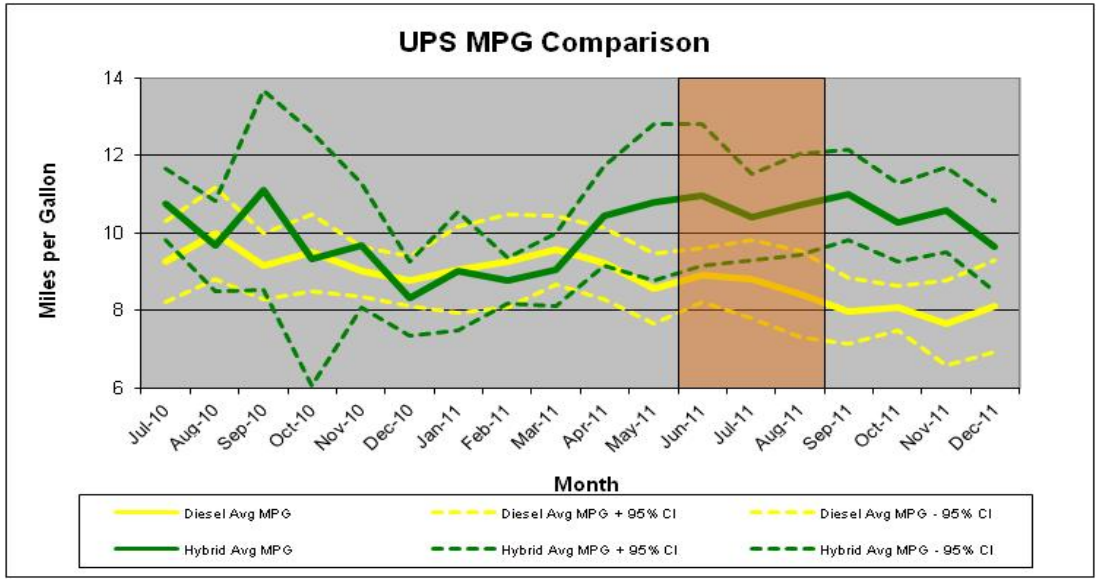


Technical Accomplishments – UPS HEV Gen II

- **Route switch:**
  - Monthly group miles clearly shows route switch
  - MPG comparison is less distinctive because spring MPG increase took place right before route switch

- **Detailed route switch fuel economy analysis still underway – results final in May 2012**
  - Overall mpg before and after route switch:
  - Total cost per mile:





Technical Accomplishments – UPS HEV Gen II

Laboratory Chassis Dynamometer:

In the laboratory, hybrids demonstrated a statistically significant 21% to 45% improvement in ton-mi./gal fuel economy, or 13% to 36% on an mpg basis

Ton Fuel Economy	NYC Comp	HTUF4	HHDDT
Conventional P100D (ton-mi./gal)	51.1	56.2	72.0
Hybrid P100H (ton-mi./gal)	70.9	81.6	87.2
Hybrid Advantage (%)	39%	45%	21%
Ttest P Value	0.0000	0.0000	0.0001

Fuel Economy	NYC Comp	HTUF4	HHDDT
Conventional P100D (mpg)	6.8	7.5	9.6
Hybrid P100H (mpg)	8.8	10.1	10.8
Hybrid Advantage (%)	29%	36%	13%
Ttest P Value	0.0001	0.0000	0.0002

