National Renewable Energy Laboratory
Innovation for Our Energy Future

Heavy-Duty Vehicle Field Evaluations

2009 DOE Merit Review

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Project ID:
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Overview

Budget

Total Project Funding:

- FY08 DOE funding: $550k
- FY09 DOE funding: $600k
- Past Years Funding:

  $300k-$700k / yr over last 10 years

- Participant cost share has been in-kind support (vehicle loans, data access and data supplied to NREL) and varies by project

Timing:

- Varies by project
- 12-18 months per project

Barriers to Overcome

- Data Analysis: Users and OEMs need better understanding of state-of-the-art technology performance information
- 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:
  - Veh Mfg's (New Flyer, Freightliner, Workhorse, International, Orion, and many more)
  - System Mfgs (Allison Transmission, Eaton, Enova, Azure, Cummins, International, Caterpillar)
  - Fleets (UPS, Fed Ex, various state and local)
- Current Partners in FY09:
  - Fed Ex, UPS, Enova, Advanced Energy, Eaton, Navistar/IC Corporation

Project Goal & 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 potential vehicle customers and OEM's with the un-biased, accurate data and analysis they need to make informed decisions on advanced technology vehicle purchases and fleet implementation.

Specific Technical Objectives in FY09:

- Evaluate in-use operation of Eaton's lithium battery, parallel hybrid delivery trucks in UPS fleet
- Evaluate in-use operation of Azure's gasoline hybrid electric delivery trucks in FedEx fleet
- Evaluate in-use operation of Enova's Plug-in hybrid school buses in 3 fleets in the U.S.
- Develop a mathmatical analysis tool for fleets to use to better understand their specific duty cycle characteristics

Milestones

1 - Final draft report on UPS HEV evaluation project – Sept. 09: Compile, analyze and prepare report on 12 months of data from Phoenix, AZ UPS HEV fleet study. Will include: 1) route analysis, 2) in-lab emissions and fuel economy data, 3) on-road fuel economy, 4) in-use reliability and operating costs.

2 - Final draft report on PHEV school bus evaluation – Sept. 09: Compile, analyze and prepare report on 9 months of data from IC Corp's PHEV School buses in Austin, TX, Manatee, FL, and Wake County, NC. Will include: 1) route analysis, 2) in-lab emissions and fuel economy data, 3)on-road fuel economy and 4) in-use reliability and operational costs.

3 - Interim draft report on FedEx HEV evaluation project – Sept. 09: Compile, analyze and prepare interim report on data from Los Angeles, CA Fed Ex HEV fleet study. Will include: 1) route analysis, 2) in-lab emissions and fuel economy data, 3) on-road fuel economy, 4) in-use reliability and operating costs.

4- Progress review at DOE of Fleet Duty Cycle Creation tool – April. 09: Update on latest development with Fleet Duty Cycle Creation tool to demonstrate functionality of tool to 1)filter data, 2) sort GPS data and create files according to shift, 3) provide statistical comparison to known cycles, 4) automatically create a custom short (30 min) cycle from large data sets

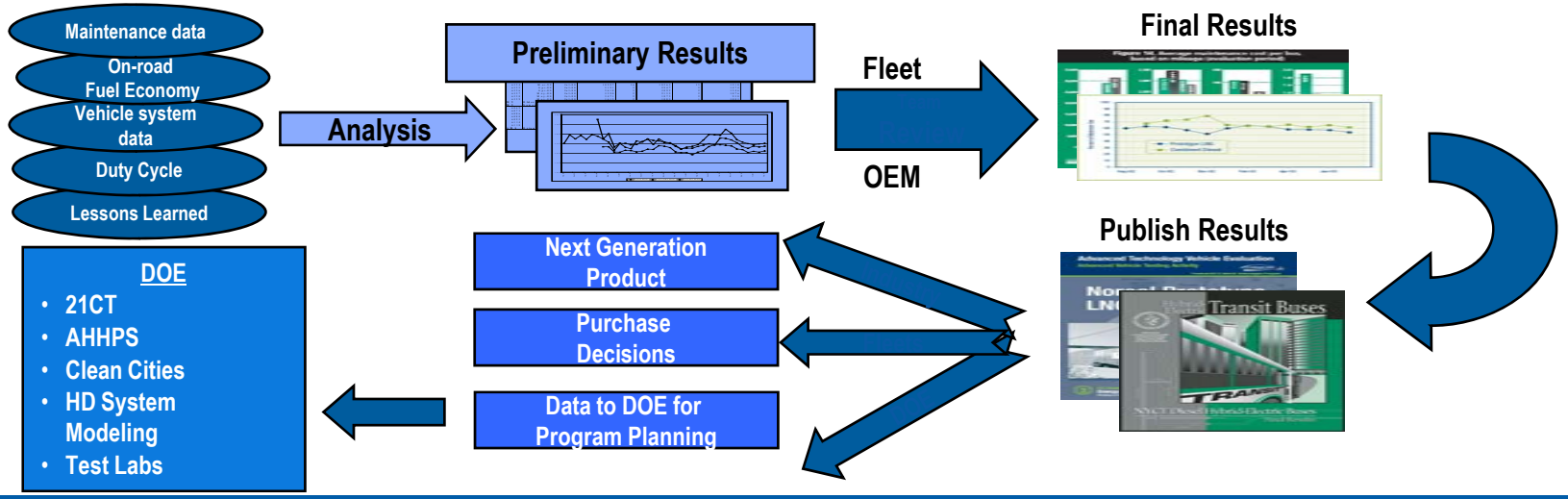
Approach

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
2. their potential for widespread commercialization
3. the interest of the DOE (including 21st Century Truck partners and other DOE program managers)

