National Renewable Energy Laboratory
Innovation for Our Energy Future

Medium and Heavy-Duty Vehicle Field Evaluations

2010 DOE Merit Review

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Project ID: VSS001 (Walkowicz)

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Overview

Budget

Total Project Funding:

- FY09 DOE funding: $300k
- FY10 DOE funding: $800k
- Past Years Funding:

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

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

Timing:

- Varies by project
- 12-18 months per project
- Some ‘in-process’, some ‘new’

Barriers to Overcome

- Lack of Unbiased Data : Users and OEMs need unbiased, 3rd party evaluation and better understanding of state-of-the-art technology performance to improve and 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:
  - Veh Mfg’s (New Flyer, Freightliner, Workhorse, International, Orion)
  - System Mfgs (Allison Transmission, Eaton, Enova, Azure, Cummins, International, Caterpillar)
  - Fleets (UPS, Fed Ex, Coke, NYC Transit)
- Current Partners in FY10:
  - Fed Ex, UPS, Coke, Enova, Eaton, Navistar Corporation

Relevance

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.
- Supports the VTP Programs Strategic Goal of: *Support the laboratory and field evaluations of large-scale demonstration fleets of advanced commercial and passenger PHEVs and EVs.*

Specific Technical Objectives in FY10:

- Evaluate in-use operation of Eaton's Gen II lithium battery, parallel hybrid delivery trucks in the UPS fleet
- Evaluate in-use operation of Azure's gasoline hybrid electric delivery trucks in the FedEx fleet
- Evaluate in-use operation of Eaton's Gen II lithium battery, parallel hybrid class 8 delivery trucks in Coca-Cola's fleet
- Evaluate in-use operation of BAE/A123 lithium battery packs in operation in transit fleets
- Evaluate PHEV School Bus developed by Navistar Corporation

Current Milestones

1 - Draft interim report on UPS Gen II HEV evaluation project – Sept. 2010:
Compile, analyze and prepare report on results to date of 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. New Start in FY10.

2 – Draft Final report on FedEx HEV evaluation project – Sept. 2010: Compile, analyze and prepare final 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.

3 - Draft interim report on Coca Cola HEV evaluation project – Sept. 2010:
Compile, analyze and prepare report on results to date of 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.

4 - Draft interim progress report on PHEV school bus testing – Sept. 2010:
Provide interim results of testing and analysis of Navistar PHEV school bus evaluation (route analysis)

5 - Draft interim progress report on BAE/A123 battery evaluations– Sept. 2010:
Provide interim results of testing and analysis of BAE/A123 systems as tested at transit fleets