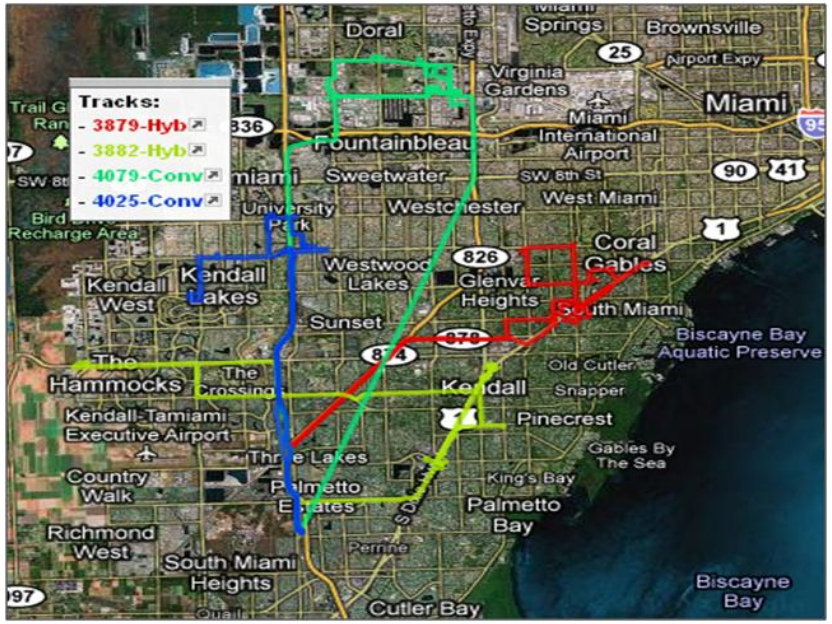
Technical Accomplishments – Coca Cola HEV

Project Background & Accomplishment:

Final report published on 13-month, on-road evaluation of Eaton's hybrid electric system in class 8 day cab tractor application at Coca-Cola.

Data collected:

- Fuel economy and maintenance records
- ECU records downloaded regularly
  - Miles traveled
  - Fuel consumed
  - Percent idle time
  - DPF regenerations
- GPS route data logging summer and winter
- ReFUEL dynamometer testing

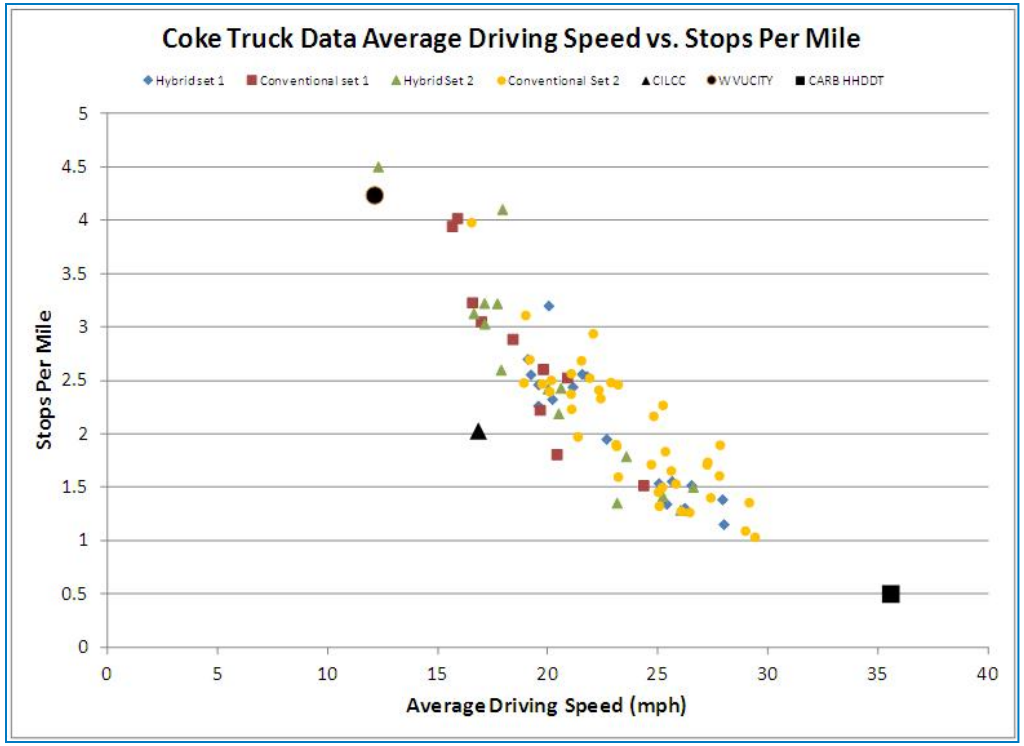


Details:

- Miami study location
- Five 2010 hybrid tractors (2007 emissions)
- Five 2009 conventional tractors
- Nightly "wet hosing" at depot for fueling