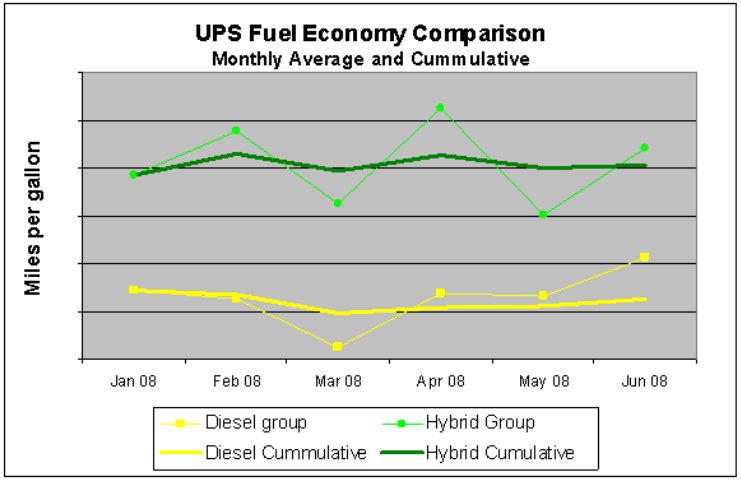
General Approach:

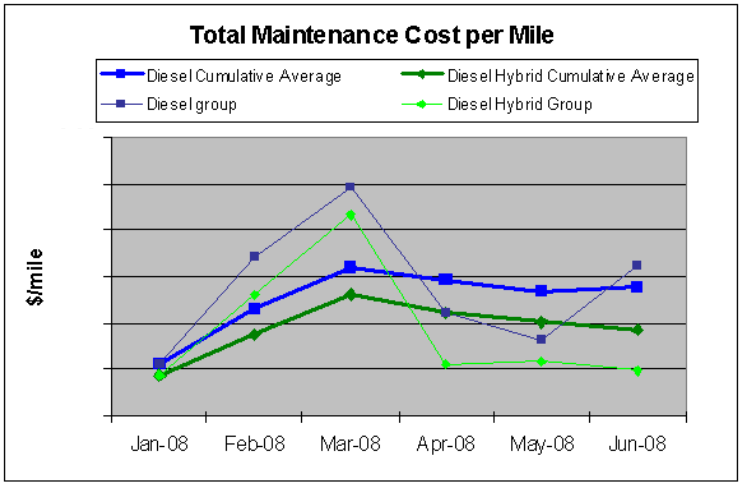
1. NREL collects data on: sub-system and vehicle performance (varies by project), maintenance (if applicable) and/or operational costs relative to the new technology.
2. Data is analyzed and provided back to the DOE and project teams on the performance of the technology and its potential improvement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



Accomplishments, Progress and Results - Milestone #1: UPS

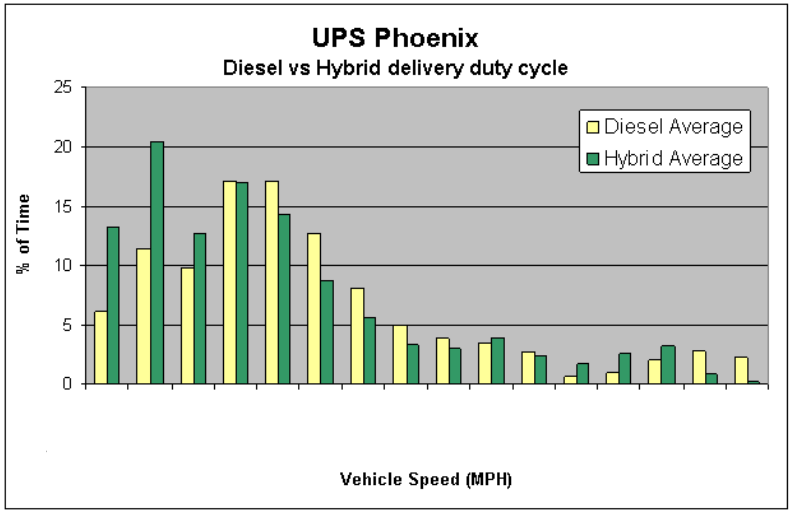
- Identical Freightliner P70 vehicles with MBE 904 engines except addition of hybrid system
- Eaton Parallel Hybrid Electric System
- 6 hybrids and 6 conventional diesels in Phoenix studied
- Monthly miles per van for the hybrids consistently were less than for the diesels
- Hybrids got 20-30% better fuel economy during the first 6 months
- Total maintenance costs per mile were less for the hybrids
- Last 6 months of data received and being analyzed – final results expected to be published in May 2009





Accomplishments, Progress and Results - Milestone #1: UPS

- 2 vehicles from each study group were monitored with a GPS device for 5 days.
- Route and duty cycle data analyzed to determine group-group drive variability
  - Hybrid vans had twice the idle time
  - Hybrids spent 12% more time in the 0 to 10 mph range
  - Diesel vans spent 8% more time in the 20-35 mph range
  - Both groups spent much of their non-idle driving time at speeds less than 35mph
  - Hybrids spent twice as much time in the 50-65 mph range
  - Diesels spent more time above 65 mph than hybrids
  - Both groups spent equal amounts of their driving time at speeds above 50mph
  - Hybrids had twice as many stops per mile
- Hybrids were determined to be in more severe city/stop-and-go type route (slower avg speed)
- Fuel economy comparison is valid but hybrid fuel economy would improve more if put on more similar routes



Accomplishments, Progress and Results - Milestone #1: UPS

- 2 UPS delivery vans tested on the NREL ReFUEL dynamometer
- Both are workhorse P100 chassis with VT275 engines
  - Not the same chassis or engine evaluated at the Phoenix location due to vehicle availability
  - Eaton hybrid system is the same
- CILCC, WVU City, CBD and a UPS Custom Composite cycle
  - developed from in-use data on the P100 delivery routes
- Hybrids showed decreases in regulated emissions
- Hybrids showed 31-37% fuel economy improvement on the standard cycles, but only a 13% improvement on the custom cycle; max speed significant factor in custom cycle (hybrids limited to 55 mph, cycle speed = 62mph)

