NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Medium Duty ARRA Data Reporting and Analysis

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National Renewable Energy Laboratory

VTO Annual Merit Review and Peer Evaluation
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Project ID # VSS159

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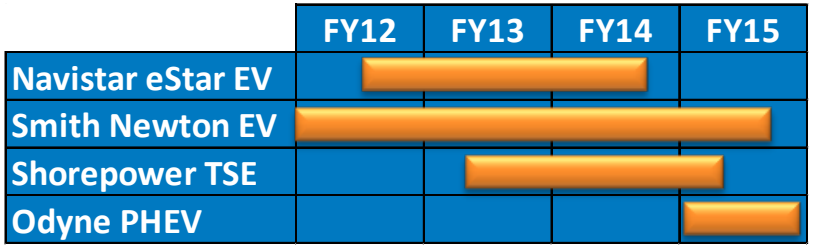
Overview

Timeline

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



Budget

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

- **DOE Funding Received**
  - **FY13: $200K**
  - **FY14: $250K**

Barriers

- **Long Term OEM Viability and Support:** Owners must have confidence in OEM's ability to provide service, support and parts several years into the future
- **Vehicle & Facility Costs:** New technology must make financial sense for fleet managers on both an energy and operational basis.
- **Unbiased Data:** OEMs & researchers need unbiased, 3rd-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, SCAQMD, EPRI

- **Project Lead:** National Renewable Energy Laboratory (NREL)