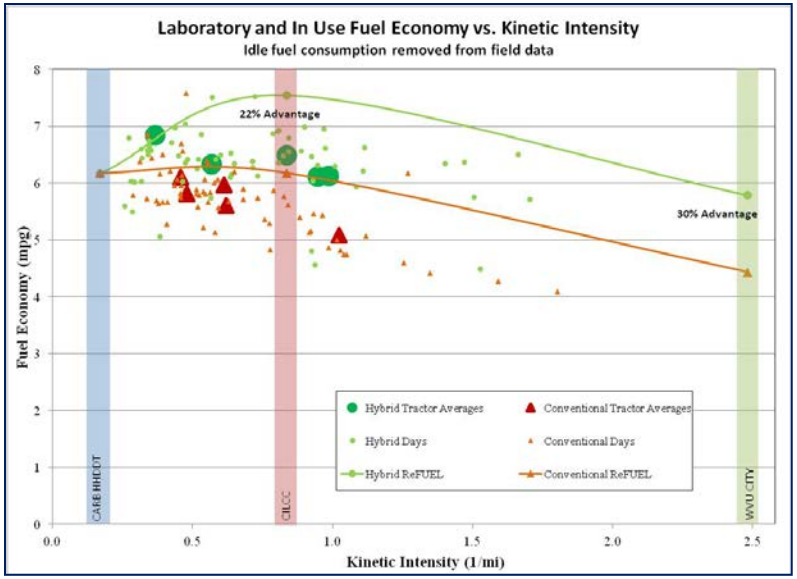
Technical Accomplishments – Coca Cola HEV

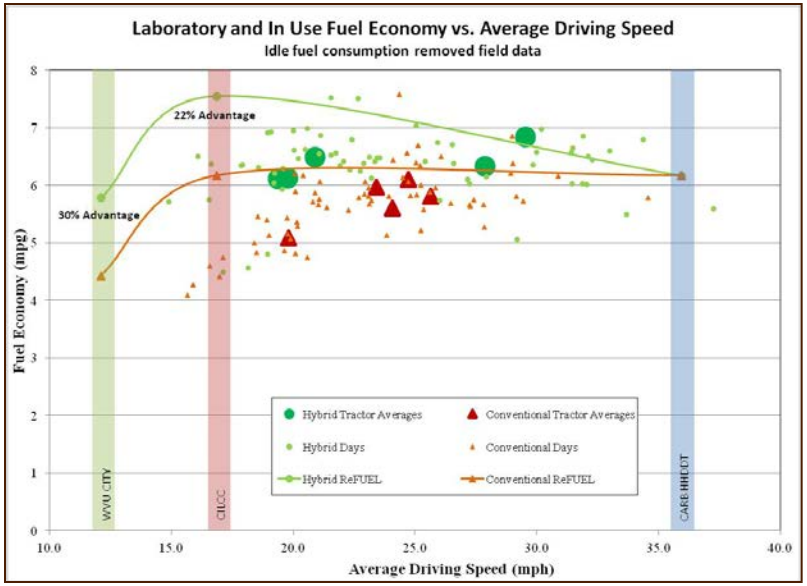
- Using DRIVE, route & drive cycle analysis showed that both study groups drive similar duty cycles, similar KI, average speed, idle time, and stops per mile.



Technical Accomplishments – Coca Cola HEV

- **Laboratory dynamometer testing demonstrated 0%–30% hybrid fuel economy improvement, (up to 31% improvement in ton-mile/gal) depending on duty cycle**
  - Chosen cycles matched very well with field GPS data
    - WVU City
    - CILCC
    - CARB HHDDT





Technical Accomplishments - Field Testing

In-Process Projects:

- FedEx HEV Class 7 Box Trucks
  - Ontario, CA study of 6 HEVs vs.. 6 diesel
  - 2010 emission level
  - Drive cycle analysis will determine placement and chassis dyno testing protocols
  - 6-month duration
  - Started March 2012, completion expected in November 2012