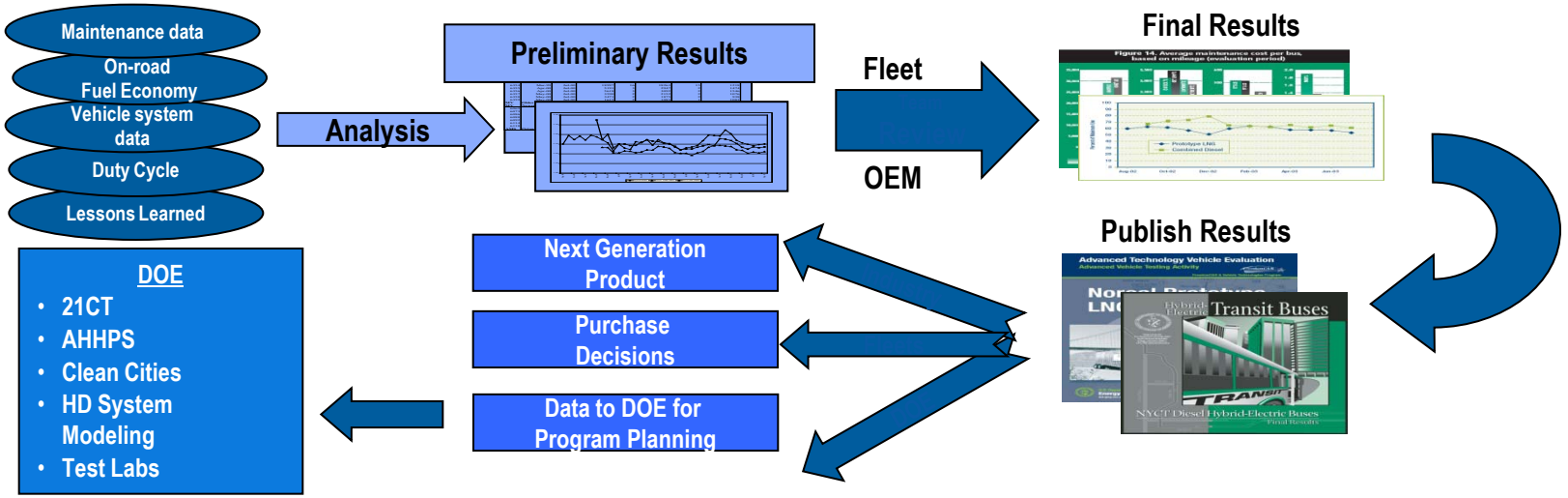
Approach

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.



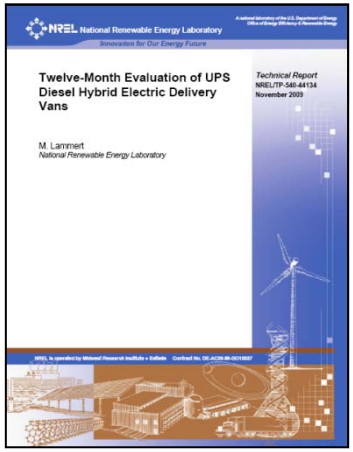
Accomplishments, Progress and Results - Milestone #1: UPS

1. New 'Gen II Evaluation' – 13 vehicle study of latest generation Eaton parallel hybrid system in UPS fleet in Eagan, MN (engine off capability added) – vehicles added to fleet in March 2010
2. Year 2 & 3 Gen I Evaluation in Phoenix – builds on FY09 work, shows durability and costs with year 3.

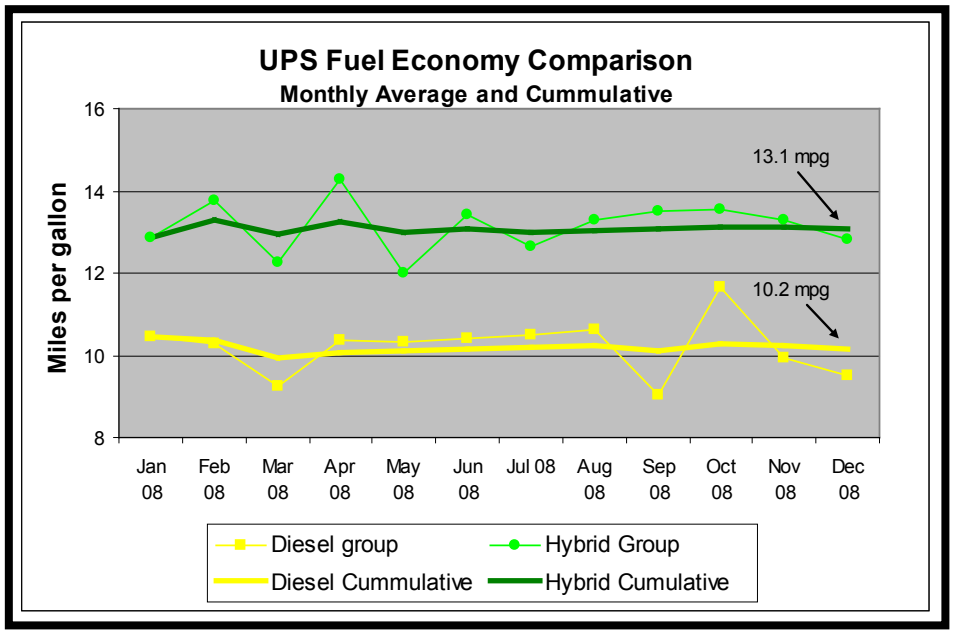
- **Additional data to be gathered on Gen II study:**
  1. Fuel economy and maintenance records from fleet
  2. ECU/CAN download
     - Miles Traveled
     - Fuel Consumed
     - Percent Idle Time
     - DPF Regenerations
  3. GPS route data logging
  4. On-board instrumentation - DPF analysis, mpg verification, system analysis, battery data
  5. Chassis dyno (ReFUEL) testing

