Medium-Duty ARRA Data Reporting and Analysis

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National Renewable Energy Laboratory
June 11, 2015

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

• **Multiple Sites/Projects**: Varies by project
• **Project Length**: Varies by project
• **For FY15**: Some "in-process," some "new"
• **Percent Complete**: About 90%

Timeline

<table>
<thead>
<tr>
<th></th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navistar eStar EV</td>
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<tr>
<td>Smith Newton EV</td>
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<tr>
<td>Shorepower TSE</td>
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<tr>
<td>Odyne PHEV</td>
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</table>

Budget

• **Total Project Funding**: $630K
  o **DOE Share**: $180K in FY15
  o Participant cost share: in-kind support (data supplied to NREL)

• **DOE Funding Received**
  o FY13: $200K
  o FY14: $250K

Barriers

• **Long-Term Original Equipment Manufacturer (OEM) Viability and Support**: Owners must have confidence in OEM’s ability to provide service, support and parts several years into the future
• **Vehicle and Facility Costs**: New technology must make financial sense for fleet managers on both an energy and operational basis
• **Unbiased Data**: OEMs and researchers need unbiased, third-party data for better understanding of technology performance and areas for improvement
• **Varied Vehicle Use**: Variable performance by technologies due to wide-ranging duty cycles

Partners

• **Industry collaboration required for successful studies. Current Partners in FY15**:
  Smith Electric Vehicle, Navistar, Shorepower, Odyne, South Coast Air Quality Management District (SCAQMD), Electric Power Research Institute (EPRI)
• **Project Lead**: National Renewable Energy Laboratory (NREL)
Relevance

This project compiles medium-duty (MD) aggregated deployment data and analysis to industry

• The DOE’s American Recovery and Reinvestment Act (ARRA) deployment and demonstration projects are helping to commercialize technologies for all-electric vehicles (EVs), electrified accessories such as electric power take-off (ePTO) and electric charging infrastructure.
  o Over 4.0 million miles of in-service MD EV data from 560 different vehicles have been collected since 2011
  o Usage data from 50 truck-electrification sites have been collected since 2013

• Through the DOE’s Vehicle Technologies Office, NREL is working to analyze real-time data from these deployment and demonstration projects to quantify the benefits
  o Results and summary statistics are made available through the NREL website as quarterly and annual reports
  o Over 25 reports have been published on the performance and operation of these vehicles
  o Detailed data are being extracted to help further understand battery use and performance
Project Framework

U.S. Department of Energy

DOE Funding

Contractor Technology Reports

Smith

Navistar

Shorepower Technologies

Odyne Hybrid Systems

Data Summary & Analysis Reports

DOE Funding

National Renewable Energy Laboratory

Data

Publically Available Data and Reports

http://www.nrel.gov/transportation/fleettest_electric.html
### Milestones

<table>
<thead>
<tr>
<th>Month / Year</th>
<th>Milestone or Go/No-Go Decision</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Milestone</td>
<td>Status report on all projects</td>
<td>Complete</td>
</tr>
<tr>
<td>Q2</td>
<td>Milestone</td>
<td>Status report on all projects</td>
<td>Complete</td>
</tr>
<tr>
<td>Q3</td>
<td>Milestone</td>
<td>Status report on all projects</td>
<td>On-Track</td>
</tr>
<tr>
<td>Q4</td>
<td>Milestone</td>
<td>Final report &amp; data on all projects</td>
<td>On-Track</td>
</tr>
</tbody>
</table>

- In addition to the above reports, aggregated quarterly and aggregated cumulative reports will be published.

**Data available at:**

**Periodic summary reports available at:**
[http://www.nrel.gov/transportation/fleetteltest_electric_smith_navistar.html](http://www.nrel.gov/transportation/fleetteltest_electric_smith_navistar.html)
Approach/Strategy

• Obtain 25+ parameters at 1 Hz from each vehicle to be stored and analyzed by NREL

• Obtain Truck Stop Electrification (TSE) usage records that detail each time a site is used

• Securely collect, store, analyze, and back up this dataset. Data to be made publically available via NREL’s Fleet DNA web portal

• Refine and optimize processing routines to handle increased volumes of data

• Continue to increase the number of metrics used, and cross-correlate these data with other fleet evaluations to better understand petroleum and emissions displacement