- MD EV implementation study and comparison
  - Case study of EVs in commercial application
  - Utilize data from vehicles funded under ARRA (Smith or Navistar)
  - Compare to conventional vehicles for energy use
  - Characterize battery duty cycles for further battery life analysis
  - Characterize installation and operation of high power EV supply equipment in commercial buildings
  - Analysis opportunities for grid-related operating cost improvements

Technical Accomplishments - Field Testing

In-Process Projects:

- UPS delivery vans equipped with hydraulic hybrid systems
  - Possible lower-cost option to electric hybrid system
  - Baltimore, MD study of Parker Hannifin HHVs
  - At least 5 HHVs vs.. 5 conventional on similar routes
  - 2010 emission level
  - Drive cycle analysis will determine placement and chassis dyno testing protocols
  - 6-12 month duration, assess seasonal differences in efficiency, assess reliability and availability, fuel use and emissions
  - Start in May 2012

Technical Accomplishments –PEV Data Collection

•ARRA funds helped deploy vehicles and EVSEs, some of which were MD/HD focused:

- Smith Electric Vehicles - Newton (500 vehicles)
- Navistar - eStar™ (up to 950 vehicles)
- South Coast Air Quality Management District / EPRI – Utility bucket trucks and shuttle buses (~350 vehicles)
- Cascade Sierra Solutions - sleeper cab trucks and electrified truckstops (50 sites and 5000 trucks)

• VT Program collecting and analyzing data to understand usage, barriers and challenges

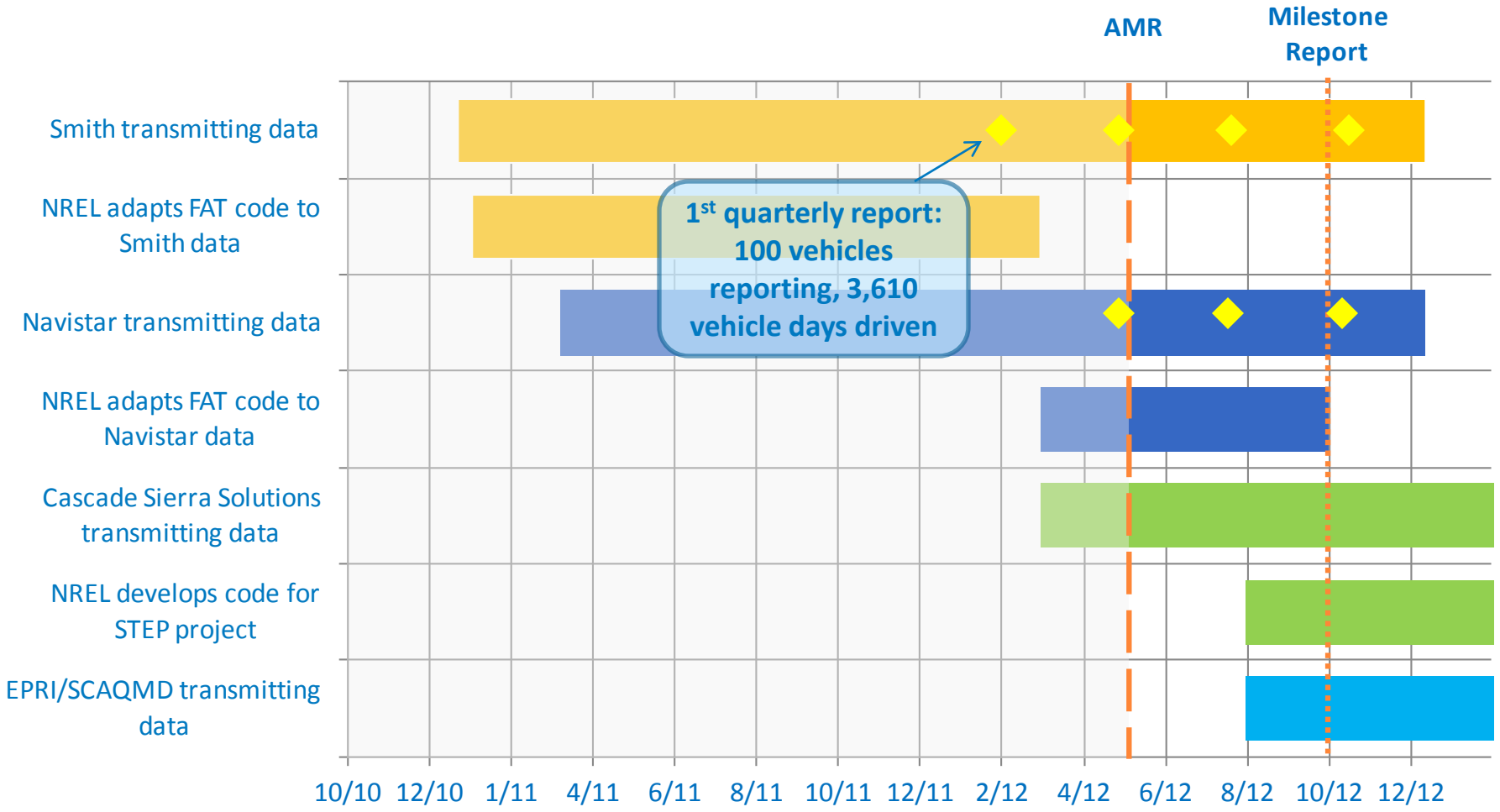
- ~30 channels of 1hz data collected and stored at NREL
- ~30 distinct data analysis products produced as data received
- Quarterly reports published on basic usage statistics – similar to ANL format on LD EV's

