Fuel and Emissions Reduction in Electric Power Take-Off Equipped Utility Vehicles

Arnaud Konan, Adam Ragatz, Robert Prohaska, Adam Duran, Kenneth Kelly

Presented by: Arnaud Konan, NREL

Electric Vehicle Symposium & Exhibition (EVS29)
Montréal, Québec, Canada

June 22, 2016
NREL/PR-5400-66737

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Electric Vehicle Symposium & Exhibition

June 19-22, 2016 | du 19 au 22 juin 2016

Montréal, Québec, Canada
National Renewable Energy Laboratory is one of 17 U.S. Department of Energy national labs. It is operated by the Alliance for Sustainable Energy, LLC, in Golden, Colorado.
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

Vehicle Systems Modeling and Simulation
- Connected and Automated Vehicles
- Vehicle Systems Analysis

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

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

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

Vehicle Systems Modeling
- Connected and Automated Vehicles
- Vehicle Systems Analysis

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

Vehicle Systems Modeling
- Connected and Automated Vehicles
- Vehicle Systems Analysis

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

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
Provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

- **Third-party unbiased data**: Provides data that would not normally be shared by industry in an aggregated and detailed manner.

- More than 9.5 million miles of advanced technology MD and HD truck data have been collected, documented, and analyzed on more than 1,577 different vehicles from more than 50 different providers 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
  - Define intelligent usage of newly developed technology
  - Fleets/users understand all aspects of advanced technology.
• The accessibility to an alternative energy source provided by the e-PTO system allows for idle and fuel reduction through running auxiliary loads from the battery.
• Emissions benefits are implied and can be calculated using emissions standards.
• Others benefits are harder to quantify.
PG&E Fleet Test Project

PHEV Utility Truck Study

• Instrumented 20 PG&E Altec utility trucks
  o 10 “Trouble Trucks” AT (5 w/ ePTO / 5 w/o)
  o 10 “Material Handlers” AM (5 JEMS + 5 AM Diesel)

• 8 weeks of data collection at 7 sites

• Collecting data on:
  o Drive cycle/duty cycle
  o J1939 CAN (including fuel use and NOx sensor)
  o Battery charge/discharge power
  o Electric AC
  o Electric hydraulics
  o Electric auxiliaries.
## Fleet Data Collection Locations

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>ePTO OFF</td>
<td>B27959</td>
</tr>
<tr>
<td>1</td>
<td>ePTO ON</td>
<td>B27961</td>
</tr>
<tr>
<td>30</td>
<td>AM Conv</td>
<td>B28082</td>
</tr>
</tbody>
</table>

### Chico

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>ePTO OFF</td>
<td>B27950</td>
</tr>
<tr>
<td>9</td>
<td>ePTO ON</td>
<td>B27956</td>
</tr>
<tr>
<td>11</td>
<td>AM JEMS</td>
<td>B26135</td>
</tr>
</tbody>
</table>

### Auburn

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>AM JEMS</td>
<td>B26152</td>
</tr>
<tr>
<td>15</td>
<td>ePTO ON</td>
<td>B27944</td>
</tr>
</tbody>
</table>

### Concord

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>ePTO OFF</td>
<td>B27946</td>
</tr>
<tr>
<td>26</td>
<td>AM Conv</td>
<td>B26155</td>
</tr>
</tbody>
</table>

### Richmond

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>ePTO OFF</td>
<td>B27958</td>
</tr>
<tr>
<td>5</td>
<td>AM Conv</td>
<td>B26143</td>
</tr>
<tr>
<td>3</td>
<td>AM JEMS</td>
<td>B26140</td>
</tr>
</tbody>
</table>

### Edenvale

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>AM JEMS</td>
<td>B26131</td>
</tr>
</tbody>
</table>

### Salinas

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>ePTO OFF</td>
<td>B27948</td>
</tr>
<tr>
<td>10</td>
<td>ePTO ON</td>
<td>B27954</td>
</tr>
<tr>
<td>25</td>
<td>AM Conv</td>
<td>B28493</td>
</tr>
<tr>
<td>14</td>
<td>ePTO ON</td>
<td>B27953</td>
</tr>
<tr>
<td>17</td>
<td>AM JEMS</td>
<td>B25956</td>
</tr>
<tr>
<td>12</td>
<td>AM Conv</td>
<td>B25959</td>
</tr>
</tbody>
</table>

### Bakersfield

<table>
<thead>
<tr>
<th>Logger</th>
<th>config</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>AM Conv</td>
<td>B28493</td>
</tr>
<tr>
<td>14</td>
<td>ePTO ON</td>
<td>B27953</td>
</tr>
<tr>
<td>17</td>
<td>AM JEMS</td>
<td>B25956</td>
</tr>
<tr>
<td>12</td>
<td>AM Conv</td>
<td>B25959</td>
</tr>
</tbody>
</table>
Altec’s JEMS system (Jobsite Energy Management System), a smart plug-in hybrid system that manages energy use at the jobsite. The hybrid system is designed to power the unit through a typical work day without running the chassis engine.
PG&E – AT- “Trouble Trucks”