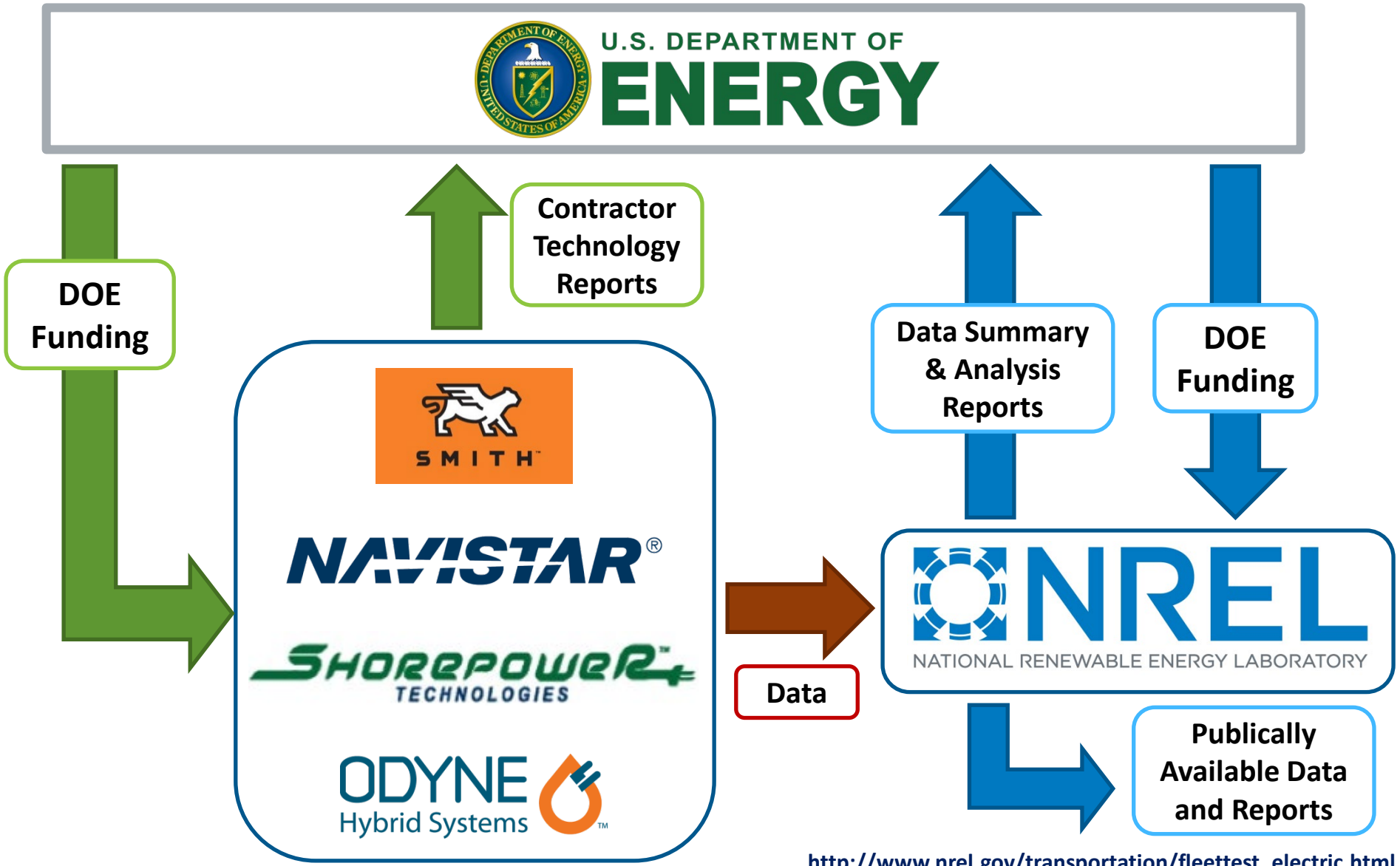
Relevance

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

- The U.S. Department of Energy's (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 ePTO and electric charging infrastructure.
  - Over 4.0 million miles of in-service medium duty EV data from 560 different vehicles have been collected since 2011
  - 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
  - Results and summary statistics are made available through the NREL website as quarterly and annual reports
  - Over 25 reports have been published on the performance and operation of these vehicles
  - Detailed data are being extracted to help further understand battery use and performance

Project Framework



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

Milestones

Month / Year	Milestone or Go/No-Go Decision	Description	Status
Q1	Milestone	Status Report on all Projects	Complete
Q2	Milestone	Status Report on all Projects	Complete
Q3	Milestone	Status Report on all Projects	On-Track
Q4	Milestone	Final Report & Data on all Projects	On-Track

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

Data available at:
http://www.nrel.gov/transportation/fleettest_fleet_dna.html

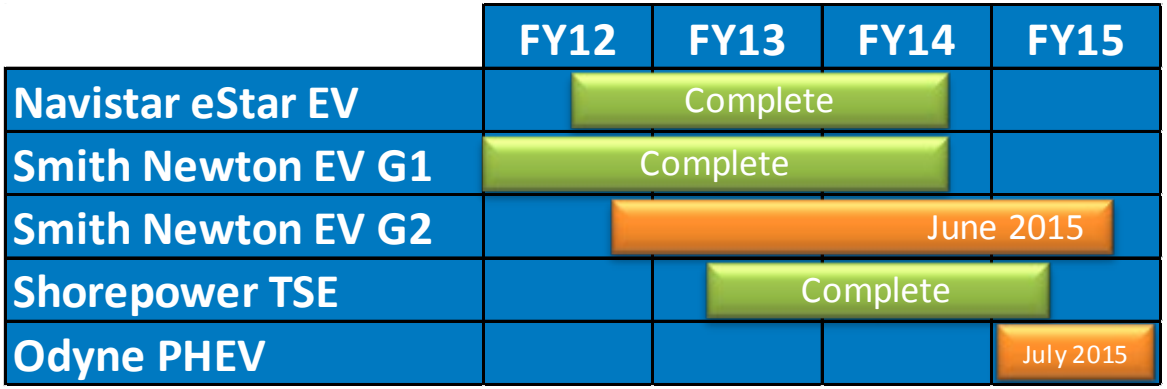
Periodic summary reports available at:
http://www.nrel.gov/transportation/fleettest_electric_smith_navistar.html

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 this 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 PHEV**
  - Data collection scheduled to complete July 2015



Technical Accomplishments and Progress

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)

GVW	22–27K lbs.
Drag Coefficient	~0.5
Charging Standards	J1772 or 3-phase
Onboard Charger Power	5–6 kW
Battery Capacity	80 – 120 kWh
Inverter Efficiency	94%
Motor	
Peak Motor Power	134 kW