	CILCC	WVU City	CBD	Custom
Fuel Economy (mpg) % increase w/hybrid	31%	37%	34%	13%

Future Work

- Remainder of FY09:
  - Complete analysis of 12 months of data and include in final report to DOE
  - Initiate discussion with UPS on additional testing of Gen II vehicles in fleet (vehicles have incorporated engine off at idle and some electrified accessories) – begin data collection activity into FY10 if possible
  - Initiate discussion on comparison of hydraulic hybrids in UPS to HEV's in fleet
  - Test additional trucks in Emission Laboratory for further analysis

Accomplishments, Progress and Results - Milestone #2: PHEV School Bus

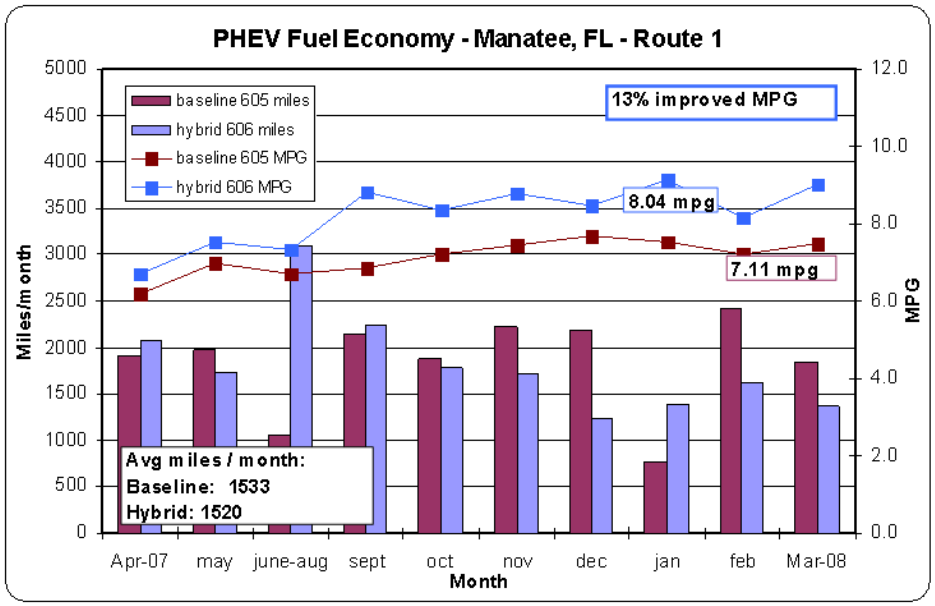
- **Project to assess fuel consumption and reliability performance of PHEV school buses in coordination with analysis of MD PHEV (3 pronged approach):**
  - analysis of fleet data
  - chassis dyno testing
  - analysis and modeling support to locate improvements

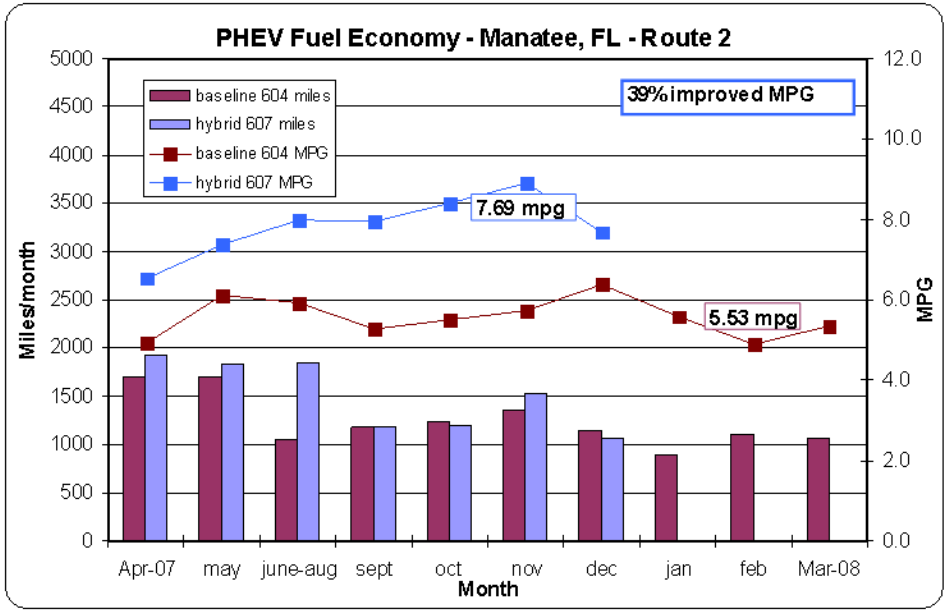
- **'Case Study' report for performance of buses:**
  - Coordinating with Advanced Energy and NC State
  - Description of technology
  - Deployment details
  - Austin, TX and Wake County added as 2nd and 3rd sites (1 bus each). Manatee was 1st.
  - Route descriptions and analysis of routes (in process) – Austin logging data now. Will compare to conventional duty cycles (UDDS) and NC data
  - Performance analysis of buses in 3 fleets vs conventional diesels
  - Chassis dyno test at NREL ReFUEL planned for April to compare to field data – will utilize logged route data to determine best cycle to use. Also will determine optimal test length for charge depleting system
  - Final report to be completed in Aug 2009 with 3 locations

Accomplishments, Progress and Results - Milestone #2: PHEV School Bus

On-Road Data Analysis through Feb 2009

- Fuel Economy shows improvement but variable depending on duty cycle
- Exploring:
  - electrical propulsion usage (charge depletion typical for use)
  - route specifics in each location
  - driver behavior (CAN data from Advanced Energy Wireless)





Future Work

- Remainder of FY09:
  - Complete analysis 12 months of data on 3 locations and include in final report to DOE
  - Test PHEV School Bus at NREL ReFUEL on 2-3 school bus specific cycle (UDDS, Custom, ?)
    - pending data from site data collection
    - compare against conventional
  - Input data from emission testing into vehicle simulation and analysis efforts through DOE's Systems Analysis Team
  - Investigate additional 'Gen II' analysis of next generation school bus from IC Corporation that will include enhanced control strategy and engine off capability

Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

- Robust drive cycle characterization
- Emissions and fuel economy measurement at ReFUEL
- 12-month in-use evaluation
- Modeling of PHEV potential

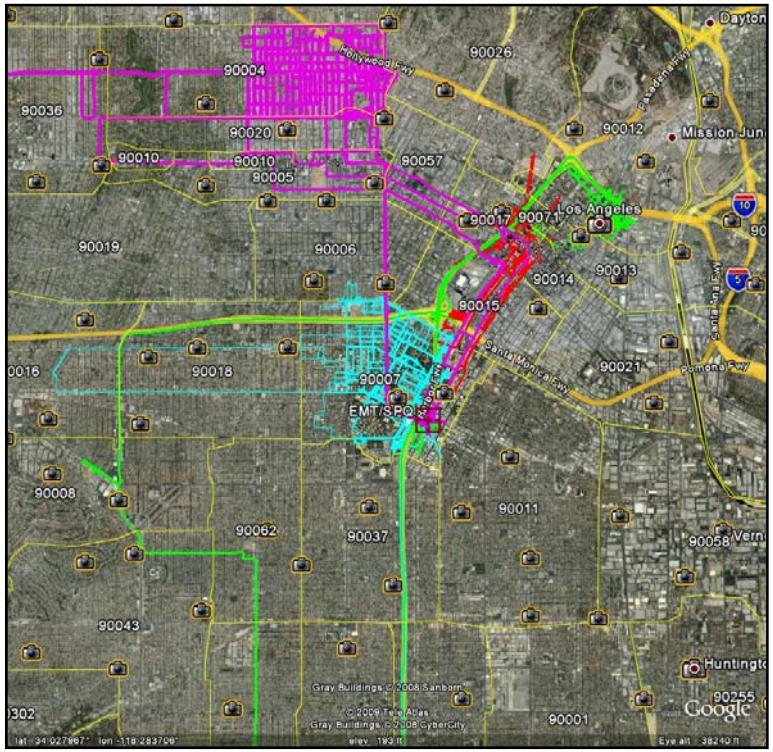
Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

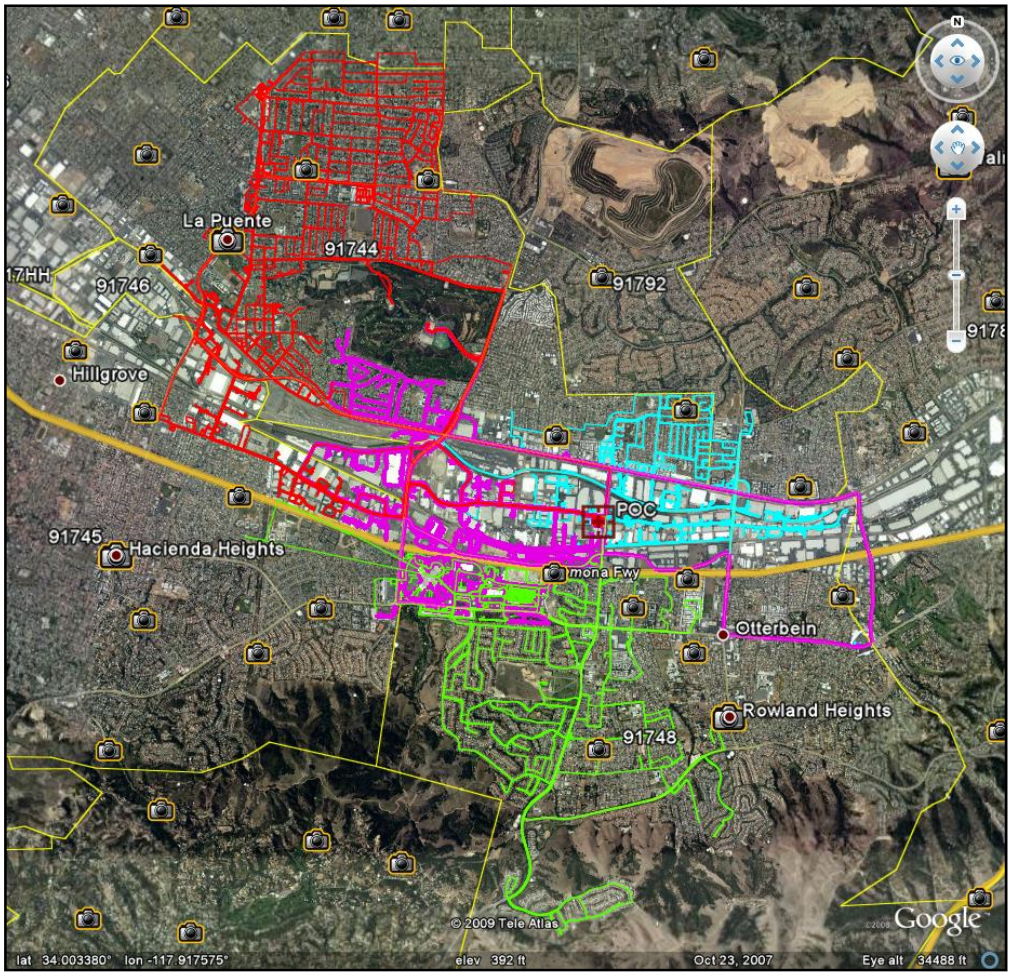
- 8 trucks at 4 depots instrumented with GPS data loggers
- 1 Hz speed, position logging
- 62 route-days captured and analyzed

Truck	Depot	Days Logged	Days Valid	Day #:	1	2	3	4	5	6	7	8	9	10	11
242286	EMT	4	3		OFF	ON	ON	ON							
242288	EMT	11	8		ON	ON	ON	ON	OFF	OFF	ON	ON	ON	ON	OFF
242289	SPQ	8	6		ON	ON	ON	ON	OFF	OFF	ON	ON			
242290	SPQ	10	8		ON	ON	ON	ON	OFF	OFF	ON	ON	ON	ON	
242292	POC	10	9		ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF	
242293	POC	10	10		OFF	ON	ON	ON	ON	ON	ON	ON	ON	ON	
242294	POC	9	9		ON	ON	ON	ON	ON	ON	ON	ON	ON		
242295	POC	9	9		ON	ON	ON	ON	ON	ON	ON	ON	ON		
		71	**62**												

Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

- Latitude / Longitude data filtered, uploaded to Google Earth for visualization
- Key considerations:
  - Screen out off-days
  - Day-to-day consistency
  - Route repeatability

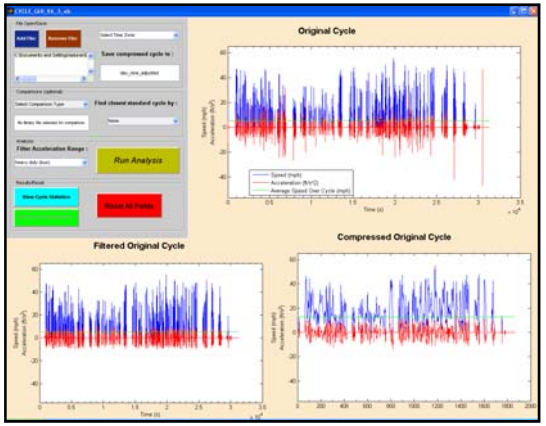




Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

- NREL Duty Cycle Analysis Tool used for comparative analysis of depots and routes
  - 48 drive cycle characteristics
  - Filtering
  - Compression to create 'custom cycle'
  - Comparison to other known cycles

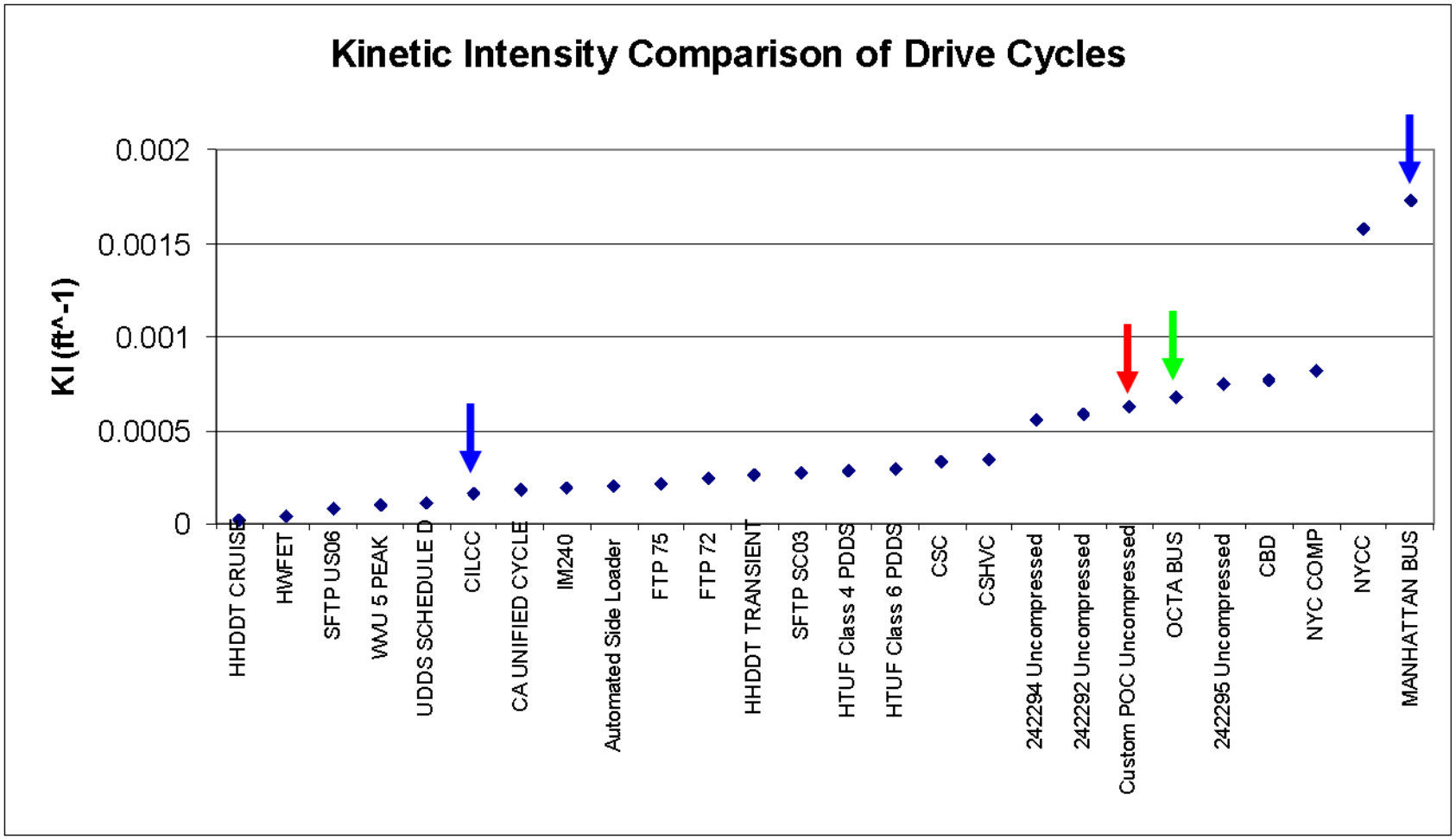
- 3 routes selected at POC depot – statistical equality



- **Distance traveled (miles)**
- **Average speed over cycle (mph)**
- **Average driving speed (mph)**
- **Maximum speed (mph)**
- **Time at idle (s)**
- **Maximum acceleration (ft/s^2)**
- **Maximum deceleration (ft/s^2)**
- **Acceleration (% of total cycle)**
- **Deceleration (% of total cycle)**
- **Average acceleration (ft/s^2)**
- **Average deceleration (ft/s^2)**
- **Number of acceleration events**
- **Number of acceleration events per mile**
- **Number of deceleration events**
- **Number of deceleration events per mile**
- **Number of stops**
- **Average duration of stop (s)**
- **Number of stops per mile**
- **Kinetic Intensity**

Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

- CILCC and Manhattan Bus represent “boundary cycles”
- OCTA bus cycle closely matches Custom POC cycle



Accomplishments, Progress and Results - Milestone #3: FedEx Hybrid

Begin in-use data collection	→	March 2009
Begin model development for PHEV performance	→	March 2009
Conduct emissions testing at ReFUEL	→	April 2009
Interim Report on data	→	September 2009
Project Complete	→	Aug 2010

Future Work

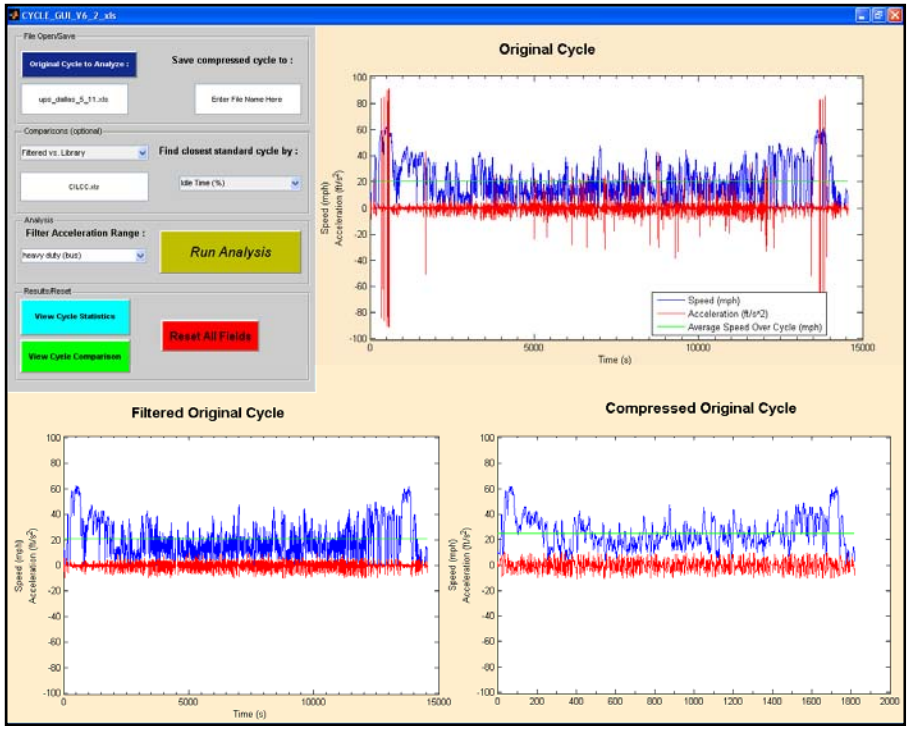
- Remainder of FY09 / begin FY10:
  - Complete analysis of 6 months of data on LA location and include in interim report in September
  - Complete analysis of 12 months of data on LA location and include in final report in FY10
  - Test FedEx truck at NREL ReFUEL on 3 specific cycles based on cycle analysis
    - compare against conventional
  - Input data from emission testing into MD PHEV vehicle simulation and analysis efforts through DOE's Systems Analysis Team

Accomplishments, Progress and Results - Milestone #4: Duty Cycle Tool

- **Background: Tool to allow fleets to easily capture drive cycle data and analyze for internal analysis**

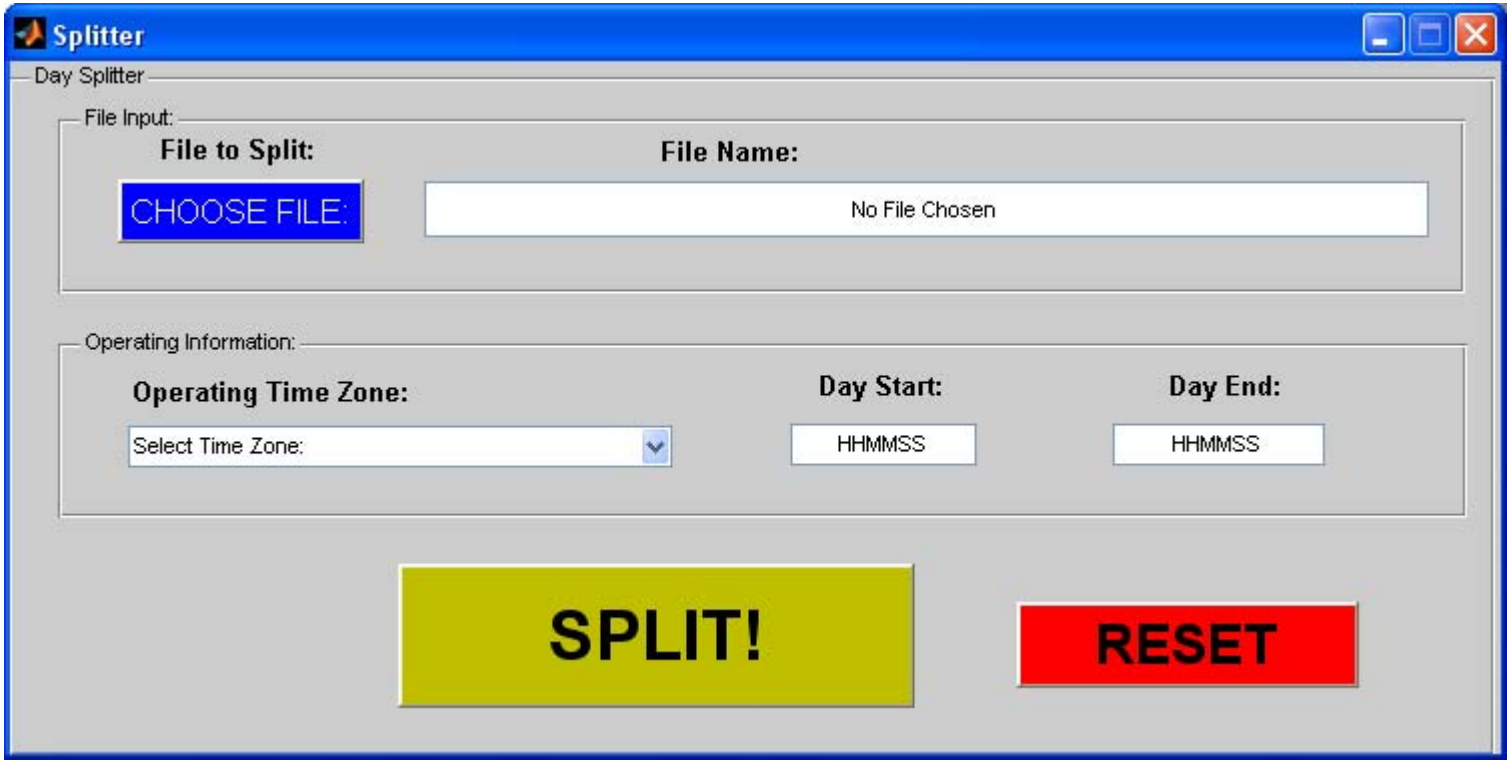
1) Creates easy to use process for analyzing and creating duty cycles with fleet provided GPS data
2) Provides metrics and equations for cycle analysis and puts into an easy to use GUI format/process
3) Fleets will be able to capture a vehicle, route or depot worth of GPS data and create a testable duty cycle as well as compare their data to existing cycles and associated stats