Power Electronics
## Specifications of the Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Ford F-550 Altec (AT)</th>
<th>International WorkStar 7500 (AM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVWR</td>
<td>19,500 lbs</td>
<td>56,000 lbs</td>
</tr>
<tr>
<td>Engine</td>
<td>Ford Powerstroke 6.7L</td>
<td>International MaxxForce 7.6L</td>
</tr>
<tr>
<td>Horsepower</td>
<td>300 hp @ 2,800 rpm</td>
<td>300 hp @ 2,200 rpm</td>
</tr>
<tr>
<td>Torque</td>
<td>660lb-ft @ 1600 rpm</td>
<td>860lb-ft @ 1300 rpm</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>8 kWh</td>
<td>18 kWh</td>
</tr>
<tr>
<td>Battery Voltage</td>
<td>~ 12 V</td>
<td>~ 48 V</td>
</tr>
<tr>
<td>Charging Standards</td>
<td>-</td>
<td>SAE J1772</td>
</tr>
<tr>
<td>Transmission</td>
<td>6 speed Auto</td>
<td>Allison 3500 RDS 5-speed</td>
</tr>
<tr>
<td>Drive</td>
<td>4x4</td>
<td>6x6</td>
</tr>
</tbody>
</table>

**Ford F-550 Altec (AT)**

- **Engine**: Ford Powerstroke 6.7L
- **Horsepower**: 300 hp @ 2,800 rpm
- **Torque**: 660lb-ft @ 1600 rpm
- **Battery Capacity**: 8 kWh
- **Battery Voltage**: ~ 12 V
- **Charging Standards**: -
- **Transmission**: 6 speed Auto
- **Drive**: 4x4

**International WorkStar 7500 (AM)**

- **Engine**: International MaxxForce 7.6L
- **Horsepower**: 300 hp @ 2,200 rpm
- **Torque**: 860lb-ft @ 1300 rpm
- **Battery Capacity**: 18 kWh
- **Battery Voltage**: ~ 48 V
- **Charging Standards**: SAE J1772
- **Transmission**: Allison 3500 RDS 5-speed
- **Drive**: 6x6
### Summary Statistics on Vehicles

<table>
<thead>
<tr>
<th></th>
<th>AT Vehicles</th>
<th>AM Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Time [hr]</td>
<td>3,742</td>
<td>6,688</td>
</tr>
<tr>
<td>Total Distance [mi]</td>
<td>60,800</td>
<td>8,574</td>
</tr>
<tr>
<td>Fuel [Gallons]</td>
<td>7,543</td>
<td>2,533</td>
</tr>
<tr>
<td>Driving Fuel Econ. [mpg]</td>
<td>9.11</td>
<td>4.11</td>
</tr>
<tr>
<td>Driving Time [hr]</td>
<td>1,964</td>
<td>280</td>
</tr>
<tr>
<td>Number of Days</td>
<td>604</td>
<td>284</td>
</tr>
</tbody>
</table>
Fuel Economy vs Kinetic Intensity

Daily Fuel Economy vs Kinetic Intensity

MPG vs Kinetic Intensity graph with data points labeled as 'am_pzo_off', 'am_pzo_on', 'at_pzo_off', and 'at_pzo_on'. The graph includes images of AT and AM vehicles.
Daily Operations Fuel Breakdown

- PTO Fuel [gal]
  - AM_PTO
  - AM_ePTO
  - AT_PTO
  - AT_ePTO

- IDLE Fuel [gal]
  - AM_PTO
  - AM_ePTO
  - AT_PTO
  - AT_ePTO

- Driving Fuel [gal]
  - AM_PTO
  - AM_ePTO
  - AT_PTO
  - AT_ePTO

- Daily Fuel [gal]
  - AM_PTO
  - AM_ePTO
  - AT_PTO
  - AT_ePTO
Fuel Consumption Breakdown – All conventional Vehicles

**Trouble Truck - AT**

- **Idle**: 88.15%
- **PTO**: 8.38%
- **DRIVING**: 3.47%

**Material Handlers - AM**

- **Idle**: 79.05%
- **PTO**: 5.68%
- **Low RPM PTO**: 15.27%

<table>
<thead>
<tr>
<th></th>
<th>Idle</th>
<th>PTO</th>
<th>Low RPM PTO</th>
<th>High RPM PTO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>0.43 [gal/hr]</td>
<td>0.88 [gal/hr]</td>
<td>0.86 [gal/hr]</td>
<td>1.59 [gal/hr]</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>0.38 [gal/hr]</td>
<td>0.86 [gal/hr]</td>
<td>0.86 [gal/hr]</td>
<td>1.48 [gal/hr]</td>
</tr>
</tbody>
</table>
Comparison of Operational Time by Vehicle Type