GVW = gross vehicle weight

Smith Newton Vehicle Performance

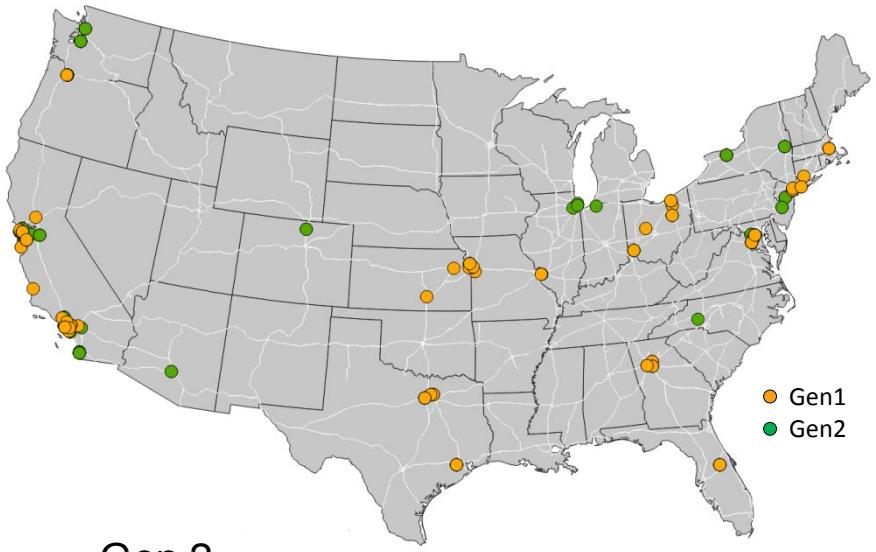
Number of Vehicles (Gen1/Gen2): 259/200

Number of Vehicle Days Driven: 96,461 / 45,702

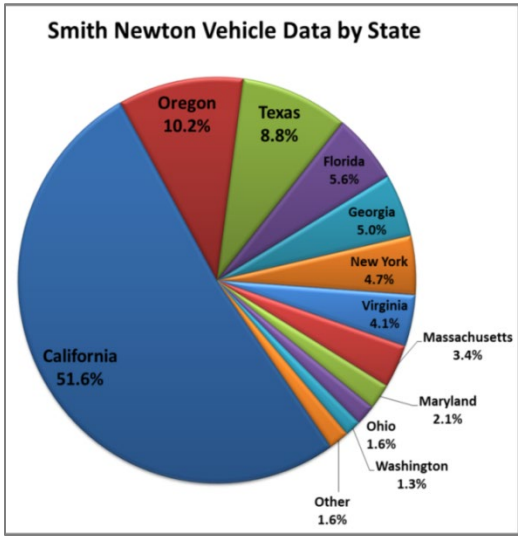
Number of operating cities: 81 / 40

Objective:

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



Trip Data	Gen 1 11/2011 - 03/2014	Gen 2 01/2013 - 12/2014
Overall Diesel Equivalent Fuel Economy	24.7 mpge	29.5 mpge
Overall AC Energy	1,858.0 Wh/mi	1,755.2 Wh/mi
Overall DC Electrical Energy Discharged	1,519.5 Wh/mi	1,329.7 Wh/mi
Total Number of Charges	155,057.0	94,676.0
Total Charge Energy Delivered	3,953,616 kWh	2,437,103 kWh
Total Distance Traveled	2,127,895 miles	1,392,514 miles
City | Highway Distance	1,381,555 | 752,060 miles	770,560 | 621,954 miles
City | Highway Distance	64.9 | 35.3 %	55.3 | 41.3 %

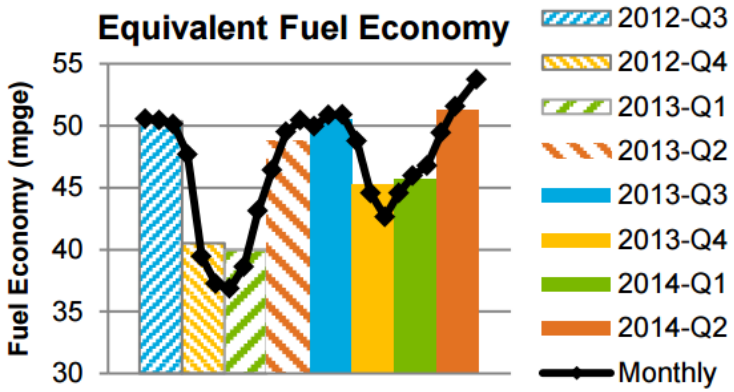


Technical Accomplishments and Progress

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)

GVW	12,122 lbs.
Payload (Max)	5,100 lbs.
Curb Weight	7,022 lbs.
Charging Standard	J1772
Battery Capacity	80 kWh
Motor Power	70 kW
Top Speed	50 mph
Advertised Range	Up to 100 miles



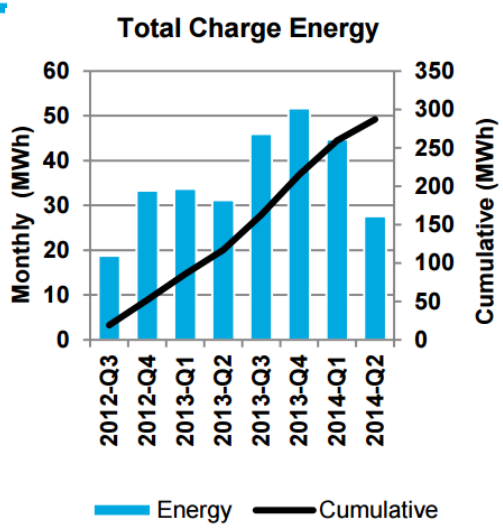
Navistar eStar Vehicle Performance

Number of vehicles reporting:	101	Number of vehicle days driven:	17,447
Reporting period:	7/1/2012 to 6/30/2014	Number of operating cities:	35

