National Renewable Energy Laboratory
Innovation for Our Energy Future

Medium- and Heavy-Duty Vehicle Field Evaluations

2011 DOE Merit Review

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Project ID: VSS001 (Walkowicz)

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

Overview

Budget

Total Project Funding

- FY10 DOE funding: $800k
- FY10 DOE funding: $1,150k ($750k + $400k for MD electric vehicle (EV) data collection)
- Past Year Funding:

  $300k-$800k / yr over last 10 years
- Participant cost share has been substantial in-kind support (vehicle loan, technical support, data access and data supplied to NREL) and varies by individual project (estimated @ 20%)

Timing

- Varies by project
- 12-18 months per project to complete
- Some “in-process,” some “new”

Barriers to Overcome

- Industry Needs Unbiased Data: Users and OEMs need unbiased, third-party evaluations and better understanding of state-of-the-art technology performance to improve and overcome technical barriers
- Understanding Vehicle Use: Variable performance by advanced technologies due to multiple and wide-ranging duty cycles (data and analysis of this data are valuable in overcoming this barrier)

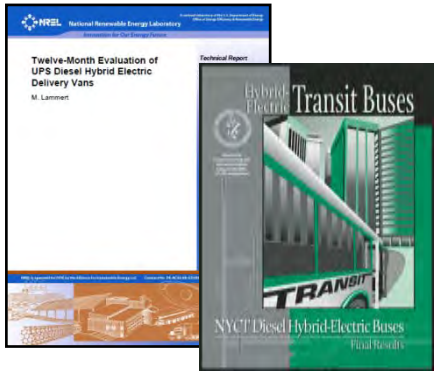
Partners

- Industry collaboration required for successful projects. Partners (past and present) include:
  - Vehicle Manufacturers (New Flyer, Freightliner, Workhorse, International, Orion, Navistar)
  - System Manufacturers (Allison Transmission, Eaton, Enova, Azure, Cummins, Navistar, Caterpillar)
  - Fleets (UPS, Fed Ex, Coke, NYC Transit, KCM)
- Current Partners in FY11:
  - FedEx, UPS, Coca Cola Refreshments, Eaton, Navistar Corporation, Smith Electric Vehicle, South Coast Air Quality Management District (SCAQMD)/ Electric Power Research Institute (EPRI)

Relevance

Recent & Relevant Medium- and Heavy-Duty (MD and 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
- HEV Delivery Tractors: 1 model tested to date at 1 location, 75,000 miles of operation documented



3.3 million test miles have been accumulated on 85 different electric drive vehicles since 2006.

Relevance

Overall objectives of this project are :

- Test and analyze recently introduced 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 potential vehicle customers and OEMs with un-biased, accurate data and analysis needed to make informed decisions on advanced technology vehicle purchases, fleet implementations and vehicle development.
- Support the Vehicle Technology (VT) Program's Strategic Goal: *Support the laboratory and field evaluations of large-scale demonstration fleets of advanced commercial and passenger PHEVs and EVs.*

Specific Field Evaluation Technical Objectives in FY11:

Project will assess and evaluate four vocationally diverse and relevant MD & HD vehicle applications in commercial fleets. In addition, data will also be collected, analyzed and reported on 4 MD EV platforms operated at multiple locations. Targeted fleets being evaluated and analyzed include:

1. UPS with the Eaton Gen II propulsion system installed in class 4 HEV delivery trucks
2. Coca-Cola Refreshments with the Eaton Gen II propulsion system installed in class 8 HEV tractor-trailers
3. A transit bus fleet using the BAE propulsion system with lithium battery systems installed
4. FedEx with the Eaton Gen II propulsion system installed in a class 6 HEV box truck
5. Class 3, class 6 delivery vans from Navistar and Smith, trouble trucks from Eaton/Ford and shuttle buses from Azure/Ford

Specific Milestones / Deliverables

1. Milestone 1: *Draft Interim Report on MD & HD In-Use Performance Evaluations*

   - Provides a year-end summary report on overall status and results of each project
   - In addition to the summary report deliverable above, the following 8 individual project reports will be completed:
     - Coca Cola Refreshments – interim (6 month) & final draft report (12 month)
     - UPS Gen I (Phoenix) – final 3-year data published
     - UPS Gen II (Minneapolis) – interim (6 month) & final draft report (12 month)
     - FedEx gasoline hybrid delivery van (Los Angeles), Final – *completed in Feb 2011*
     - FedEx Freightliner M2 box truck (Oakland, CA) – draft interim (6 month)
     - BAE / A123 Lithium Battery Eval (NYC?) – interim update

2. Milestone 2: *Interim Status Report on MD PHEV/EV Data Collection and Reporting*

   - Smith EV, Navistar EV, Azure EV shuttle bus, Eaton plug-in hybrid electric vehicle (PHEV) trouble truck
   - Usage data summarized, will include metrics such as charge characteristics, battery state of charge (SOC), driving characteristics, etc.

