Medium and Heavy-Duty Vehicle Field Evaluations - Line Haul Truck Platooning

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NREL – part of DOE’s Network of National Labs

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NREL – Scope of EERE Mission

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<th>Energy Productivity</th>
<th>Renewable Electricity</th>
<th>Systems Integration</th>
<th>Partners</th>
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<td>Residential Buildings</td>
<td>Solar</td>
<td>Grid Integration of Clean Energy</td>
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<td>Hydrogen</td>
<td>Commercial Buildings</td>
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<td>Biofuels</td>
<td>Water: Marine Hydrokinetics</td>
<td>Water: Marine Hydrokinetics</td>
<td>Batteries and Thermal Storage</td>
<td>State/Local Government</td>
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<td>Energy Analysis</td>
<td>International</td>
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NREL Transportation RD&D Activities & Applications

Vehicle Thermal Management
- Integrated Thermal Management
- Climate Control/Idle Reduction
- Advanced HVAC

Vehicle Deployment/Clean Cities
- Guidance & Information for Fleet Decision
- Makers & Policy Makers
- Technical Assistance
- Online Data, Tools, Analysis

Regulatory Support
- EPAct Compliance
- Data & Policy Analysis
- Technical Integration
- Fleet Assistance

Infrastructure
- Vehicle-to-Grid Integration
- Integration with Renewables
- Charging Equipment & Controls
- Fueling Stations & Equipment
- Roadway Electrification
- Automation

Advanced Combustion/Fuels
- Advanced Petroleum and Biofuels
- Combustion/Emissions Measurements
- Vehicle & Engine Testing

Vehicle and Fleet Testing
- MD/HD Dynamometer Testing
- MDV & HDV Testing/Analysis
- Drive Cycle Analysis/Field Evaluations
- Technology Performance Comparisons
- Data Collection, Storage, & Analysis
- Analysis & Optimization Tools

Advanced Power Electronics and Electric Motors
- Thermal Management
- Thermal Stress and Reliability

Advanced Energy Storage
- Development, Testing, Analysis
- Thermal Characterization/Management
- Life/Abuse Testing/Modeling
- Computer-Aided Engineering
- Electrode Material Development
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 10 million miles of advanced technology MD and HD truck data have been collected, documented, and analyzed on over 600 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
Medium- and Heavy- Vehicle 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

Vehicle & Equip Mfg’s

Useful Data, Analysis and Published Reports
## Current Heavy Vehicle Evaluation Projects

<table>
<thead>
<tr>
<th>Current DOE Projects</th>
<th>EV Fleet Data Collection Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPS HHV Solazyme biofuel</td>
<td>Miami HHV Refuse Trucks</td>
</tr>
<tr>
<td>Frito Lay EV</td>
<td>Natural Gas Refuse Trucks</td>
</tr>
<tr>
<td>Fleet Platooning</td>
<td>Battery EV Transit Bus</td>
</tr>
<tr>
<td>PG&amp;E Electrified Utility Trucks</td>
<td>EV – V2G School Bus</td>
</tr>
<tr>
<td>SCAQMD</td>
<td>CA Air Resources Board (CARB)</td>
</tr>
<tr>
<td>• Fleet DNA</td>
<td>• Heavy Hybrid Vehicle Analysis</td>
</tr>
<tr>
<td>• Zero Emissions Cargo Transport</td>
<td>• Aerodynamics Device Testing</td>
</tr>
<tr>
<td></td>
<td>EPA</td>
</tr>
<tr>
<td></td>
<td>Heavy-Duty Phase II GHG Drive</td>
</tr>
<tr>
<td></td>
<td>Cycle Development</td>
</tr>
</tbody>
</table>
Fleet DNA

Objectives:

• Capture and quantify drive cycle and technology variation for the multitude of **medium- and heavy-duty** vocations

• Provide a common data storage warehouse for medium- and heavy-duty vehicle data across DOE activities and labs – [www.nrel.gov/fleetdna](http://www.nrel.gov/fleetdna)

• Integrate existing DOE tools, models, and analyses to provide data driven decision making capabilities

For Government: Provide in-use data for standard drive cycle development, R&D, tech targets, and rule making

For OEMs: Real-world usage datasets provide concrete examples of customer use profiles

For Fleets: Vocational datasets help illustrate how to maximize return on technology investments

For Funding Agencies: Reveal ways to optimize impact of financial incentive offers

For Researchers: Provides a data source for modeling and simulation

[www.nrel.gov/fleetdna](http://www.nrel.gov/fleetdna)
Secure Storage Paired with Expert Analysis and Validation

Alternative Fuels Data Center (AFDC)
*Public clearinghouse of information on the full range of advanced vehicles and fuels*

National Fuel Cell Technology Evaluation Center (NFCTEC)
*Industry data and reports on hydrogen fuel cell technology status, progress, and challenges*