- 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

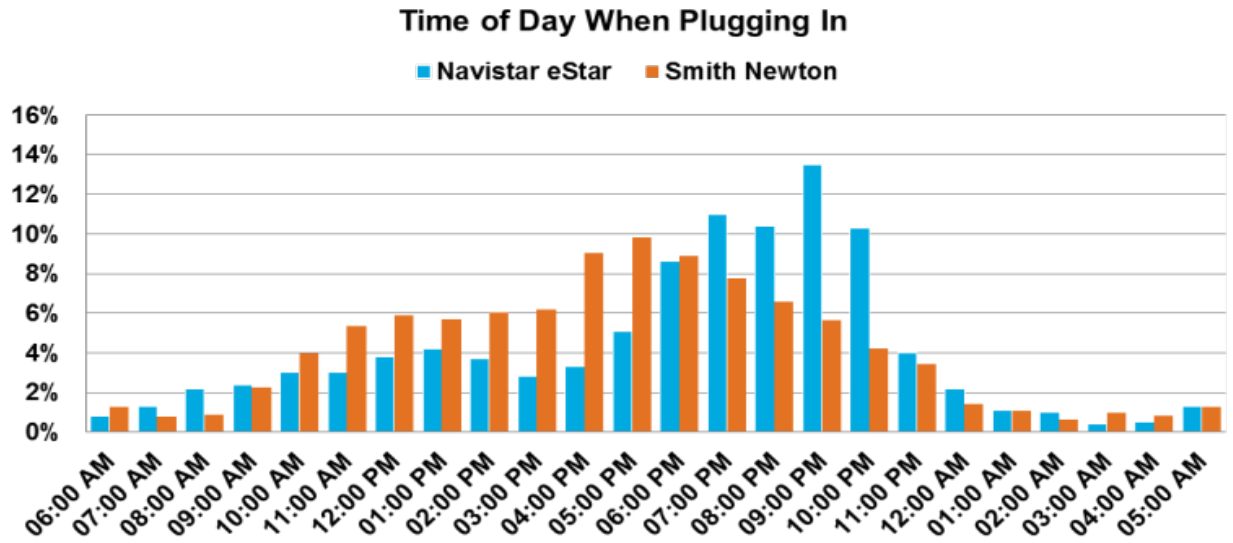
Trip Data	
Overall Diesel Equivalent Fuel Economy[3]	46.2 mpge
Overall AC Electrical Energy Charged++	892.2 Wh/mi
Overall DC Electrical Energy Charged	843.2 Wh/mi
Overall DC Electrical Energy Discharged	813.3 Wh/mi
Driving DC Electrical Energy Consumption[4]	737.3 Wh/mi
Total Number of Charge Events	16,152
Total Charge Energy Delivered	298,260.1 kWh
Total Distance Traveled	353,733.3 miles
City | Highway Distance[5]	269,806 | 83,927 miles
City | Highway Distance[5]	76.3 | 23.7 %

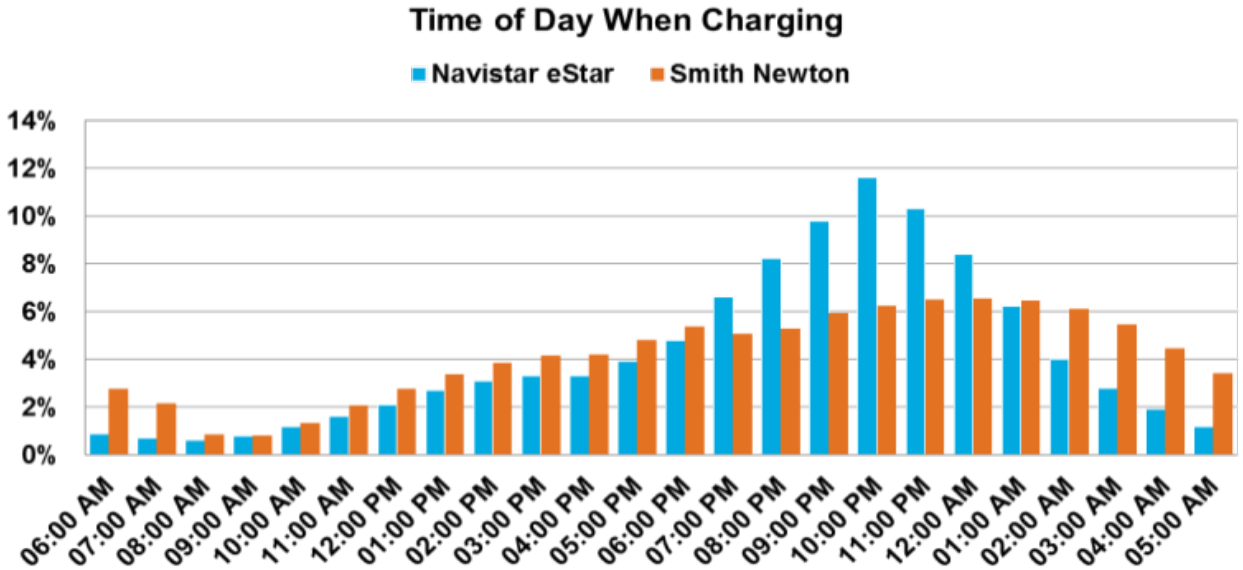
NREL 18624



Charging Patterns – Smith G1 & Navistar

- Typical nightly charging patterns
- Charging ramping up around 5PM and ramping down around 12AM
- Navistar peak charging occurs between 7PM and 12AM
- Smith peak charging occurs between 10PM and 3AM