Accomplishments, Progress and Results - Milestone #1: UPS

1st Generation Year 1 Study Results (Dec. 2009 Report):

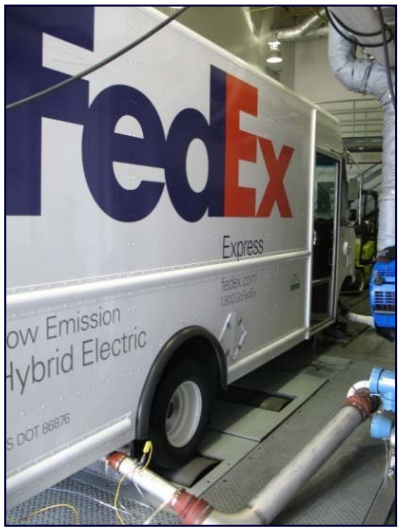


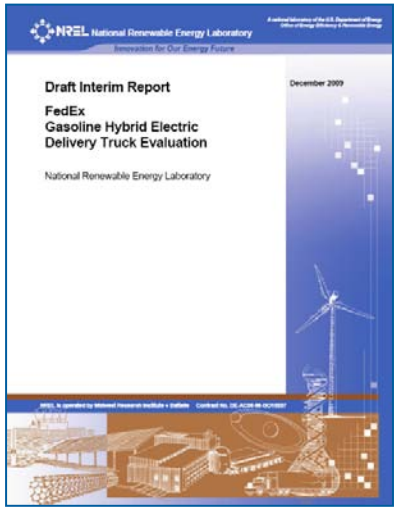
- 29% on-road fuel economy improvement for hybrids over 12 month period
- 31-37% improvement in-lab (CILCC/CBD/WVU City)
- Diesel = $0.53 per mile operating costs
- Hybrid = $0.43 per mile operating costs
- Anticipating improvements with Gen II system



Accomplishments, Progress and Results - Milestone #2: Fed Ex HEV

- Azure HEV Delivery Vehicles @ Fed Ex
  - **Timing:** Dyno testing and on-road evaluation - April 2009 thru April 2010
  - **Technology:** Azure Gen I gasoline HEV in Southern CA vs conventional diesels
  - **Data:** Final report April 2010; Includes on-road, chassis dyno data, Drive Cycle data
  - **Results:** Chassis Dyno
    - MPG: -2 to +20 % improvement in MPG (dge) (gasoline engine vs diesel)
    - Emission Reductions:
      - Much cleaner!
      - NOx = 75-89%
      - PM = 99.9%
  - **Results:** On-Road (MPG dge)
    - 7.77 mpg diesel, 8.15 HEV
    - Group avg = between NYCC / OCTA