• Work with industry partners to understand what metrics are most useful for analyzing and growing these technologies

• Report data and progress back to DOE and the general public
Data Collection Status

- **Navistar eStar EV**
  - Data collection completed 6/30/2014

- **Smith Newton EV**
  - Gen 1 data collection completed 6/30/2014
  - Gen 2 scheduled to complete 6/30/2015

- **Shorepower TSE**
  - Data collection completed 2/28/2015

- **Odyne plug-in hybrid electric vehicle (PHEV)**
  - Data collection scheduled to complete July 2015

<table>
<thead>
<tr>
<th></th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navistar eStar EV</td>
<td>Complete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smith Newton EV G1</td>
<td>Complete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smith Newton EV G2</td>
<td></td>
<td></td>
<td>June 2015</td>
<td></td>
</tr>
<tr>
<td>Shorepower TSE</td>
<td>Complete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odyne PHEV</td>
<td></td>
<td></td>
<td></td>
<td>July 2015</td>
</tr>
</tbody>
</table>
Smith Electric Vehicles – Newton

- 500+ Newton's deployed in the U.S.
  - Manufactured in Kansas City, MO
  - $32 million ARRA award
  - Currently reporting
    - 259 of 309 first generation
    - 200 of 203 second generation
  - 80–120-kWh Li-ion battery packs
  - Service and delivery applications
  - Deployments include:
    - Frito-Lay (13 states)
    - Staples (6 states)
    - FedEx (CA, CO, IL, MD, NY)
    - Coca Cola (IL, NY)
    - AT&T (MO)
    - PG&E (CA)

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**Technical Accomplishments and Progress**

**GVW** = gross vehicle weight

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>GVW</strong></td>
<td>22–27K lbs.</td>
</tr>
<tr>
<td><strong>Drag Coefficient</strong></td>
<td>~0.5</td>
</tr>
<tr>
<td><strong>Charging Standards</strong></td>
<td>J1772 or 3-phase</td>
</tr>
<tr>
<td><strong>Onboard Charger Power</strong></td>
<td>5–6 kW</td>
</tr>
<tr>
<td><strong>Battery Capacity</strong></td>
<td>80 – 120 kWh</td>
</tr>
<tr>
<td><strong>Inverter Efficiency</strong></td>
<td>94%</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Peak Motor Power</strong></td>
<td>134 kW</td>
</tr>
</tbody>
</table>

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NREL 22851
Objective:
Performance evaluation of ARRA-funded Smith EVs deployed throughout the United States in MD delivery applications

<table>
<thead>
<tr>
<th>Trip Data</th>
<th>Gen 1</th>
<th>Gen 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Diesel Equivalent Fuel Economy</td>
<td>24.7 mpge</td>
<td>29.5 mpge</td>
</tr>
<tr>
<td>Overall AC Energy</td>
<td>1,858.0 Wh/mi</td>
<td>1,755.2 Wh/mi</td>
</tr>
<tr>
<td>Overall DC Electrical Energy Discharged</td>
<td>1,519.5 Wh/mi</td>
<td>1,329.7 Wh/mi</td>
</tr>
<tr>
<td>Total Number of Charges</td>
<td>155,057.0</td>
<td>94,676.0</td>
</tr>
<tr>
<td>Total Charge Energy Delivered</td>
<td>3,953,616 kWh</td>
<td>2,437,103 kWh</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>2,127,895 miles</td>
<td>1,392,514 miles</td>
</tr>
<tr>
<td>City</td>
<td>Highway Distance</td>
<td>1,381,555</td>
</tr>
<tr>
<td>City</td>
<td>Highway Distance</td>
<td>64.9</td>
</tr>
</tbody>
</table>
Navistar – eStar