Quarterly and cumulative summary results are available on the Fleet Test and Evaluation subsite,

http://www.nrel.gov/vehiclesandfuels/fleettest/

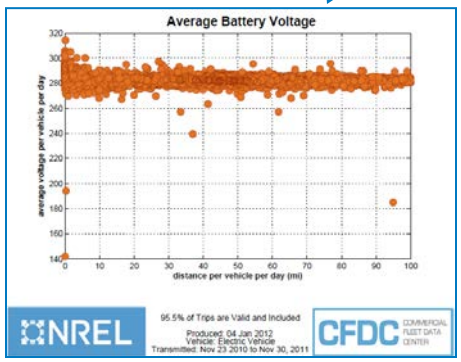
Technical Accomplishments –PEV Data Collection

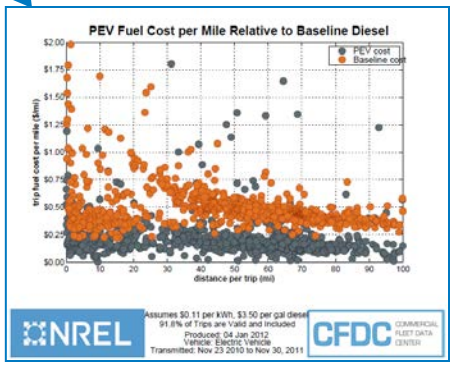
Progress to date

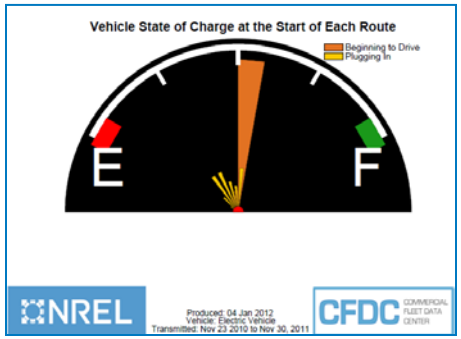


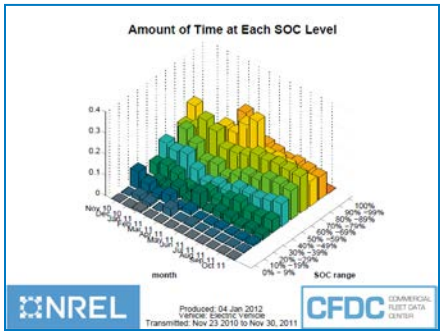
Technical Accomplishments – PEV Data Collection