Transportation Secure Data Center (TSDC)
*Detailed light-duty fleet data, including GPS travel profiles*

Fleet DNA Database
*Medium- and heavy-duty drive-cycle, fueling, and powertrain data from advanced commercial fleets*

<table>
<thead>
<tr>
<th>Features</th>
<th>AFDC</th>
<th>NFCTEC</th>
<th>TSDC</th>
<th>Fleet DNA</th>
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<tbody>
<tr>
<td>Securely Archived Sensitive Data</td>
<td></td>
<td>Y</td>
<td>Y</td>
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</tr>
<tr>
<td>Publicly Available Cleansed Composite Data</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Quality Control Processing</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Spatial Mapping/GIS Analysis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Custom Reports</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
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<tr>
<td>Controlled Access via Application Process</td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Detailed GPS Drive-Cycle Analysis</td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
# Fleet DNA – Data Fusion

<table>
<thead>
<tr>
<th>Geography and Infrastructure</th>
<th>Vehicle Data</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOHS US Infrastructure</td>
<td>CAN</td>
<td>RL Polk</td>
</tr>
<tr>
<td>Navteq Road Layer</td>
<td>GPS</td>
<td>US Census</td>
</tr>
<tr>
<td>Tom Tom Road Network</td>
<td>Standard Cycles</td>
<td>EPA Moves</td>
</tr>
<tr>
<td>Tom Tom Road Grade</td>
<td>Dyno Results</td>
<td>EMFAC</td>
</tr>
<tr>
<td>National Elevation Dataset</td>
<td></td>
<td>TEDB</td>
</tr>
</tbody>
</table>

![Elevation / Grade](image1)

![CAN Data](image2)

![EPA MOVES](image3)

![Vehicle Registrations](image4)

![GPS Drive Cycles](image5)

![Digital Street Maps](image6)
National Road Grade Characterization

US Highway Network

Highway Road Grade Data

Activity Data

National Road Grade Stats
Approach: Field Data & 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
Explore & Optimize
Communicate & Inform

Identify Barriers, New R&D Opportunities, Validate Efforts

Partnership with Fleets and Technology Providers = Relevant Results & Optimized Solutions for Real World Applications
Line-Haul Truck “Semi-Autonomous” Platooning Evaluation

- Conduct repeatable track testing to assess fuel savings potential from semi-automated truck platooning
  - Supported by DOE’s Vehicle Technologies Office
- Demonstration system provided by Peloton Technology
- Test US-style line haul sleeper cabs with modern aerodynamics
  - EPA SmartWay tractors; trailers with side skirts
- Tested range of following distances, vehicle loading and speeds common in the U.S. (up to 70 mph)
Platooning System Evaluation – Test Details

- SAE J1321 Type II Fuel Consumption Test Procedure
- Ten constant speed tests and one variable speed test
- Each test 60 miles (7 laps)
- Range of gaps between lead/trailing vehicle: 20-75 ft vehicle gaps
- Gravimetric fuel measurements with weigh tanks
- J1939 data collection including coolant temperature and fan state

<table>
<thead>
<tr>
<th>Trailing Distance</th>
<th>55 mph, 65,000 lb</th>
<th>65 mph, 65,000 lb</th>
<th>70 mph, 65,000 lb</th>
<th>Variable Speed, 65,000 lb</th>
<th>65 mph, 80,000 lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 ft</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 ft</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 ft</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>75 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Summary Results

- Team fuel savings ranged from 3.7% to 6.4%
- Closer following distances (<40 ft) caused the engine fan on the trailing truck to engage, negatively impacting fuel savings

**Class 8 - Two Truck Platooning**

**Fuel Savings at 65 mph 65,000 lb**

- **Lead Truck**
- **Trail Truck**
- **Platoon "Team"**

Not Statistically Significant
Summary of Key Findings

- Significant line-haul fuel savings possible through platooning
  - Tests showed fuel savings for the lead (up to 5.3%) and trailing (up to 9.7%) trucks
  - The demonstrated “team” savings of 6.4% could be an attractive return on investment for a fleet
- Engine coolant temperature needs to be monitored/addressed for the trailing vehicle
  - Optimum following distance may depend on ambient temperature and vehicle load (absent some aerodynamic aid for radiator air flow)
- Heavy payloads affect the percent improvement from platooning, but still result in substantial fuel savings

Published Results:


http://www.nrel.gov/docs/fy15osti/62348.pdf
Follow-on Work

- Computational Fluid Dynamics & Wind Tunnel testing at Lawrence Livermore (LLNL) to better understand & optimize the platooning operational envelope and aerodynamic design.
- Analysis of in-use fleet operational/logistics data to evaluate “Big Picture” fuel savings potential at fleet and national levels.
- Follow-on track testing to confirm CFD and Wind-tunnel findings.
- Partnership with fleet and technology provider to evaluate technology under real world conditions.

Images courtesy of LLNL
Thank You!