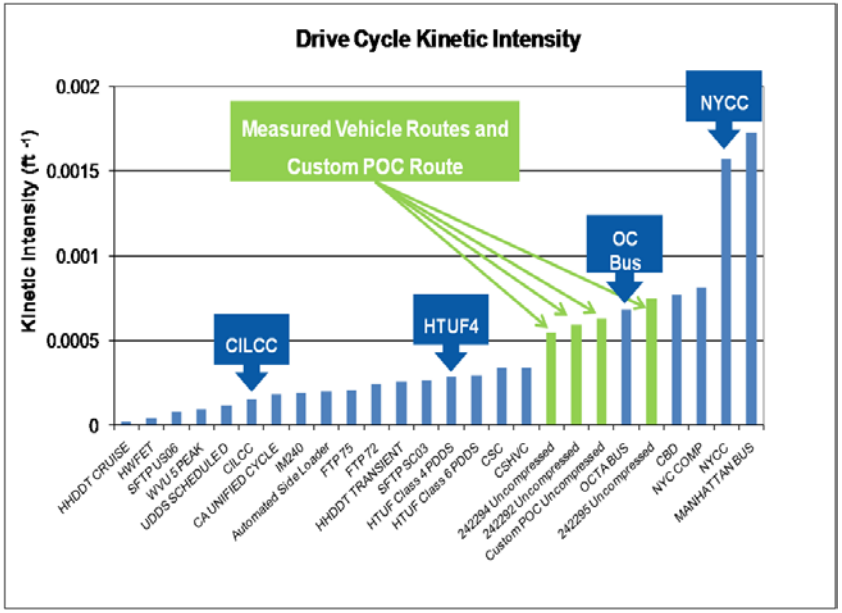




Accomplishments, Progress and Results - Milestone #2: Fed Ex HEV

- Results: Drive Cycle Analyzed for Depot

Drive Cycle Characteristic	Vehicle #			
	242292	242293	242294	242295
Average Driving Speed (mph)	16.8	17.3	16.9	16.2
Daily VMT (miles)	43.8	25.4	47.2	21.3
Stops per Mile	3.86	5.42	3.80	4.24
Avg. Acceleration (ft/s^2)	2.27	3.63	2.11	2.10
Avg. Deceleration (ft/s^2)	-2.61	-3.36	-2.58	-2.56
Accelerations per Mile	20.90	27.26	20.88	23.08
Decelerations per Mile	20.36	27.72	19.83	22.81
Kinetic Intensity $(ft^{-1})^1$	0.00059	0.00101	0.00055	0.00075



Accomplishments, Progress and Results - Milestone #2: Fed Ex HEV

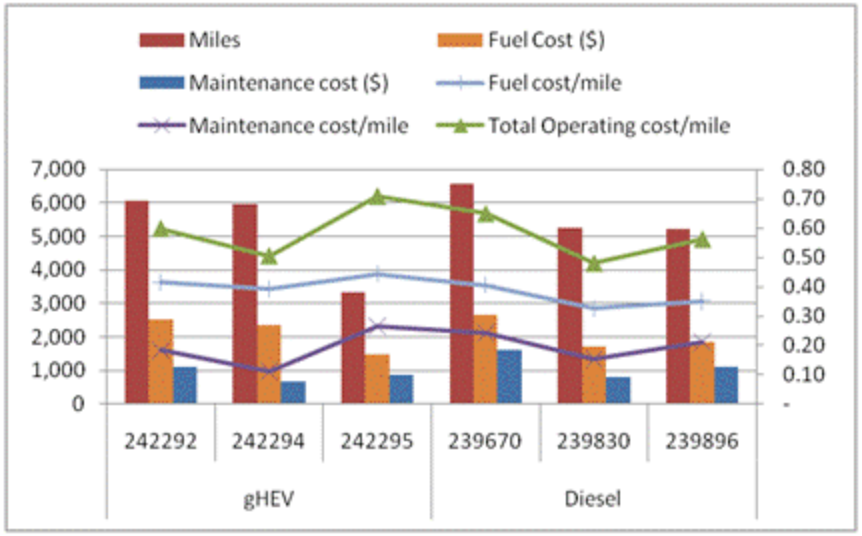
- Results: Fuel economy measured against actual observed drive cycles

Increasing KI ↓

Drive Cycle	gHEV FE (mpg)	gHEV Diesel Equivalent FE (mpg)	Diesel FE (mpg)	Energy Content Adj GHEV Advantage
HTUF4	10.45	11.36	11.66	-2.6%
OCTA Bus	8.61	9.36	9.52	-1.7%
NYCC	6.75	7.34	6.08	+20.7%