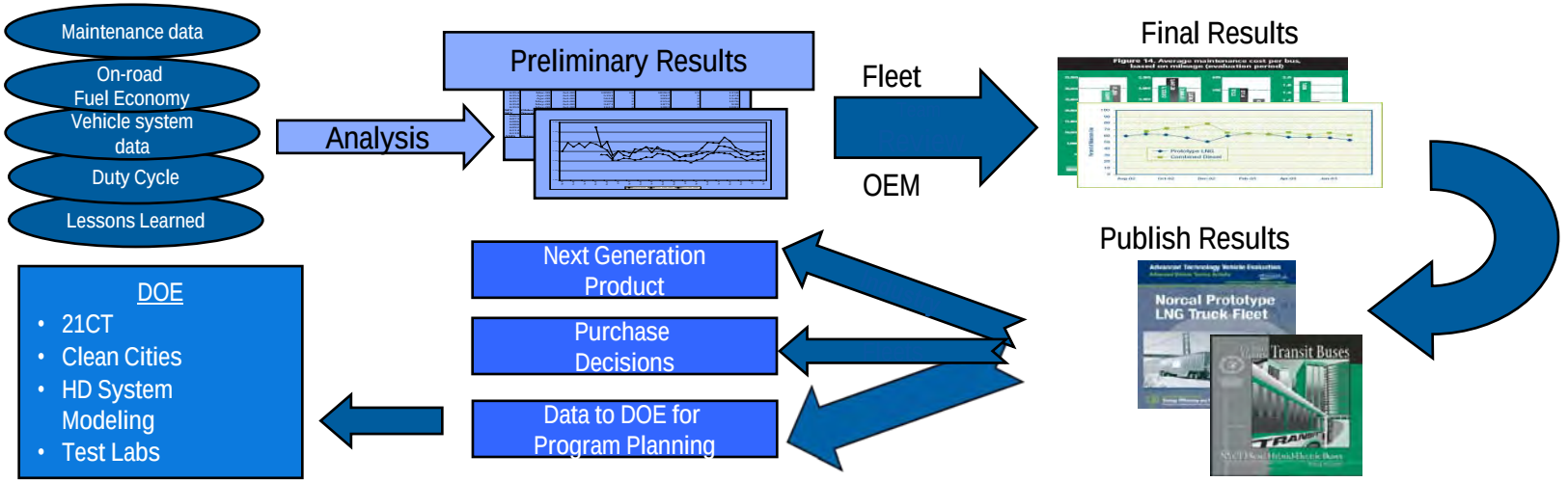
Approach – Selection & Data Flow

This project will co-operate 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
3. The interest of the DOE (including 21st Century Truck partners and other DOE program managers)

General Approach:

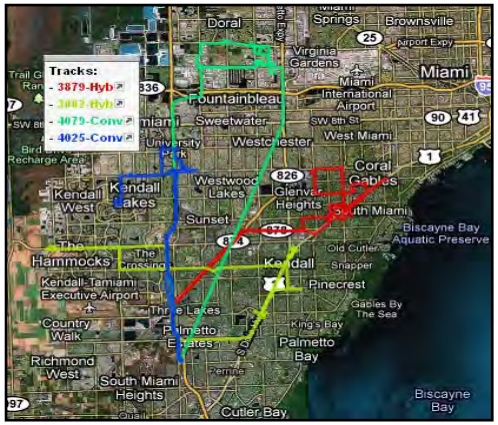
1. NREL collects data on sub-system and vehicle performance (varies by project), maintenance and warranty (if applicable) and/or operational costs relative to the new technology.
2. Data are analyzed and provided back to the DOE and project teams on the performance of the technology and its potential 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.



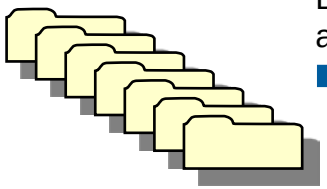
Approach – Data Acquisition

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 of data: multiple methods to assess fuel economy of new technology in service, automated processes

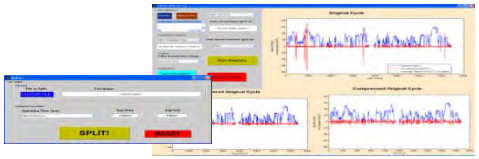


Enhanced capability in 2010/2011 (20+ data loggers)

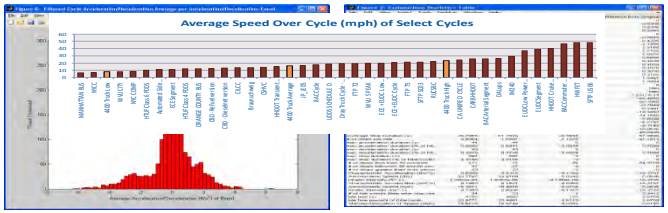


Sets of GPS, CAN & analog data (per day or per shift)

Drive cycle analysis

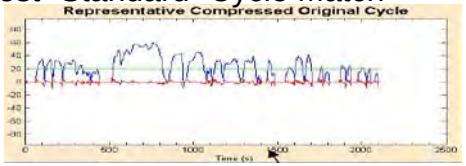


Analysis includes drive cycle tool filtering and sorting of GPS data in desired set



Full understanding of supplied data: daily variation info; stats for original, filtered and shortened data

Closest "Standard" Cycle Match



User-Specific Test Cycle Generated

Accomplishments, Progress and Results: Coca Cola

Project Background

Kickoff in June 2010: Fleet test of Eaton Gen II hybrid electric system in single-axle day cab tractor application at Coca-Cola.