- The Navistar eStar
  - 12K lbs GVW (class 3)
  - Lithium ion, A123 Systems
  - Manufactured in Elkhart, IN
  - Fleet deployments
    - FedEx (CA)
    - Cascadia Dealer (OR)
    - Pacific Gas and Electric (CA)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVW</td>
<td>12,122 lbs.</td>
</tr>
<tr>
<td>Payload (Max)</td>
<td>5,100 lbs.</td>
</tr>
<tr>
<td>Curb Weight</td>
<td>7,022 lbs.</td>
</tr>
<tr>
<td>Charging Standard</td>
<td>J1772</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>80 kWh</td>
</tr>
<tr>
<td>Motor Power</td>
<td>70 kW</td>
</tr>
<tr>
<td>Top Speed</td>
<td>50 mph</td>
</tr>
<tr>
<td>Advertised Range</td>
<td>Up to 100 miles</td>
</tr>
</tbody>
</table>
Navistar eStar Vehicle Performance

- Evaluate the performance of class 3 Navistar eStar EVs deployed throughout the United States in MD delivery applications
- Leverage NREL-developed tools for automated data filtering and processing
- Data collection completed 6/30/2014

**Number of vehicles reporting:** 101
**Reporting period:** 7/1/2012 to 6/30/2014

**Number of vehicle days driven:** 17,447
**Number of operating cities:** 35

<table>
<thead>
<tr>
<th>Trip Data</th>
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</thead>
<tbody>
<tr>
<td>Overall Diesel Equivalent Fuel Economy$^3$</td>
<td>46.2 mpge</td>
</tr>
<tr>
<td>Overall AC Electrical Energy Charged++</td>
<td>892.2 Wh/mi</td>
</tr>
<tr>
<td>Overall DC Electrical Energy Charged</td>
<td>843.2 Wh/mi</td>
</tr>
<tr>
<td>Overall DC Electrical Energy Discharged</td>
<td>813.3 Wh/mi</td>
</tr>
<tr>
<td>Driving DC Electrical Energy Consumption$^4$</td>
<td>737.3 Wh/mi</td>
</tr>
<tr>
<td>Total Number of Charge Events</td>
<td>16,152</td>
</tr>
<tr>
<td>Total Charge Energy Delivered</td>
<td>298,260.1 kWh</td>
</tr>
<tr>
<td>Total Distance Traveled</td>
<td>353,733.3 miles</td>
</tr>
<tr>
<td>City</td>
<td>Highway Distance$^5$</td>
</tr>
<tr>
<td>City</td>
<td>Highway Distance$^5$</td>
</tr>
</tbody>
</table>

**Total Charge Energy**

- Monthly (MWh)
- Cumulative (MWh)

NREL 18624
Charging Patterns – Smith G1 & Navistar

• Typical nightly charging patterns
• Charging ramping up around 5 p.m. and ramping down around 12 a.m.
• Navistar peak charging occurs between 7 p.m. and 12 a.m.
• Smith peak charging occurs between 10 p.m. and 3 a.m.
Truck Stop Electrification Project

- TSE allows truck operators to stop their engines and pull power from the grid for accessory loads that would otherwise require extended idle
- All 50 ARRA-funded sites operational

Plug-In Infrastructure

<table>
<thead>
<tr>
<th>Reporting period:</th>
<th>1/1/2013 – 2/28/2015</th>
<th>Number of TSE sites completed:</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power:</td>
<td>208/240/480 V (min 50 A) 4 wire circuit</td>
<td>Number of pedestals installed:</td>
<td>314</td>
</tr>
<tr>
<td>Output Power:</td>
<td>120/208/240/480 V, 20/30 A outlets</td>
<td>Total vehicle capacity:</td>
<td>1,256</td>
</tr>
</tbody>
</table>
Truck Stop Electrification Project

- Utilization at ARRA-funded locations totaled 77,273 hours with 56,073 kWh used

- Offsetting an estimated 61,818 gallons of diesel fuel that would have otherwise been used during idle

<table>
<thead>
<tr>
<th>Utilization Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle-reduction rebate approvals</td>
</tr>
<tr>
<td>Completed equipment installations</td>
</tr>
<tr>
<td>Number of TSE sites with &gt;90% uptime</td>
</tr>
<tr>
<td>Number of plug-in events</td>
</tr>
<tr>
<td>Total hours booked</td>
</tr>
<tr>
<td>Total kWh used</td>
</tr>
<tr>
<td>Average kWh/event</td>
</tr>
<tr>
<td>Estimated gallons of diesel fuel saved</td>
</tr>
<tr>
<td>Metric tons of CO₂ avoided</td>
</tr>
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</table>
Truck Stop Electrification Project