- **April Milestone – progress review**
- **Updates thus far in FY09:**
  - **Day/shift splitting, time correction**
  - **Added stats / metrics**
  - **Picking closest cycle logic**
  - **Refinement of compression / cycle creation**



Accomplishments, Progress and Results - Milestone #4: Duty Cycle Tool

File Splitting: splits based on shift, time zone – user defined



Accomplishments, Progress and Results - Milestone #4: Duty Cycle Tool

Recently Added Functions:

- **Characteristic Acceleration (measure of positive acceleration events)**
- **Aerodynamic Speed**

  (characteristic to measure aerodynamic losses for cycle comparison – ratio of cubic speed to average speed)
- **Kinetic Intensity**

  (measure of cycle kinetics – unit derived from speed and acceleration to define how much *stop and go* is in the cycle)
- **48 metrics now calculated for each 'batch' of data entered into tool**
- **functionality added to 'split' data files into individual days or periods based on user input (allows users to log with GPS loggers for longer than 1 day between collection)**

Figure 2

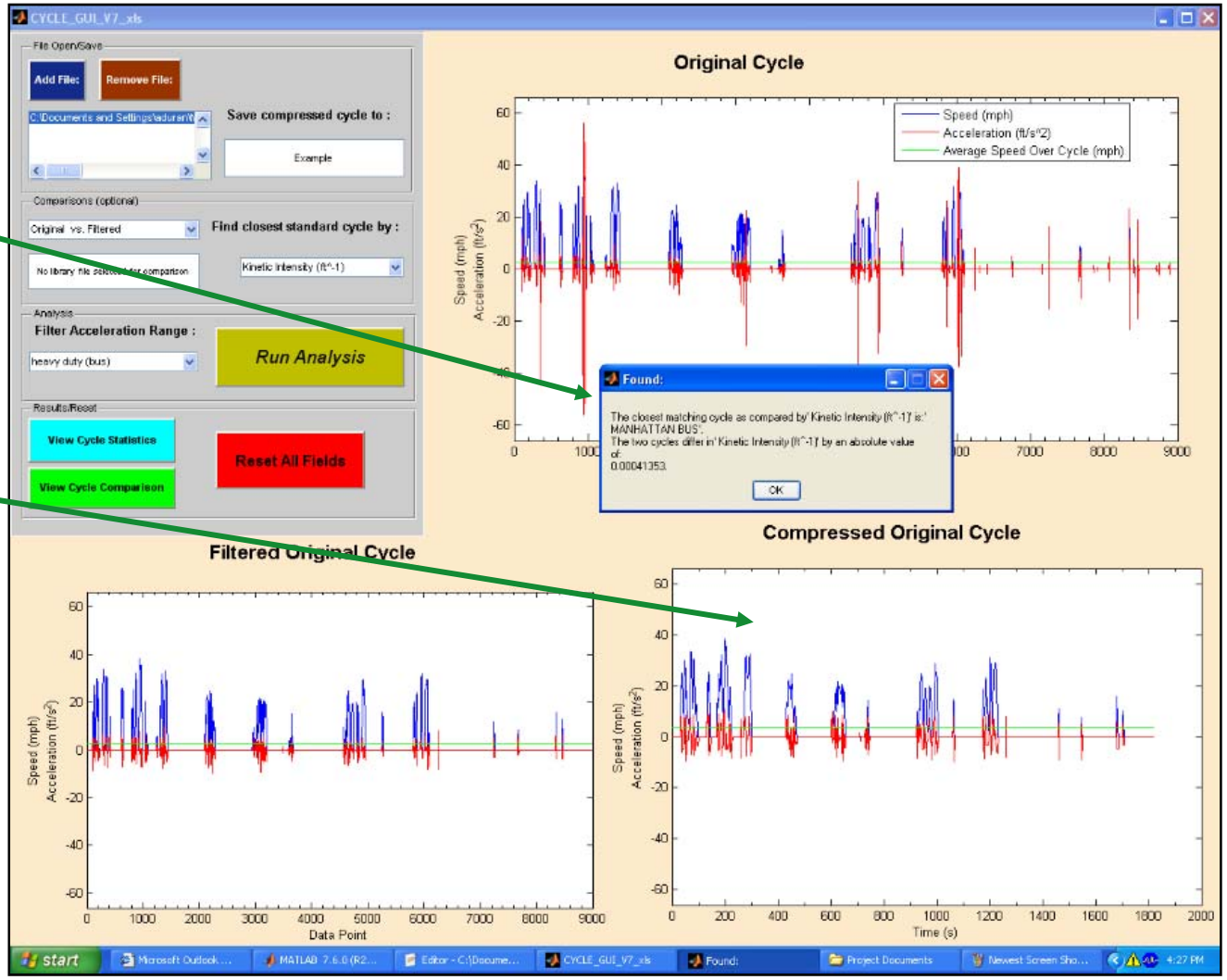
File Edit View Insert Tools Desktop Window Help