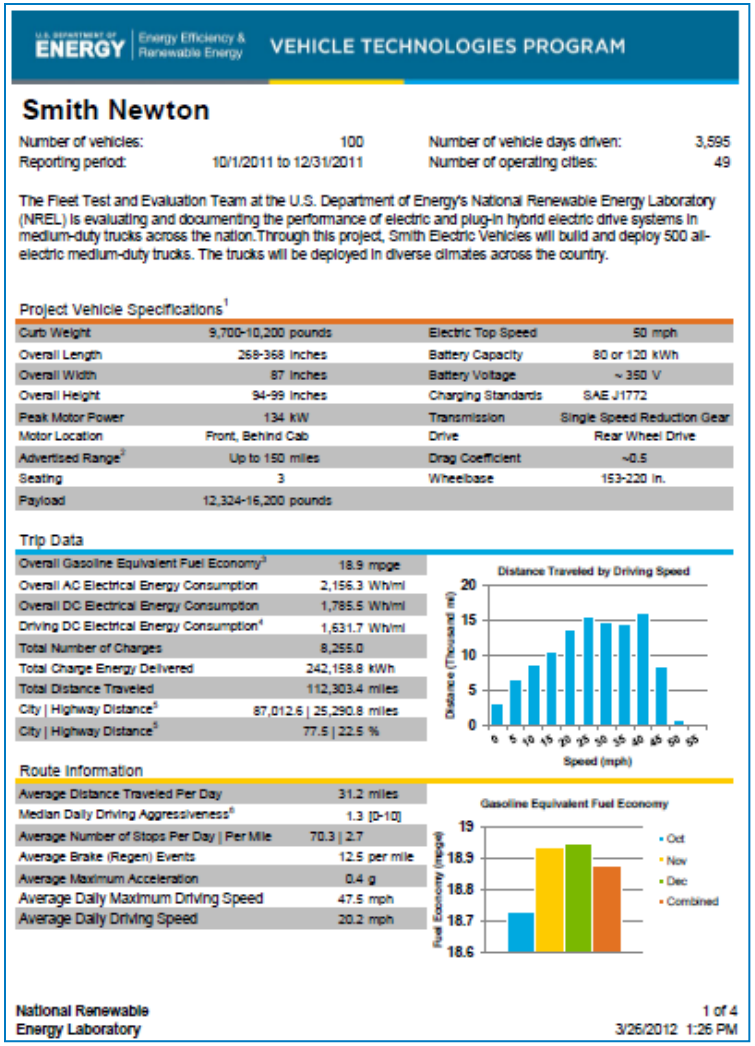
Sample Data Products and quarterly reports produced with acquired data











U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy — VEHICLE TECHNOLOGIES PROGRAM

Smith Newton

Number of vehicles:	100	Number of vehicle days driven:	3,595
Reporting period:	10/1/2011 to 12/31/2011	Number of operating cities:	49

The Fleet Test and Evaluation Team at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) is evaluating and documenting the performance of electric and plug-in hybrid electric drive systems in medium-duty trucks across the nation.Through this project, Smith Electric Vehicles will build and deploy 500 all-electric medium-duty trucks. The trucks will be deployed in diverse climates across the country.

Project Vehicle Specifications[1]

Curb Weight	9,700-10,200 pounds	Electric Top Speed	50 mph
Overall Length	268-368 inches	Battery Capacity	80 or 120 kWh
Overall Width	87 inches	Battery Voltage	~ 350 V
Overall Height	94-99 inches	Charging Standards	SAE J1772
Peak Motor Power	134 kW	Transmission	Single Speed Reduction Gear
Motor Location	Front, Behind Cab	Drive	Rear Wheel Drive
Advertised Range[2]	Up to 150 miles	Drag Coefficient	~0.5
Seating	3	Wheelbase	153-220 in.
Payload	12,324-16,200 pounds		

Trip Data

Overall Gasoline Equivalent Fuel Economy[3]	18.9 mpge
Overall AC Electrical Energy Consumption	2,156.3 Wh/mi
Overall DC Electrical Energy Consumption	1,785.5 Wh/mi
Driving DC Electrical Energy Consumption[4]	1,631.7 Wh/mi
Total Number of Charges	8,255.0
Total Charge Energy Delivered	242,158.8 kWh
Total Distance Traveled	112,303.4 miles
City | Highway Distance[5]	87,012.6 | 25,290.8 miles
City | Highway Distance[5]	77.5 | 22.5 %