This is the first major fleet deployment of hybrids in class 8 tractor-trailer service. Coca Cola Refreshments has over 400 of these tractors currently in service in the U.S.

Data to be gathered in Gen II study

1. Fuel economy and maintenance records from fleet
2. ECU/CAN download
   - Miles Traveled
   - Fuel Consumed
   - Percent Idle Time
   - Diesel particulate filter (DPF) Regenerations
3. GPS based route data logging
4. On-board instrumentation – DPF analysis, mpg verification, system analysis, battery data
5. Chassis dynamometer (ReFUEL) testing

Details

- Miami fleet June 2010 start
- Five 2009 / 2010 hybrid tractors (2007 emissions) vs. four 2007 conventional tractors
- Coca-Cola provided tractors for ReFUEL testing from its Denver depot in June 2010

Accomplishments, Progress and Results: Coca Cola

Results

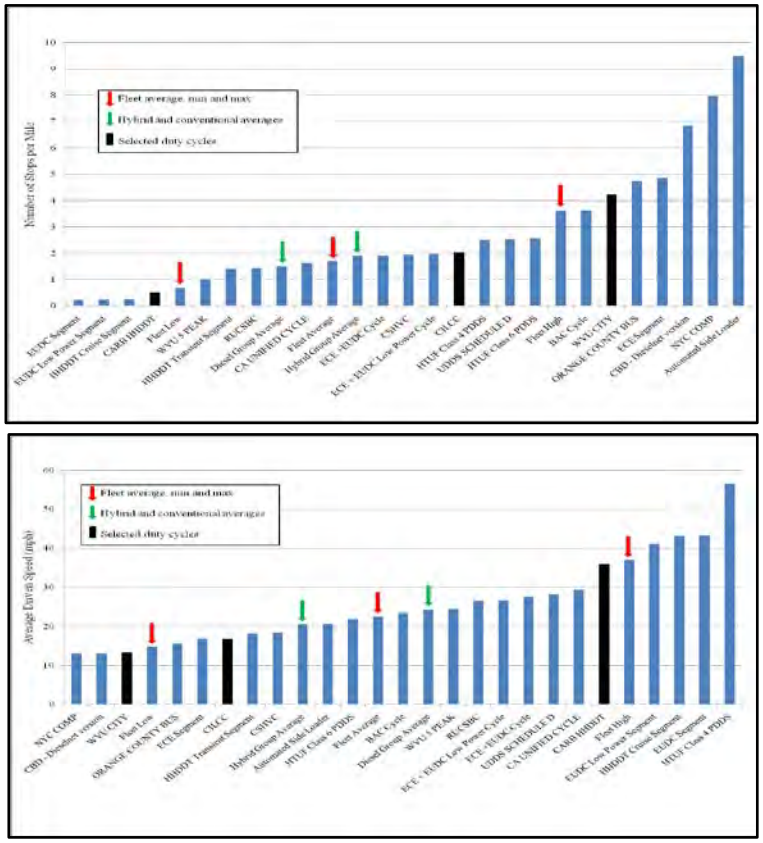
- Collecting delivery shifts in Miami
- First collection effort yielded 63 individual delivery shifts
  - 26 hybrid trips
  - 37 conventional diesel trips
- Data analyzed to determine test cycles and characterize usage
- Additional GPS/CAN data collected in Feb 2011 (additional 150 shifts / 1200 hours of operation collected)

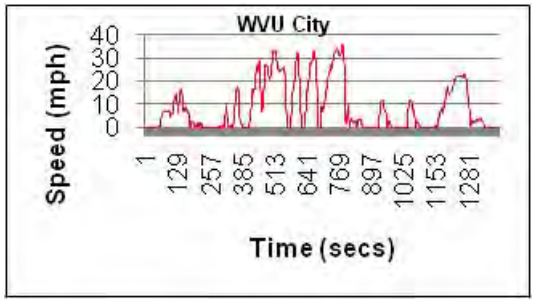
Vehicle Number	Distance Traveled (miles)	Average Driving Speed (mph)	Maximum Speed (mph)	Number of stops	Average Stop Duration (sec)	Number of stops per mile	Number of stops > 60 seconds	Kinetic Intensity (1/mi)
1H Avg	30.65	18.33	55.87	78.33	179.90	2.66	22.83	0.99
2H Avg	58.64	25.68	67.19	49.40	130.63	0.83	17.60	0.53
3H Avg	42.63	19.71	64.31	59.40	144.86	1.40	19.80	1.00
4H Avg	31.46	18.61	59.37	84.00	201.90	2.72	31.67	1.29
5H Avg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1C Avg	37.05	24.63	64.60	61.50	521.71	1.71	23.00	0.57
2C Avg	56.10	24.56	66.78	80.00	209.76	1.56	28.09	0.57
3C Avg	42.52	27.30	71.89	64.14	213.39	1.49	22.00	0.53
4C Avg	53.61	26.68	69.41	73.43	201.50	1.38	22.14	0.48
5C Avg	36.67	18.18	59.77	51.60	211.37	1.46	21.70	1.29
Hybrid Avg	40.84	20.58	61.68	67.78	164.33	1.91	22.98	0.95
Conventional Avg	45.19	24.27	66.49	66.13	271.55	1.52	23.39	0.69