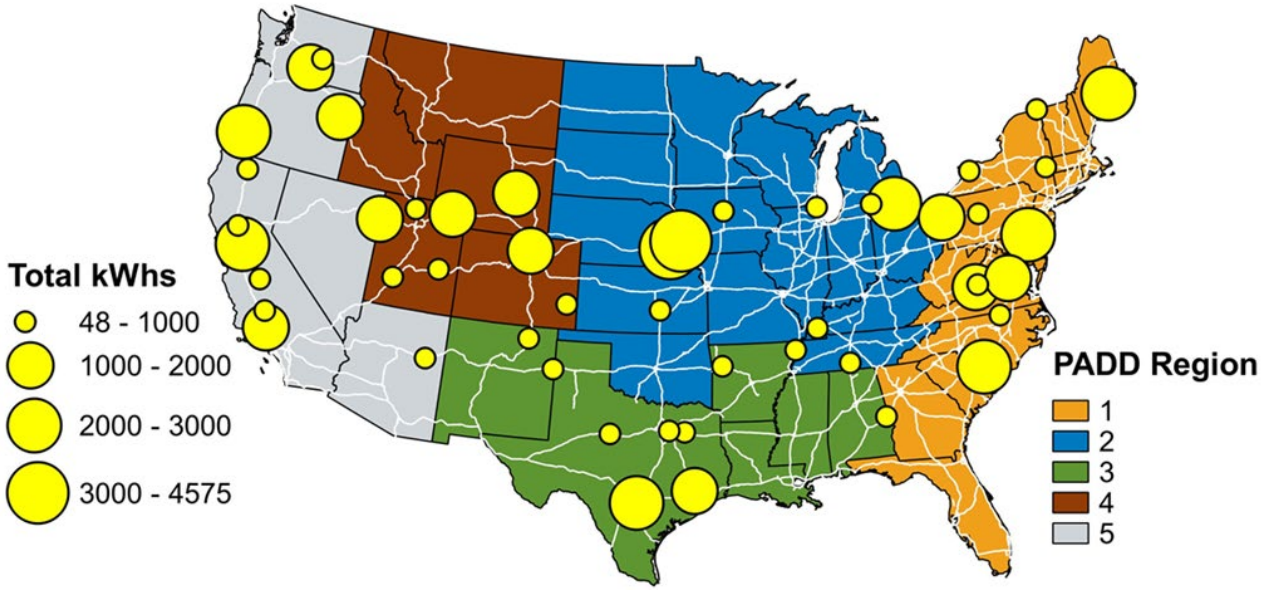


Truck Stop Electrification Project

- 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

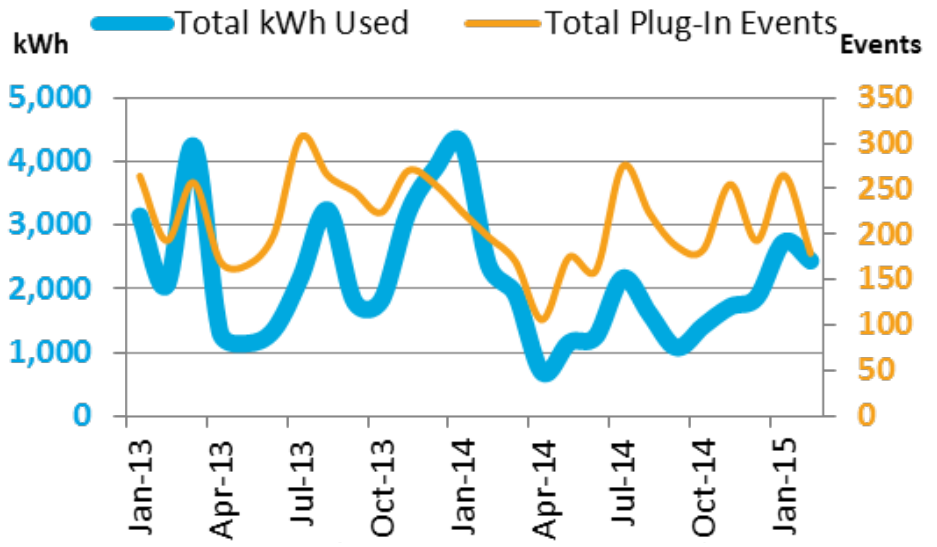
Plug-In Infrastructure

Reporting period:	1/1/2013 – 2/28/2015	Number of TSE sites completed:	50
Input Power:	208/240/480 V (min 50 A) 4 wire circuit	Number of pedestals installed:	314
Output Power:	120/208/240/480 V, 20/30 A outlets	Total vehicle capacity:	1,256