Questions/Discussion

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Vehicle Selection
- Typically 10-20 vehicles
- Representative of typical fleet operations
- Conventional and technology of interest (if available)

Data Collection
1. Pre-installed telemetric and CAN devices
2. Data Loggers

Vehicle Specifications

<table>
<thead>
<tr>
<th>Engine parameters:</th>
<th>Chassis parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Weight class</td>
</tr>
<tr>
<td>Model</td>
<td>Body type</td>
</tr>
<tr>
<td>Cert Year</td>
<td>Transmission type</td>
</tr>
<tr>
<td>Displacement</td>
<td>GVWR</td>
</tr>
<tr>
<td>Rated power/max torque</td>
<td>Vocation</td>
</tr>
<tr>
<td>Tire size in rev/mile</td>
<td>Final gear ratio, Rear Axle ratio</td>
</tr>
<tr>
<td>Total number of gears &amp; gearing ratios</td>
<td></td>
</tr>
</tbody>
</table>
Contributing Data to Fleet DNA

Minimum Data
• 1 Hz telemetric data
• GPS location, vehicle speed, date & time, engine status, power take-off status

Expanded Data – J1939 CAN Channels
• Wheel based vehicle speed (SAE SPN 84)
• Instantaneous fuel rate (SAE SPN 183)
• PTO status (SAE SPN 976)
• Current gear (SAE SPN 523)
• Referenced engine torque (SAE SPN 544)
• Engine rated speed (SAE SPN 189)
• Engine Speed (SAE SPN 190)
• Engine Speed at Idle (SAE SPN 188)
• Actual engine percent torque (SAE SPN 513)
• Aftertreatment Outlet NOx (SAE SPN 322)
• Aftertreatment Inlet NOx (SAE SPN 322)

Data Reporting
User-Specific Reports

www.nrel.gov/fleetdna
Technical Accomplishments: Miami-Dade Hydraulic Hybrid 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** – 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

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<th>FY15 Accomplishment Highlights</th>
<th>FY15/FY16 Plan Forward</th>
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<tr>
<td>Kick-off meeting held with Miami-Dade – January 2015</td>
<td>Log data from 10-12 Gen 2 vehicles when deployed (underway)</td>
</tr>
<tr>
<td>Draft start-up fact sheet completed</td>
<td>Collect fuel and maintenance data from fleet – baseline, HHV-Gen 1 and Gen 2</td>
</tr>
<tr>
<td>Fleet agreed to provide electronic maintenance and refueling and other operational data</td>
<td>Calculate total cost of ownership including reliability and maintenance on all projects</td>
</tr>
<tr>
<td>Parker NDA completed for vehicle-specific technical data</td>
<td>Perform analysis to show optimal placement of new technology (i.e. Route vs benefit)</td>
</tr>
<tr>
<td>Initial duty-cycle data collected on Gen 1 HHV’s and conventional Diesels: 2/25/2015 - 3/25/2015</td>
<td>Chassis dynamometer tests of HHV and baseline for controlled fuel economy and emissions using representative and standard drive cycles</td>
</tr>
<tr>
<td>Gen 2 duty cycle data currently being collected</td>
<td>Final Technical Report FY16</td>
</tr>
</tbody>
</table>

**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 evaluated by independent 3rd party
**Initial Duty-Cycle Data from Miami HHVs**

**HHV Technology Basics**

The Miami-Dade test vehicles are Autocar E3 refuse trucks equipped with Parker Hannifin’s RunWise hydraulic hybrid drive, the HHVs are reported to recover as much as 70% of the energy typically lost during braking and reuse it to power the vehicle. The system features a two-speed hydrostatic drive combined with a mechanical direct drive, which optimizes vehicle performance at both low and high speeds.

**Covanta Waste-to-Energy plant**

Refuse haulers deliver load from residential pickup to Covanta 77 mega-watt WTE plant. Traces in the above image are from actual GPS on data collected by NREL.

**Initial Duty cycle data**

Images above show initial GPS route data collected from Miami fleet. GPS data is used to develop duty-cycle statistics and used in vehicle models. Data collected also include vehicle and engine operating parameters – including vehicle speed, fuel rate, engine speed/torque, NOx sensor, etc.
Miami-Dade County currently operates 35 Gen 1 hydraulic hybrid system

Additional 29 Gen 2 HHVs deployed starting in August 2105 – Gen 2 HHVs are now in service with 3000-4000 miles accumulated

Miami-Dade will provide operational data on Gen 1 & Gen 2 HHVs and conventional

Preliminary data shown from 8 Gen 1 HHVs and diesel baseline
Initial Comparison w/ Baltimore UPS MY13 HHV’s

Kinetic Intensity vs Avg MPG

- Broader range of FE for Parcel Delivery
Comparison w/ Baltimore UPS MY13 HHV’s

Kinetic Intensity vs Stops per Day

- Refuse vehicles stop many more times per day