Accomplishments, Progress and Results: Coca Cola

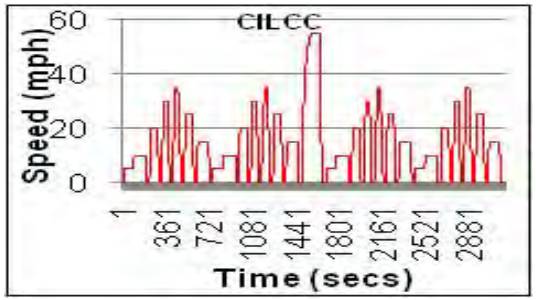
Results

- Using drive cycle data and in-house tools, three standard test cycles were selected to represent most urban, most rural and “best average fit”

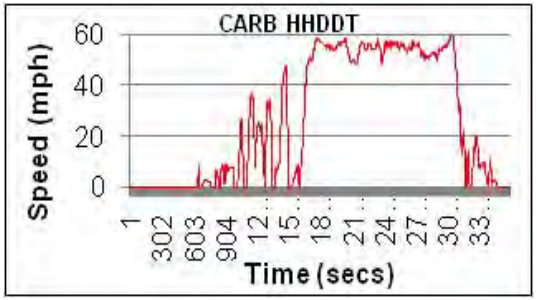




urban



avg



rural

Accomplishments, Progress and Results: Coca Cola

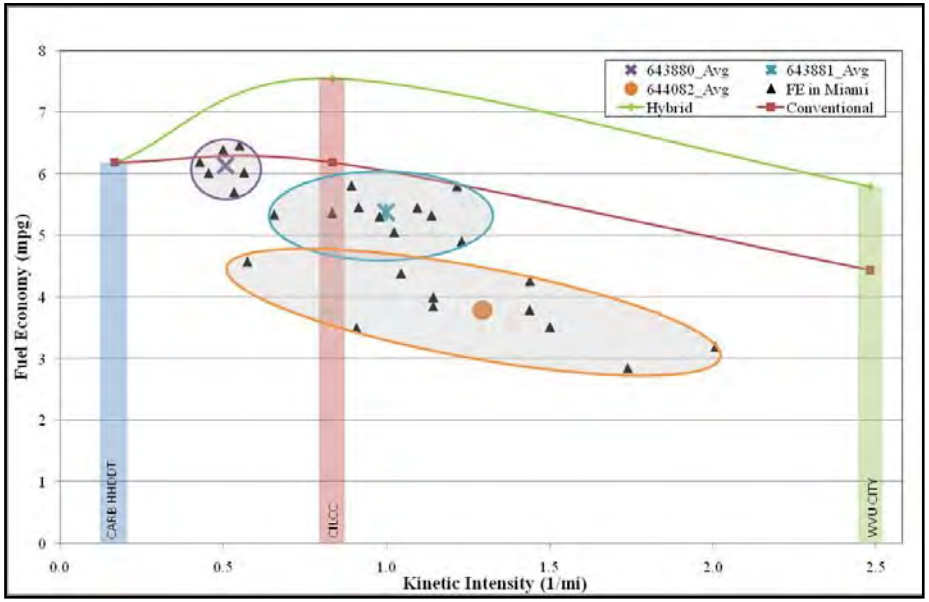
Results

- 2 representative vehicles (supplied by Coca Cola) were tested on NREL's Heavy Duty Chassis Dynamometer in Denver, CO (ReFUEL):
  - Measured regulated emissions + fuel economy
  - 0%–30% increase in fuel economy (mpg)
  - CILCC was "average" cycle; 22% improvement observed

- In addition to laboratory testing, 6 months of on-road data have been collected and documented:
  - 16% improvement in mpg observed over 6 months for two groups of vehicles

Drive Cycle	HEV Fuel Economy (mpg)	Conventional Diesel Fuel Economy (mpg)	HEV Percent Increase (%)	P Value
WVU City	5.79	4.44	30.3%	8.8E-6
CILCC	7.55	6.18	22.2%	1.8E-9
CARB HHDDT	6.17	6.18	-0.14%*	0.88