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

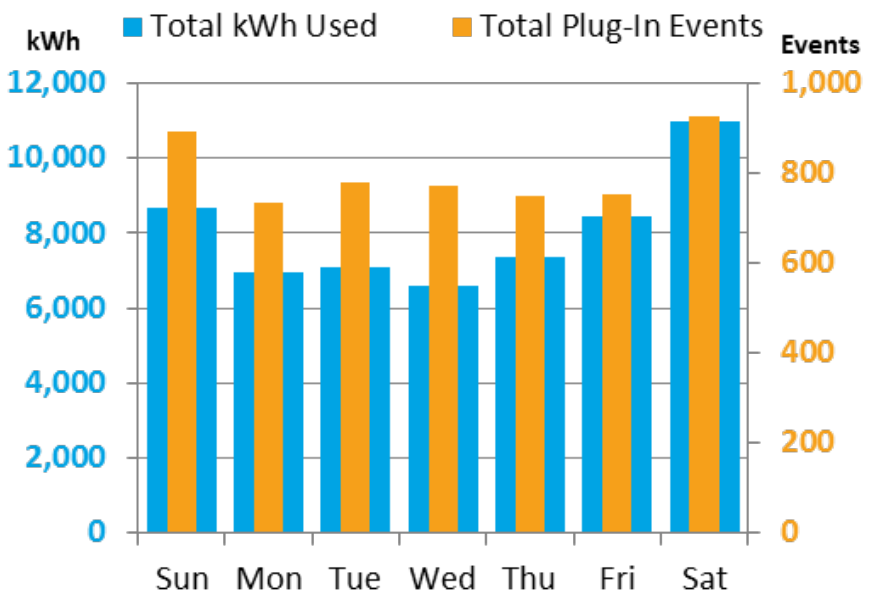


Utilization Summary

Idle-reduction rebate approvals	4,686
Completed equipment installations	4,353
Number of TSE sites with >90% uptim	50
Number of plug-in events	5,611
Total hours booked	77,273
Total kWh used	56,073
Average kWh/event	10.0
Estimated gallons of diesel fuel saved	61,818
Metric tons of CO_2 avoided[2]	629

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

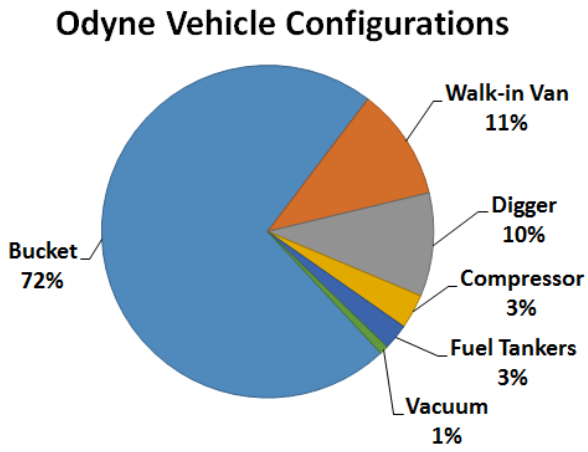


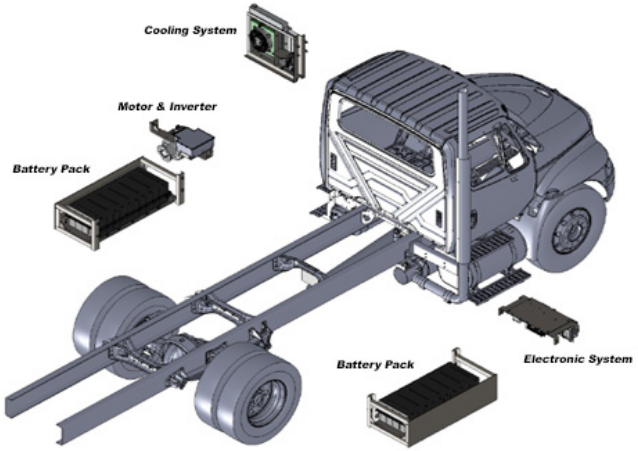
Monthly Utilization Data

	Q1 2013	Q2 2013	Q3 2013	Q4 2013	Q1 2014	Q2 2014	Q3 2014	Q4 2024	Jan|Feb 2015
Number of plug-in events	714	536	819	749	592	441	685	631	444
Number of plug-in events using STEP IDs	46	39	62	34	NA	NA	NA	NA	NA
Total hours booked	14,254	6,679	12,116	10,439	8,212	4,861	7,641	7,351	5,720
Total kWh used	9,442	3,804	7,222	8,913	8,573	3,091	4,851	5,002	5,175
Average energy used per event (kWh)	13.2	7.1	8.8	11.9	14.5	7.0	7.1	7.9	11.7
Average power per event (kW)[3]	0.662	0.570	0.596	0.854	1.044	0.636	0.635	0.680	0.905