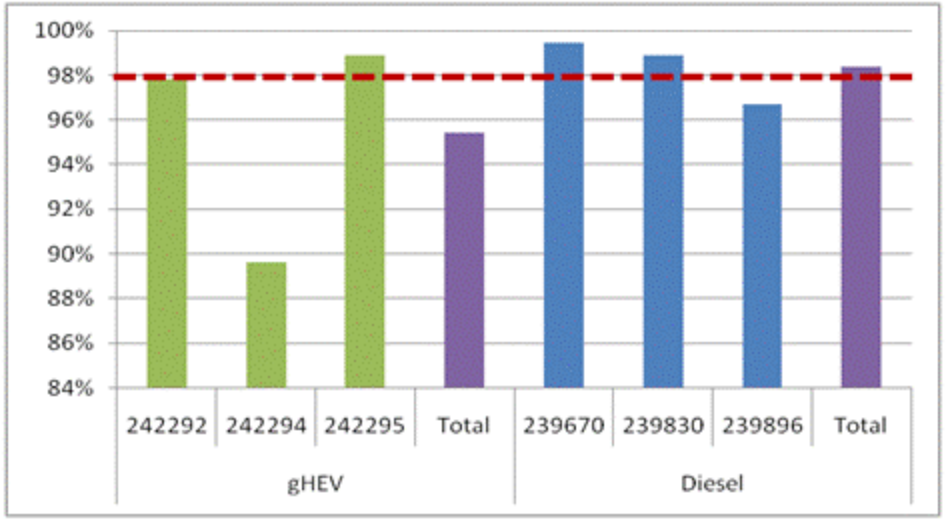
Accomplishments, Progress and Results - Milestone #2: Fed Ex HEV

- Results: On-Road Results



$0.59/mile (hybrids–vs-
$0.57/mile (diesels)

downtime was not affected by hybrid system!



Accomplishments, Progress and Results - Milestone #3: Coca Cola

Project Background:
New FY10 start - 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.

- **Data to be gathered on 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

Details:

- Atlanta fleet May 2010 start
- Five 2009 / 2010 hybrid tractors (2007 emissions) -vs- Four 2007 conventional tractors
- Coca-Cola will provide tractors for ReFUEL testing from their Denver depot in May/June

Accomplishments, Progress and Results - Milestone #4: PHEV School Bus

- **Supporting Navistar's Development of their 'Next Gen' PHEV School Bus**
- **Phase 1 (Vehicle Development) support (FY10):**
  - Duty cycle collection and analysis for correct selection of test cycles for development and validation
  - Collecting large quantities of data from various fleets around the country (Austin, Denver, NC) with more in process to aide in the selection and creation of proper test and development cycles for school buses

447 Operational Days Thus Far
105 Unique Vehicles
0-65, 65-71, and 71+ Passenger Capacity vehicle groups

Metric	Aggregate Data Average	Aggregate Data Standard Deviation
Distance Traveled (miles)	54.73	22.15130143
Average Driving Speed (mph)	25.56	3.928757439
Zero mph time (%)	47.72	12.91442967
# of stops per mile	1.17	0.463897813
Characteristic Acceleration (m/s^2)	0.21	0.029151419
Kinetic Intensity (km^-1)	0.83	0.490694993