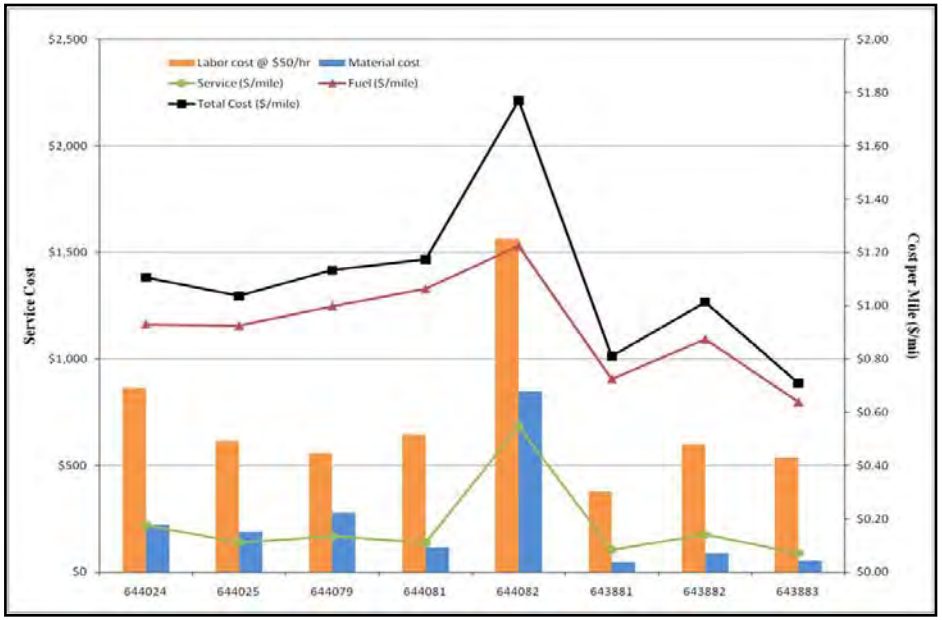
Idle time (% of trip)	
643880	27.8%
643881	38.4%
644082	47.8%

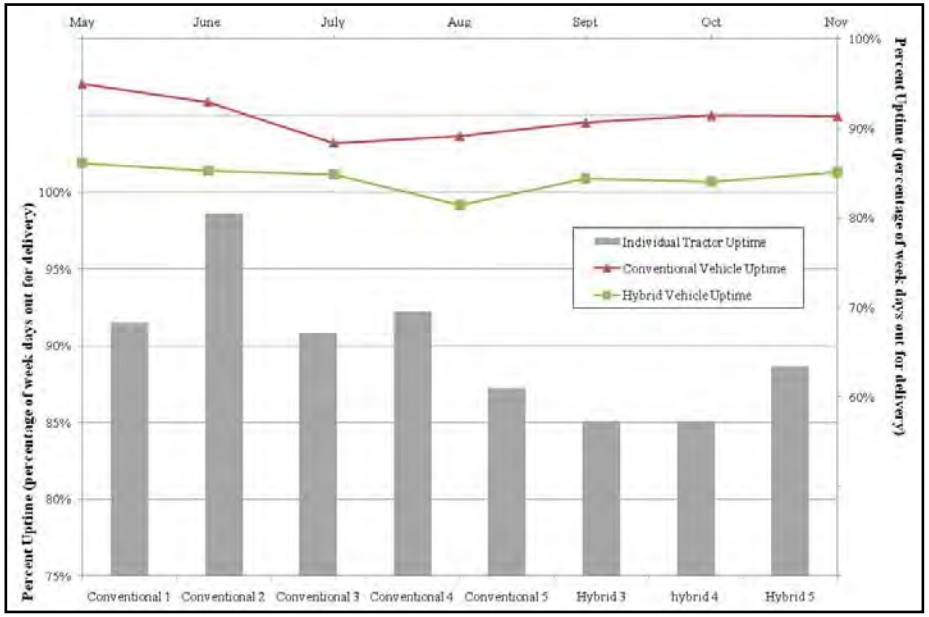


Accomplishments, Progress and Results: Coca Cola

Results

- Vehicle usage (miles per vehicle), reliability and cost per mile being tracked
- 6 months of results available in interim report (April)





Accomplishments, Progress and Results: UPS I and UPS II Evaluations

UPS I: Year 2 & 3 Gen I Evaluation in Phoenix – builds on FY09/10 work, shows durability and costs for 3 years of operation – added resolution.