- Continue to investigate usage trends and factors that may impact utilization
- Seasonally cooler months show higher utilization
- Highest weekly use Friday – Sunday

Monthly Utilization Data

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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of plug-in events</td>
<td>714</td>
<td>536</td>
<td>819</td>
<td>749</td>
<td>592</td>
<td>441</td>
<td>685</td>
<td>631</td>
<td>444</td>
</tr>
<tr>
<td>Number of plug-in events using STEP IDs</td>
<td>46</td>
<td>39</td>
<td>62</td>
<td>34</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total hours booked</td>
<td>14,254</td>
<td>6,679</td>
<td>12,116</td>
<td>10,439</td>
<td>8,212</td>
<td>4,861</td>
<td>7,641</td>
<td>7,351</td>
<td>5,720</td>
</tr>
<tr>
<td>Total kWh used</td>
<td>9,442</td>
<td>3,804</td>
<td>7,222</td>
<td>8,913</td>
<td>8,573</td>
<td>3,091</td>
<td>4,851</td>
<td>5,002</td>
<td>5,175</td>
</tr>
<tr>
<td>Average energy used per event (kWh)</td>
<td>13.2</td>
<td>7.1</td>
<td>8.8</td>
<td>11.9</td>
<td>14.5</td>
<td>7.0</td>
<td>7.1</td>
<td>7.9</td>
<td>11.7</td>
</tr>
<tr>
<td>Average power per event (kW)</td>
<td>0.662</td>
<td>0.570</td>
<td>0.596</td>
<td>0.854</td>
<td>1.044</td>
<td>0.636</td>
<td>0.635</td>
<td>0.680</td>
<td>0.905</td>
</tr>
</tbody>
</table>

STEP = Shorepower Truck Electrification Project
Odyne – PHEV Utility Trucks

- **Objective**
  - Evaluate in-use performance evaluation of Odyne’s electrified power-take-off (ePTO) hybrid system on 119 vehicles
  - Quantify fuel savings from idle reduction at the jobsite
  - Quantify fuel savings from regenerative braking and launch assist during normal driving

- **Approach**
  - In-use data supplied by Odyne through EPRI on 119 vehicles
  - Integrate into NREL’s automated drive-cycle analysis and reporting database

- **System Specifications**
  - Li-ion batteries from Johnson Controls, 28.4 kWh
  - 320-V electric motor, 56 hp continuous, 95 hp peak
Example of daily operational state-of-charge (SOC) analysis
Analysis Plan

• **Ongoing:** Periodic summary reports published online. Developing unique template for Odyne PHEV.

• **Completed (FY15):**

• **Future:** Research in-field EV performance and battery-pack size optimization. Evaluate dataset for modular energy storage opportunities.
  - Final NREL ARRA technical report
    – Technology reports supplied to DOE from each contractor
Responses to Previous Year Reviewers’ Comments

Comment #1:
The reviewer indicated that regarding project planning the project start/end dates and overall project structure are not clear. The reviewer perceived it was hard to judge what was accomplished this year and in the past. The reviewer noted that a large dataset of in-service vehicle use was collected, which is valuable. That being said, the real benefit of the project is the analysis of the data to generate insights and draw conclusions. The reviewer added that while reports were created to highlight vehicle usage, there did not appear to be a robust analysis plan in place or an explanation of what sort of objectives are sought upfront.

Response:
Addressed on Data Collection Status slide 7 & Analysis Plan slide 18

Comment #2:
The reviewer said that it was mentioned that for FY 2015, the data analysis portion of the project will begin. The reviewer would have liked to see a clear understanding what insights would like to be gained upfront, from the data collection and analysis activities.

Response:
Addressed on Data Collection Status slide 7 & Analysis Plan slide 18

Comment #3:
The reviewer reported that more definition on the future analysis that is or could be undertaken is needed. The reviewer added that the secondary analysis that was done as a result of what was learned could also be pursued.

Response:
Addressed on Analysis Plan slide 18
Collaboration and Coordination with Other Institutions

This project **absolutely requires** industry collaboration for successful studies.