Accomplishments, Progress and Results - Milestone #4: PHEV School Bus

Average Driving Speed of 25.56 mph

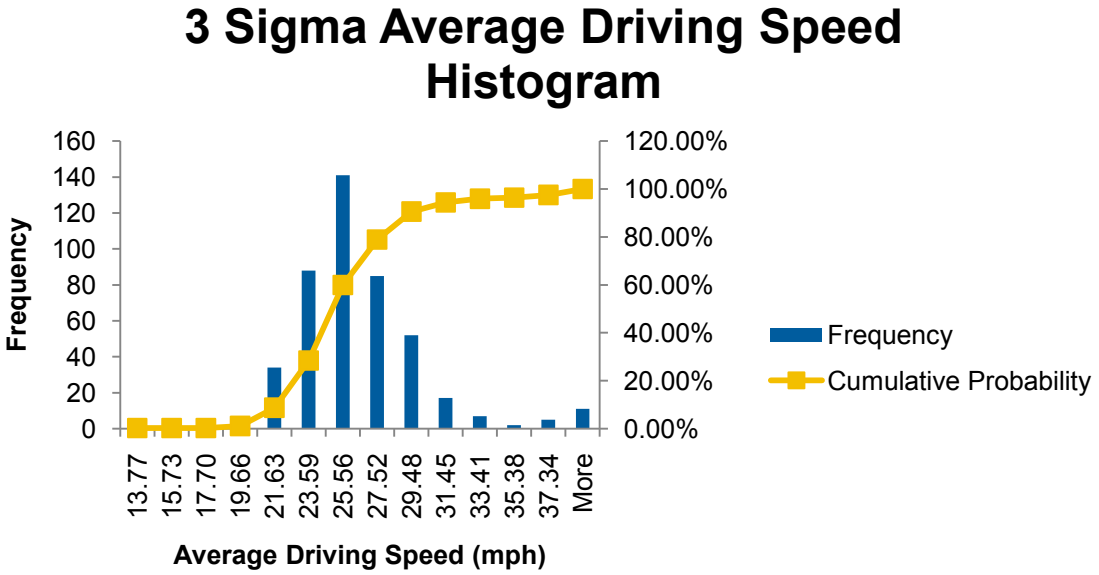
Standard Deviation of 3.93 mph

- Based on the standard deviation and assuming a normal distribution, expect 99.8% of buses to fall within an operating range of 13.77 - 37.34 mph

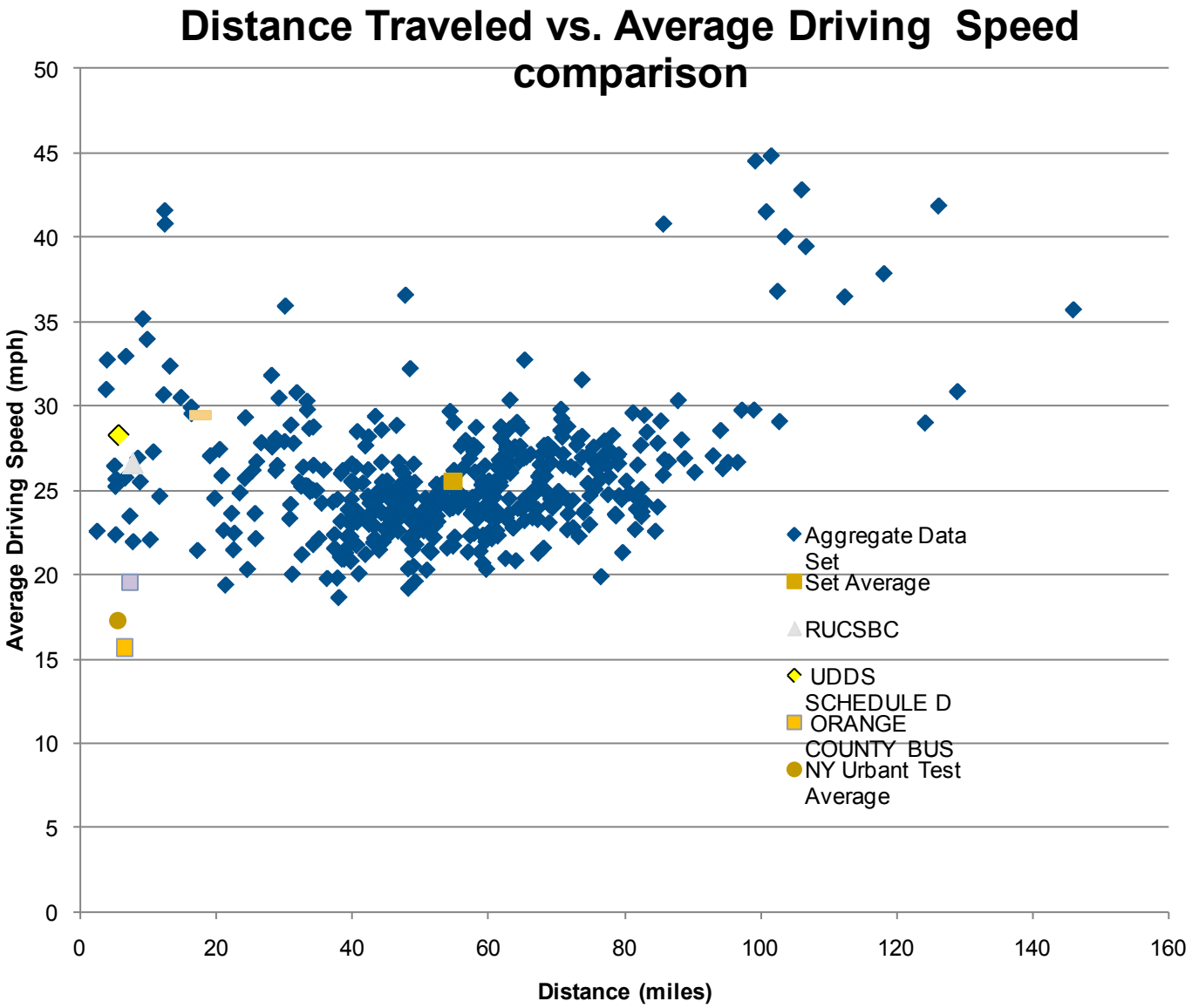
Fairly Normal Distribution, with a slight skewing to the right