- Jan 2008 through December 2010
- Trends from 1st year continue

Total Cost per Mile Comparison						
Car	PWRTRN	Mileage Total	Non-Prop Mnt ($/mile)	Prop Maint ($/mile)	Fuel Cost ($/mile)	Total Cost ($/mile)
663982	Diesel	49,637	$0.103	$ 0.037	$ 0.281	$ 0.420
665020	Diesel	55,756	$0.066	$ 0.026	$ 0.277	$ 0.368
665044	Diesel	50,128	$0.084	$ 0.024	$ 0.285	$ 0.393
665086	Diesel	59,931	$0.095	$ 0.037	$ 0.344	$ 0.476
665087	Diesel	57,883	$0.088	$ 0.016	$ 0.321	$ 0.425
665150	Diesel	48,994	$0.090	$ 0.028	$ 0.286	$ 0.405
Total	**Diesel**	**322,329**	**$0.087**	**$ 0.028**	**$ 0.300**	**$ 0.416**
666131	Hybrid Diesel	35,480	$0.089	$ 0.033	$ 0.261	$ 0.383
666132	Hybrid Diesel	51,501	$0.051	$ 0.018	$ 0.221	$ 0.290
666133	Hybrid Diesel	51,414	$0.070	$ 0.011	$ 0.246	$ 0.328
666139	Hybrid Diesel	47,740	$0.087	$ 0.022	$ 0.255	$ 0.364
666142	Hybrid Diesel	41,100	$0.117	$ 0.050	$ 0.273	$ 0.440
666145	Hybrid Diesel	42,544	$0.161	$ 0.061	$ 0.244	$ 0.467
Total	**Hybrid Diese**	**269,779**	**$0.094**	**$ 0.031**	**$ 0.249**	**$ 0.373**

- On-road fuel economy improved by 23% (13.3 vs. 10.8 mpg)
- $0.043 / mile improved operating costs
- No major operational issues

Accomplishments, Progress and Results: UPS I and UPS II Evaluations

UPS II: New "Gen II Evaluation" – 13-vehicle study of latest generation Eaton parallel hybrid system (engine off capability added)

- Latest system from Eaton
- Different location (climate, drive cycle)

Project Details

- Eagan, MN, study location
- Eagan location received hybrid units in March 2010, put them into service in April 2010
- 2007 level engine emissions
- P100 chassis

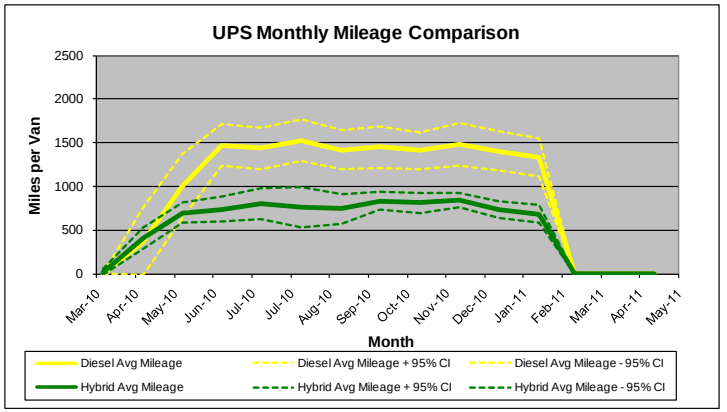
Additional data to be gathered in Gen II study

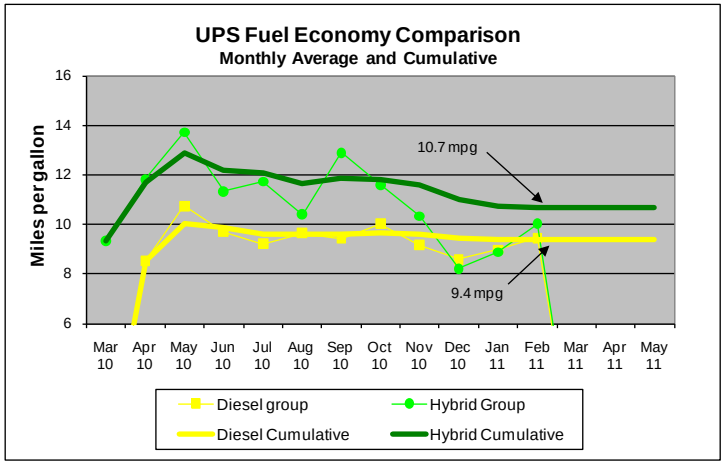
1. Fuel economy and maintenance records from fleet
2. ECU/CAN download
   - Miles Traveled
   - Fuel Consumed
   - Percent Idle Time
   - DPF Regenerations
3. GPS route data logging
4. On-board instrumentation – DPF analysis, mpg verification, system analysis, battery data
5. Chassis dyno (ReFUEL) testing scheduled for June 2011

Accomplishments, Progress and Results: UPS I and UPS II Evaluations

UPS II Results

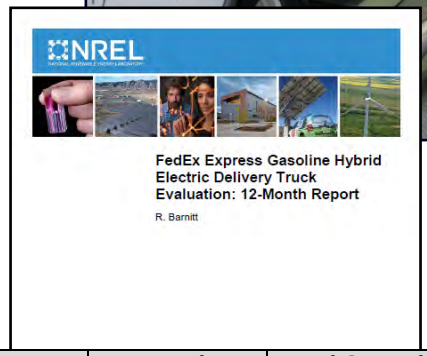
- July 2010 start date ('clean' data point)
- Hybrids driving roughly half as many miles a month as conventionals
- Study groups will switch routes in April 2011 to account for this
- Hybrids are achieving 14% better fuel economy on average
- Hybrid routes are more kinetically intense with slower speed, which affect the fuel economy comparison. (Diesels would likely get worse mpg on the hybrid routes)
- One hybrid was removed from mpg calculations because consistently not logging fueling events