Distance Traveled by Driving Speed

Route Information

Average Distance Traveled Per Day	31.2 miles
Median Daily Driving Aggressiveness[6]	1.3 [0-10]
Average Number of Stops Per Day | Per Mile	70.3 | 2.7
Average Brake (Regen) Events	12.5 per mile
Average Maximum Acceleration	0.4 g
Average Daily Maximum Driving Speed	47.5 mph
Average Daily Driving Speed	20.2 mph

Gasoline Equivalent Fuel Economy

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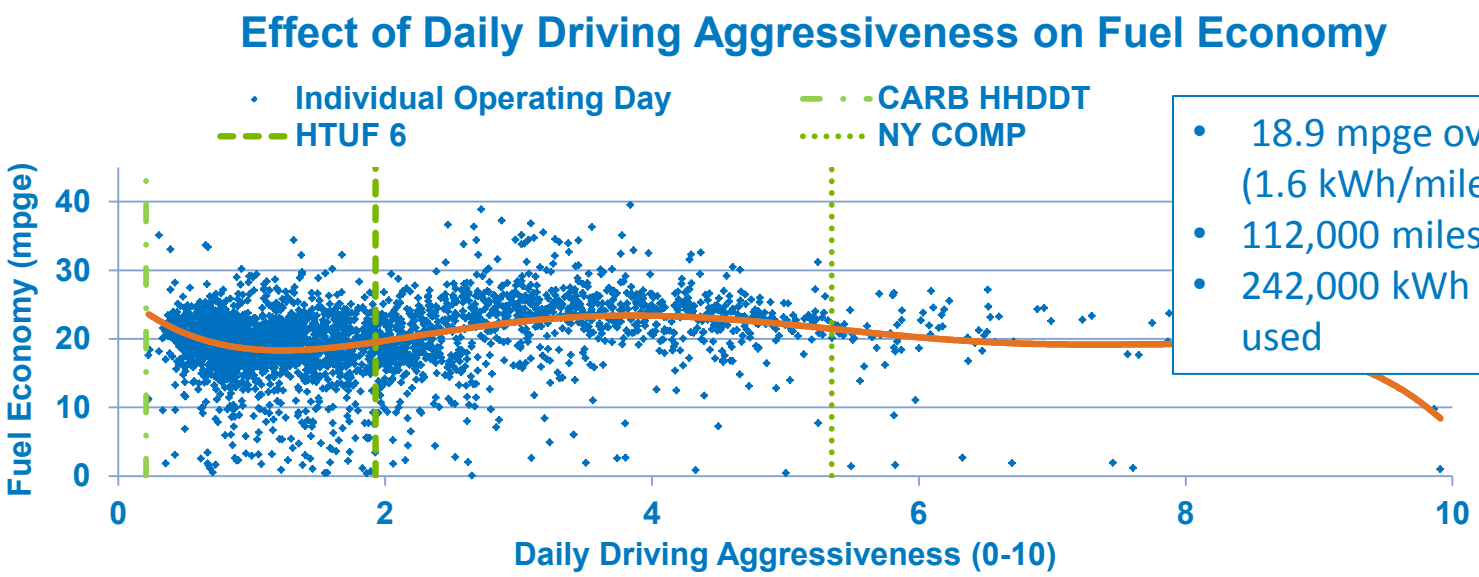
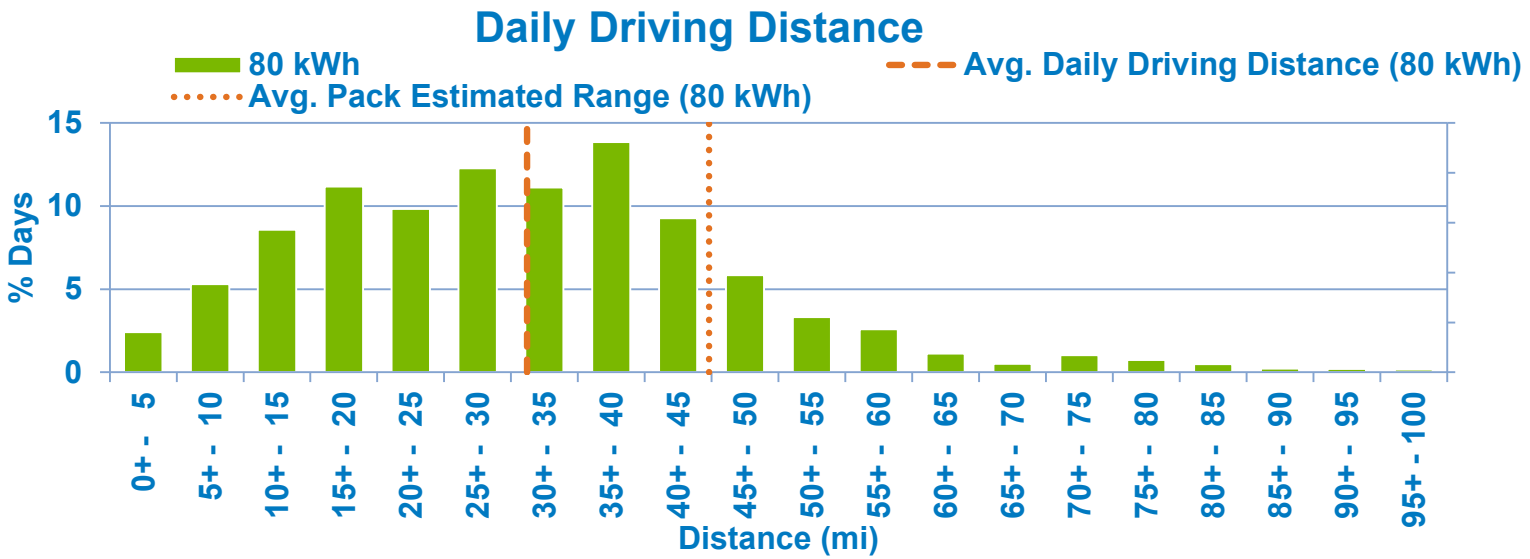
Technical Accomplishments – Smith Newton