Cycle Statistics	Original	Filtered Original	Difference from Original	Percent Difference from Original
Cycle Duration (s)	9000	9000	0	0
Distance Traveled (miles)	6.0929	6.2279	0.1349	2.2144
Average Speed Over Cycle (mph)	2.4372	2.4911	0.0540	2.2144
Average Driving Speed (mph)	13.5650	14.2896	0.7246	5.3415
Maximum Speed (mph)	38.3000	38.3000	0	0
Time at Idle (s)	7383	7431	48	0.0065
Idle Time (%)	82.0333	82.5667	0.5333	0.6501
0-5 mph time (%)	86.7889	86.3889	-0.4000	-0.4609
5-10 mph time (%)	2.9111	3.0444	0.1333	4.5802
10-15 mph time (%)	2.5889	2.6889	0.1000	3.8627
15-20 mph time (%)	2.8556	2.9222	0.0667	2.3346
20-25 mph time (%)	2.1889	2.2333	0.0444	2.0305
25-30 mph time (%)	1.6222	1.6444	0.0222	1.3699
30-35 mph time (%)	0.9444	0.9667	0.0222	2.3529
35-40 mph time (%)	0.1000	0.1111	0.0111	11.1111
40-45 mph time (%)	0	0	0	NaN
45-50 mph time (%)	0	0	0	NaN
50-55 mph time (%)	0	0	0	NaN
55-60 mph time (%)	0	0	0	NaN
60-65 mph time (%)	0	0	0	NaN
65-70 mph time (%)	0	0	0	NaN
70+ mph time (%)	0	0	0	NaN
Total Percentage	100.0000	100	-2.8422e-14	-2.8422e-14
Maximum Acceleration (ft/s^2)	56.1733	9.5333	-46.6400	-83.0287
Maximum Deceleration (ft/s^2)	-56.1733	-9.8267	46.3467	-82.5065
Acceleration (% of total cycle)	9.8111	9.2333	-0.5778	-5.8890
Deceleration (% of total cycle)	7.9778	7.6556	-0.3222	-4.0390
Average Acceleration (ft/s^2)	2.3203	1.9012	-0.4191	-18.0610
Average Deceleration (ft/s^2)	-2.8535	-2.2930	0.5604	24.1542
# of acceleration events	178	136	-42	-23.5955
# of acceleration events per mile	29.2141	21.8373	-7.3768	-25.2508
# of deceleration events	184	135	-49	-26.6304
# of deceleration events per mile	30.1989	21.6768	-8.5221	-28.2200
# of stops	94	47	-47	-50
Average Stop Duration (s)	78.5426	158.1064	79.5638	101.3003
# of stops per mile	15.4277	7.5467	-7.8810	-51.0832
max acceleration duration (s)	28	28	0	0
max acceleration duration (% of tot...	3.1710	3.3694	0.1984	6.2575
max deceleration duration (s)	20	20	0	0
max deceleration duration (% of tot...	2.2650	2.4067	0.1417	6.2575
max stop duration (s)	893	992	99	11.0862
max stop duration (% of total cycle)	9.9222	11.0222	1.1000	11.0862
# of stops less than 30 seconds	64	22	-42	-65.6250
# of stops between 30 and 60 sec...	7	9	2	28.5714
# of stops greater than sixty secon...	23	16	-7	-30.4348
Characteristic Acceleration (ft/s^2)	1.0733	0.8363	-0.2369	-22.0765
Aerodynamic Speed (ft/s)	0.0061	0.0061	4.3774e-05	0.7204
Kinetic Intensity (ft^-1)	0.0010	8.0101e-04	-2.4180e-04	-23.1872

Accomplishments, Progress and Results - Milestone #4: Duty Cycle Tool

Enhanced 'Closest Cycle' Selection & Refined Cycle 'Compression':

- Features added to allow user to determine what 'standard cycle' is closest to input data based on user defined metric
- Continued work to create a statistical 'match' of original data set to a 30 min version



Accomplishments, Progress and Results - Milestone #4: Duty Cycle Tool

Future Work

Remainder of FY09 / begin FY10:

- Completion of 'compression' function – add features to enhance ability of tool to compress data characteristics from large to small file

- Validation plan to be developed and implemented
  - •Need to confirm it compresses data properly and accurately
  - •Plan will include comparing output of this tool to output of other known 'in-depth' studies
  - •Validation plan will be documented and verified

- Convert tool to be 'web accessible'
  - •a web based interface will need to be developed to pass data back and forth to user
  - •Method of automated processing and quality checks needs to be developed

- Determine a way to 'ask permission' to catalog and keep duty cycles which have been submitted for analysis
  - •Will require additional information from user to be useful
  - •Will require some type of legal agreement / disclaimer

Future Work – Other New Projects

1. Initiate ‘generational’ study of BAE Hybrid Transit buses with A123 Lithium Battery Packs compared to current lead acid packs – in process
   - Obtain additional battery data for battery life analysis
   - Look at improved calibration and possible fuel economy improvements
   - Look at economics of lead acid versus lithium ion packs based on data from Study

2. Initiate Class 8 Truck HEV Fleet Study
   - Looks at largest fuel usage class
   - Investigates propulsion and possible cab thermal control technologies
   - New application with possible good payback

Summary

- **HD field evaluations directly support the goals of EERE's Vehicle Technologies 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 a fleet 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 with more detail to ensure the right technology is deployed on the right application

- **New Tools and Methods** being developed for researchers as well as industry as part of this project