Comparing all groups

Conventional Trucks

<table>
<thead>
<tr>
<th></th>
<th>IDLE</th>
<th>PTO</th>
<th>DRIVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>43%</td>
<td>8%</td>
<td>49%</td>
</tr>
<tr>
<td>AM</td>
<td>42%</td>
<td>35%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Hybrid Trucks

<table>
<thead>
<tr>
<th></th>
<th>IDLE</th>
<th>PTO</th>
<th>DRIVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>39%</td>
<td>12%</td>
<td>49%</td>
</tr>
<tr>
<td>AM</td>
<td>56%</td>
<td>27%</td>
<td>16%</td>
</tr>
</tbody>
</table>
Comparison of Operational Fuel by Vehicle Type

Comparing all groups

Conventional Trucks

Hybrid Trucks
1 gallon of Diesel Fuel is equivalent to 37.6 kWh

**ePTO System Fuel Savings**

- **eAM**
  - Fuel [gal]: 4.26
  - Time [hr]: 184

- **AM**
  - Fuel [gal]: 281
  - Time [hr]: 227

- **eAT**
  - Fuel [gal]: 2.19
  - Time [hr]: 214

- **AT**
  - Fuel [gal]: 162
  - Time [hr]: 183

* 1 gallon of Diesel Fuel is equivalent to 37.6 kWh
• PTO operation requires relatively low levels of energy compared to idling of large displacement diesel engines

• Showed significant emission and fuel savings benefits from engine idle reduction at the jobsite

• Additional benefits:
  o Low noise enables longer work hours in residential neighborhoods
  o Low noise enables elevated jobsite safety
  o Auxiliary HVAC and 120 VAC outlets offer comfort and convenience for power tool use and battery charging
  o Plug-in charging can be used to maintain batteries and offset fuel use from charging
Thank You!
Arnaud Konan
Arnaud.Konan@nrel.gov

Special Thanks:
DOE Vehicle Technologies Office
Vehicle Systems Program
Lee Slezak and David Anderson
National Clean Fleet Partnership
Mark Smith

INDUSTRY PARTNERS
PG&E
ALTEC INC.

Contact:
kenneth.kelly@nrel.gov
Appendix
Comparison of Operational Time by Vehicle Type

Comparing typical vehicle types

Conventional Trucks

Hybrid Trucks
Comparison of Operational Fuel by Vehicle Type

Comparing one typical vehicle type to each other

### Conventional Trucks

- **AT**
  - IDLE: 15.2%
  - PTO: 2.7%
  - Driving: 82.1%

- **AM**
  - IDLE: 7.2%
  - PTO: 9.1%
  - Driving: 83.6%

### Hybrid Trucks

- **AT**
  - IDLE: 0.3%
  - PTO: 0.0%
  - Driving: 95.7%

- **AM**
  - IDLE: 5.9%
  - PTO: 0.8%
  - Driving: 94.1%
NREL 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
- 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: Provide a data source for modeling and simulation.
The batteries on these trucks were appropriate for the application.
Daily Percent Idle Time
### Complete Stats

<table>
<thead>
<tr>
<th>AT Vehicles</th>
<th>10</th>
<th>AM Vehicles</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Engine on Time [hr]</td>
<td>3,742</td>
<td>Total Engine on Time [hr]</td>
<td>688</td>
</tr>
<tr>
<td>Total Distance [mi]</td>
<td>60,800</td>
<td>Total Distance [mi]</td>
<td>8,574</td>
</tr>
<tr>
<td>Total Work [kWh]</td>
<td>119,084</td>
<td>Total Work [kWh]</td>
<td>29,946</td>
</tr>
<tr>
<td>Fuel Econ. [mpg]</td>
<td>8.06</td>
<td>Fuel Econ. [mpg]</td>
<td>3.39</td>
</tr>
<tr>
<td>Driving Fuel Econ. [mpg]</td>
<td>9.11</td>
<td>Driving Fuel Econ. [mpg]</td>
<td>4.11</td>
</tr>
<tr>
<td>Driving Time [hr]</td>
<td>1,964</td>
<td>Driving Time [hr]</td>
<td>280</td>
</tr>
<tr>
<td>Zero Speed Time [hr]</td>
<td>1,778</td>
<td>Zero Speed Time [hr]</td>
<td>408</td>
</tr>
<tr>
<td>IDLE Time [hr]</td>
<td>1652.88</td>
<td>IDLE Time [hr]</td>
<td>180.85</td>
</tr>
<tr>
<td>PTO Time [hr]</td>
<td>397.5</td>
<td>PTO Time [hr]</td>
<td>411.4</td>
</tr>
<tr>
<td>Grid Energy [kWh]</td>
<td>14.29</td>
<td>Grid Energy [kWh]</td>
<td>136.81</td>
</tr>
<tr>
<td>Number of Days</td>
<td>604.0</td>
<td>Number of Days</td>
<td>284.0</td>
</tr>
<tr>
<td>Total Time [hr]</td>
<td>4,059</td>
<td>Total Time [hr]</td>
<td>871.4</td>
</tr>
</tbody>
</table>