- 18.9 mpge overall average (1.6 kWh/mile)
- 112,000 miles driven
- 242,000 kWh of electricity used



Proposed Future Work

1. **In-Use Performance Evaluations:** Continued on-road, in-use performance evaluations to obtain unbiased data on fleets/vocations/technology.
   - New, evolving technology is entering the MD/HD market; finding the right applications for the technology is critical to commercial success and deployment

2. **PEV Data Collection and Reporting:** ~1,500 MD EV and PHEV vehicles to be on the road starting in FY11 and continuing into FY13. Access data and look at overall trends
   - DOE-funded technology requires unbiased 3rd party to evaluate performance and provide information on technology barriers.

3. **FleetDNA Database Development:** A vocationally based drive-cycle database to aid in the development of drive cycles, provide information to OEMs on vehicle design needs and provide information to fleets to understand usage vs other vehicles in same vocation.
   - Help define the many diverse usages in the MD and HD vehicle industry. No database exists now. Recruiting new partners for FY13.

4. **Battery-focused data collection:** Provides high-fidelity, in-use field data to energy storage research efforts to understand commercial applications of energy storage systems.
   - Helps develop life cycle estimates and define power and energy needs for MD & HD markets

Summary

- HD field evaluations directly support the goals of EERE's VT Program by providing early evaluations of advanced powertrains to assess commercial readiness and providing these data to both government and private partners for future development consideration
- These tasks were created out of an overall industry need to understand how new fuels and technologies perform in commercial use and document the implementation and commercial issues surrounding this technology – a 3rd party, neutral analysis approach is valuable
- Fuel savings are a primary focus, but overall operating costs are of significant importance to commercial fleets , which is also a focus of the project
- Many different vocations have been analyzed under this project – results and data have been of value to industry
- Drive cycle metrics are being analyzed in more detail and compiled to ensure the right technology is deployed for the right application
- New tools and methods are being acquired / developed for researchers as well as industry as part of this project

Acknowledgements and Contacts

Thanks to:

Lee Slezak
Vehicle & Systems Simulation & Testing Activity
Vehicle Technologies Program - U.S. Dept of Energy

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