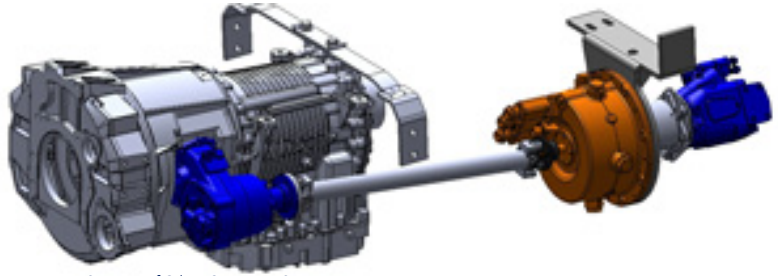
Odyne – PHEV Utility Trucks

- **Objective**
  - Evaluate In-use performance evaluation of Odyne's electrified power-take-off (PTO) 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

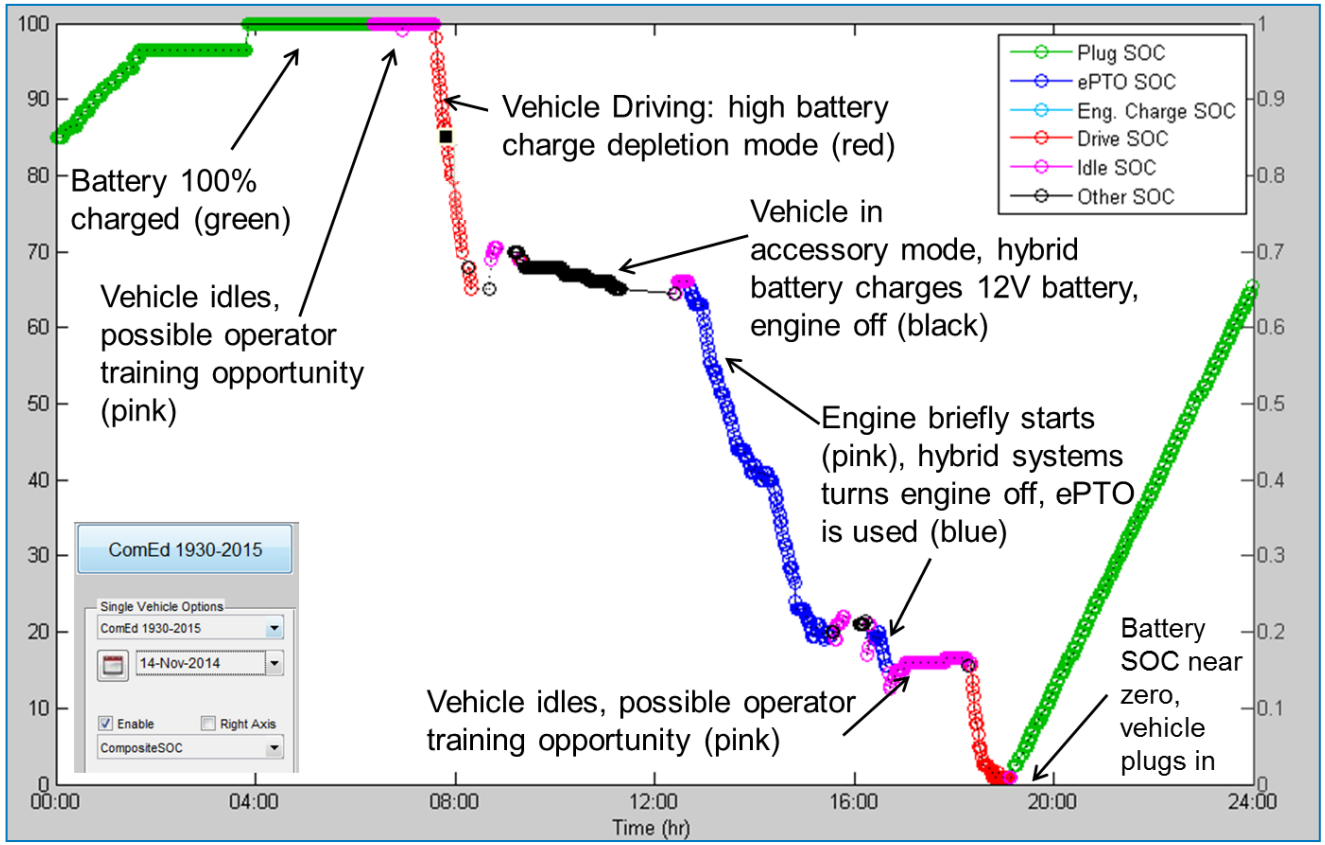




Courtesy of Odyne Systems LLC


Courtesy of Odyne Systems LLC

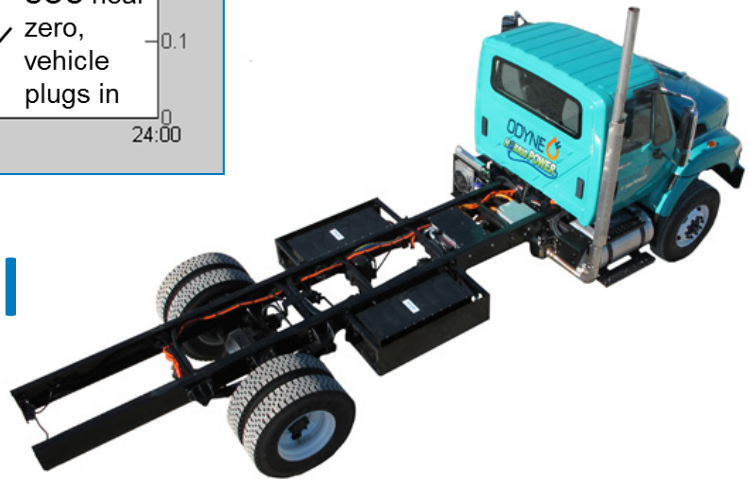
Odyne – PHEV Utility Trucks



Graph Courtesy of Odyne Systems LLC

Photo courtesy of Odyne Systems LLC

- **Example of daily operational SOC analysis**



Courtesy of Odyne Systems LLC

Analysis Plan

- **Ongoing:** Periodic summary reports published online, Developing unique template for Odyne PHEV
- **Completed (FY15):**
  - IEEE IEVC "Characterization of In-Use Medium Duty Electric Vehicle Driving and Charging Behavior"
  - EVS28 in May 2015 - "Statistical Characterization of Medium-Duty Electric Vehicle Drive Cycles"
- **Future:** Research in-field EV performance and battery pack size optimization. Evaluate data set 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 data set 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 periodic 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 thought it was nice to see plans for in-depth data analysis after the collection of data is completed. Additional parameters of interest in follow-on analysis would be battery pack failures (if any), battery/range degradation, vehicle utilization (uptime, miles between road calls) if possible compared to typical baseline vehicles. In general, the reviewer said that the opportunity to incorporate some fleet feedback might compliment the current dataset for a more complete analysis. For example, MGP equivalent might look great but there could have been start ability, cold weather issues, inadequate vehicle speed and performance according to drivers that would not necessarily come out of the current dataset.

Response:

Addressed on Project Framework slide 4 & Analysis Plan slide 18

Responses to Previous Year Reviewers' Comments

Comment #3:

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 #4:

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 required for successful studies.

Past industry partners included:

Smith, Navistar, Cascade Sierra Solutions, Shorepower, Odyne, SCAQMD, EPRI

FY15 Collaborations & Coordination with Others				
Partner	**Relationship**	**Type**	**VT Program or Outside?**	**Details**