Accomplishments, Progress and Results: Fed Ex gHEV

- **Collaborative Project:** DOE/NREL, Calstart & SCAQMD funded – final report publish in March 2011
- **Timing**
  - On-road evaluation: April 2009 thru April 2010
  - Dyno testing: April 2009
- **Technology:** Azure Gen I gasoline HEV in Southern CA vs. conventional diesels (400 Azure HEVs in US)
- **Data:** Final report completed March 2011; includes on-road, chassis dyno data, operational cost data, drive cycle data
- **Results:** Chassis Dyno
  - MPG: 0%–20% improvement in mpg (dge*) (gasoline engine vs. diesel)
  - Emission Reductions:
    - Much cleaner!
    - NOx = 75-89%
    - PM = 99.9%
- **Results:** On-Road (mpg dge)
  - No statistical difference



Vehicle Type	Asset #	Miles	Fuel Cost ($)	Maintenance Cost ($)	Total Operating Cost ($)	Total Operating Cost per Mile ($/Mile)
gHEV	H292	10,693	4,468	1,451	5,919	0.55
	H294	11,843	5,119	3,065	8,218	0.69
	H295	7,214	3,010	1,620	4,630	0.64
	Total	29,750	**12,597**	6,136	18,767	**0.63**
Diesel	D670	13,099	5,254	2,422	7,676	0.59
	D830	11,344	3,893	2,386	6,279	0.55
	D896	11,124	3,899	3,126	7,024	0.63
	Total	35,567	**13,046**	7,933	20,979	**0.59**

*dge=diesel gallon equivalent

Planned: FedEx M2 HEV Delivery + BAE Lithium Battery Eval

FedEx M2 HEV: Class 6 Delivery Box Truck – new vocation!

- **Timing:** Scheduled to start in April 2011 in Oakland CA
- **Technology:** Eaton Gen II HEV w/diesel
- **Planned Data:** On-road records, drive cycle data, dyno testing for both HEV and conventional
- **Status:** NDA signed in March 2011, kickoff meeting in May 2011

BAE/A123: Transit Bus

- **Timing**: Scheduled to start in April 2011 – NYC or Toronto
- **Technology:** BAE series HEV with A123 lithium
- **Planned Data:** On-road records, drive cycle data, dyno testing for both lithium and lead acid + detailed 1hz battery pack data to examine and document battery degradation. Project to feed battery degradation model and use coordinated lab testing (industry and gov't) to determine degradation rate vs. operating environment. Coordination and support from DOE Energy Storage group
- **Status:** Kickoff meeting in NYC schedule for April 2011

Accomplishments, Progress and Results: Smith, Navistar, AQMD EVs

Data Analysis on Four Vehicle Makes/Models:

- **Navistar**
  - 950 Class 2–3 EVs (*250 reporting*)
  - Data logging to begin in April 2011

Used with permission by Navistar

- **Smith Electric Vehicles**
  - 510 Class 4–6 EVs (*all reporting*)
  - Data logging started in Dec 2010

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- **SCAQMD**
  - 378 vehicles total
    - *Eaton equipped PHEV Bucket/Trouble Trucks*
    - *AZD Shuttle Buses*
  - Data logging beginning in 2nd half of 2011