- Buses trended slightly towards operating at above the group average

Bin	Frequency	Cumulative %
13.77	1	0.22%
15.73	0	0.22%
17.70	0	0.22%
19.66	4	1.12%
21.63	34	8.72%
23.59	88	28.41%
25.56	141	59.96%
27.52	85	78.97%
29.48	52	90.60%
31.45	17	94.41%
33.41	7	95.97%
35.38	2	96.42%
37.34	5	97.54%
More	11	100.00%



Accomplishments, Progress and Results - Milestone #4: PHEV School Bus



Looking at set – vs- specific drive cycle data

Accomplishments, Progress and Results - Milestone #5: BAE / A123 Eval

- **Evaluation / data collection for Lithium Packs (FY10 AOP)**
  - **Coordinate with '3rd Generation' BAE HEV's in NYCT & Houston to look at in-use operation vs lead acid and diesels – fuel economy vs routes, reliability of propulsion system, operational costs, life estimate of batteries derived from focused battery testing:**
    - **Battery Data Collection:**
      - **Degradation analysis of in-use pack on various duty cycles**
      - **Coordinated Laboratory Testing**
      - **Coordinated effort with DOE battery program for degradation study**
      - **Provide data for creation of lithium battery life estimation approach in FY11**
    - **12 month study to wrap up in FY2011**
      - **40-50 lithium battery buses now in service with BAE system**
      - **2 fleets / locations**

A123 SYSTEMS

BAE SYSTEMS

Status:
Implementing NDA and CRADA with both parties for data collection

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 is evaluated. Project Partners in FY09 and FY10 include:
  - BAE
  - A123
  - Fed Ex
  - UPS
  - Eaton
  - Advanced Energy
  - Coke
  - Navistar
  - Azure
  - Enova
  - NYCT

- **Projects are coordinated with others (data sharing or collaboration):** Data from evaluations are shared with other interested institutions.
  - South Coast AQMD
  - Argonne National Lab
  - CALSTART
  - Oshkosh Truck
  - NAC/TARDEC
  - Boeing
  - AMGeneral
  - 21st Century Truck

Proposed Future Activities

<u>FY2011 Activities Proposed</u>: 6 areas of 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 – multiple sites

2. **Near Term Technology Validation:** Short term, focused testing of new technology to provide most critical data for assessment of performance (hydraulics, PHEV, electric accessories)

3. **Fleet Energy Audit:** Application specific data collected; analysis of options for fleets to better understand options for saving fuel

4. **Data Collection and Reporting:** ~1700 MD EV and PHEV vehicles to be on the road starting in FY11. Access data and look at overall trends of electric drives in MD applications

5. **On-Line Voluntary Drive Cycle Data:** Industry user groups formed by vocation to assemble and analyze large data sets of drive cycle data – national perspective

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

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 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 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

Acknowledgements and Contacts

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