**Past industry partners included:**

Smith, Navistar, Cascade Sierra Solutions, Shorepower, Odyne, South Coast Air Quality Management District (SCAQMD), Electric Power Research Institute (EPRI)

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**FY15 Collaborations & Coordination with Others**

<table>
<thead>
<tr>
<th>Partner</th>
<th>Relationship</th>
<th>Type</th>
<th>VT Program or Outside?</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith Electric Vehicles</td>
<td>OEM Partner</td>
<td>Government Collaboration</td>
<td>VT Program</td>
<td>Smith has provided data and data analysis support to make the aggregated data available to the public</td>
</tr>
<tr>
<td>Navistar</td>
<td>OEM Partner</td>
<td>Government Collaboration</td>
<td>VT Program</td>
<td>Navistar has provided data and data analysis support to make the aggregated data available to the public</td>
</tr>
<tr>
<td>Shorepower</td>
<td>Industry Partner</td>
<td>Government Collaboration</td>
<td>VT Program</td>
<td>Shorepower has provided data and data analysis support to make the aggregated data available to the public</td>
</tr>
<tr>
<td>Odyne</td>
<td>OEM Partner</td>
<td>Government Collaboration</td>
<td>VT Program</td>
<td>Odyne has provided data and data analysis support to make aggregated data available to the public</td>
</tr>
<tr>
<td>SCAQMD / EPRI</td>
<td>Research Partner</td>
<td>Government Collaboration</td>
<td>VT Program</td>
<td>SCAQMD and EPRI are working together with NREL to acquire, analyze, and make data available to the public</td>
</tr>
</tbody>
</table>
Remaining Challenges and Barriers

1. Adoption of New EVs into Commercial Fleets
   - Fleets remain tentative in procurement based on return on investment (ROI) projections – limited rollout of EVs in MD sector
   - Perception of reliability and maintenance support
   - Effects of “demand charges” adding to costs

2. Unknown Life and Secondary Use of Large Commercial EV Battery Systems
   - Better understanding and modeling of battery-life estimations for MD commercial energy storage is needed
   - Use of large packs after useful life is mostly unknown
Proposed Future Work

• FY15 – Continue to collect data on Odyne Utility Trucks and Smith EVs
  o Navistar and Cascade Sierra Solutions data collection periods have ended

• New efforts in FY15 and FY16 (once all data have been collected) will be proposed:
  o Leverage NREL’s Fleet DNA database platform to analyze opportunities and feasibility for modular battery pack sizing, pack downsizing, and vehicle placement optimization
  o Modeling and simulation activities to show the affects and sensitivity that various parameters have on MD EV performance, efficiency, and battery-pack life predictions to maximize ROI
  o Additional analysis to investigate seasonal and climatic effects on EV range, as well as effects on battery-life estimations as a function of vehicle duty cycles
Summary

• MD EV data collection and analysis will help drive design, purchase, and research investments
  o Over 4 million miles and 160,000 driving days of EV driving data collected under this project.
    – Publically available data help drive technology research, development, and deployment
    – Feeding vocational database for future analysis – better understanding of usage will result in better design optimization and technology implementation
  o Performance of vehicle varies with drive cycle and cargo load – MD vehicles are “multi-functional”
  o Environment and accessory loads affect vehicle range and in turn add cost by adding battery capacity
  o MD EV vehicles can function in vocations traditionally serviced by gasoline or diesel vehicles
  o Facility implications (i.e., demand charges) need to be understood as part of site-based analysis for EV implementation
Technical Back-Up Slides

(Note: please include this “separator” slide if you are including back-up technical slides (maximum of five). These back-up technical slides will be available for your presentation and will be included in the DVD and Web PDF files released to the public.)
Acknowledgements and Contacts

Thanks to:

Vehicle & Systems Simulation & Testing Activity – Lee Slezak and David Anderson
Vehicle Technologies Office – U.S. Department of Energy

For more information:

http://www.nrel.gov/transportation/fleettest.html

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Kenneth Kelly
National Renewable Energy Laboratory
Kenneth.Kelly@NREL.gov
Phone: 303-275-4465
Approach/Strategy

Data Processing Routine – Receive, Filter, Analyze

Reports available at: http://www.nrel.gov/vehiclesandfuels/fleettest/