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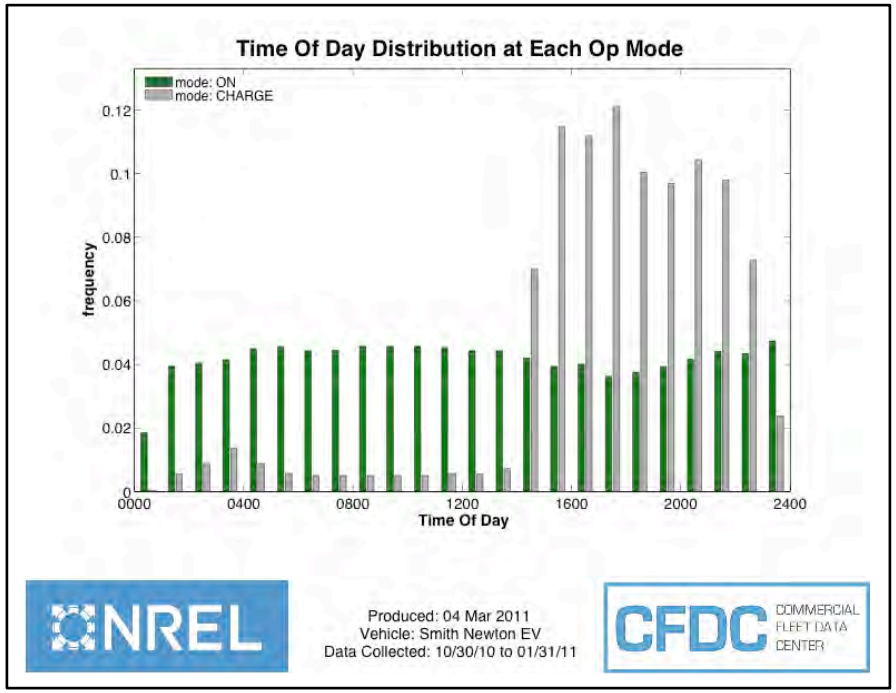
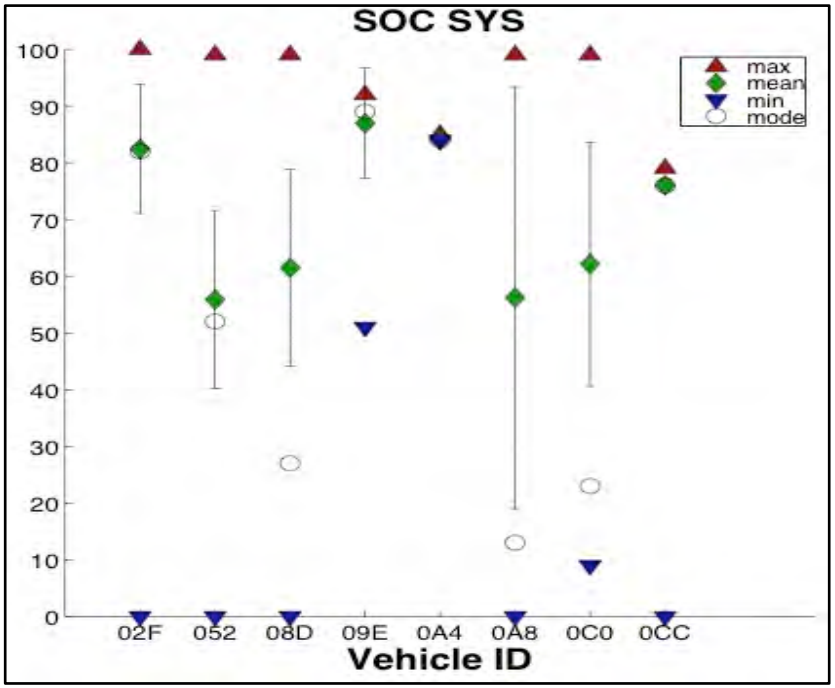
Accomplishments, Progress and Results: Smith, Navistar, AQMD EVs





- Sample data above from first 8 logged vehicles
- Reported in similar manner as light-duty AVTA projects (quarterly info documents)
- ~30 channels of data collected and displayed on each vehicle (driving, charging, system data), +40 ‘data products’ to be created (analysis)
- Non-proprietary analysis of data to be reported publically
- NREL automated file transfer, data server and analysis tools in place to securely store and analyze data

Collaborations and Coordination with Other Institutions

- **Every Project has Industry Collaboration:** Evaluations are done in coordination and cooperation with OEM or system supplier to ensure up-to-date hardware and data are evaluated. Project Partners in FY11 include:
  - BAE
  - A123
  - Fed Ex
  - UPS
  - Eaton
  - Smith
  - Coke
  - Navistar
  - Azure
  - Enova
  - New York City Transit
  - SCAQMD/EPR

- **Projects are coordinated with others (data sharing or collaboration):** Data from evaluations are shared with other interested institutions.
  - SCAQMD
  - California Air Resources Board (CARB)
  - Argonne National Laboratory
  - Oak Ridge National Laboratory
  - CALSTART
  - National Automotive Center (NAC)
  - 21st Century Truck & partners

Proposed Future Activities

FY2012 Activities Proposed: Research focused on industry needs

1. **In-Use Performance Evaluations:** Continued on-road, in-use performance evaluations to obtain unbiased data on fleets/vocations/technology

2. **Near-Term Technology Validation:** Short-term, focused testing of new technology to provide most critical data for assessment of performance

3. **Data Collection and Reporting:** ~1700 MD EV and PHEV vehicles to be on the road starting in FY11 and continuing into FY12. Access data and look at overall trends

4. **PHEV School Bus Support:** Continue to assess and analyze data from Navistar PHEV School Bus (track data from prototype vehicles in FY11)

5. **Off-Road, Non-road:** Investigate other vocations, utilize same approach: higher fuel usage and most potential first. Initial focus will be on defining usage characteristics

6. **Data Sharing Mechanism:** Central database to compile MD&HD fleet data to accelerate the evolution of vehicle design and strategic deployment while reducing cost, petroleum use and GHG.

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 this data to both gov't and private partners for future development consideration

- This task was 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 ,and this 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

- **Duty cycle metrics** are being analyzed in more detail to ensure the right technology is deployed for the right application

- **New tools and methods** being acquired / developed for researchers as well as industry as part of this project

Acknowledgements and Contacts

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