Smith Electric Vehicles	OEM Partner	Government Collaboration	VT Program	Smith has provided data and data analysis support to make the aggregated data available to the public
Navistar	OEM Partner	Government Collaboration	VT Program	Navistar has provided data and data analysis support to make the aggregated data available to the public
Shorepower	Industry Partner	Government Collaboration	VT Program	Shorepower has provided data and data analysis support to make the aggregated data available to the public
Odyne	OEM Partner	Government Collaboration	VT Program	Odyne has provided data and data analysis support to make aggregated data available to the public
SCAQMD / EPRI	Research Partner	Government Collaboration	VT Program	SCAQMD and EPRI are working together with NREL to acquire, analyze and make data available to the public

Remaining Challenges and Barriers

1. **Adoption of New EVs into Commercial Fleets**
   - Fleets remain tentative in procurement based on 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**
  - 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:**
  - Leverage NREL's Fleet DNA database platform to analyze opportunities and feasibility for modular battery pack sizing, pack downsizing, and vehicle placement optimization.
  - Modeling and Simulation activities to show the affects and sensitivity various parameters have on Medium Duty EV performance, efficiency and battery pack life predictions to maximize ROI.
  - 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:
  - Over **4M miles** and **160,000 driving days** of EV driving data collected under this project.
    - Publically available data helps drive technology RD&D
    - Feeding vocational database for future analysis – better understanding of usage will result in better design optimization and technology implementation.
  - Performance of vehicle varies with drive cycle and cargo load – MD vehicles are “multi-functional”
  - Environment and accessory loads affect vehicle range and in turn add cost by adding battery capacity
  - MD EV vehicles can function in vocations traditionally serviced by gasoline or diesel vehicles
  - Facility implications (i.e., demand charges) need to be understood as part of site-based analysis for EV implementation

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Technical Back-Up Slides

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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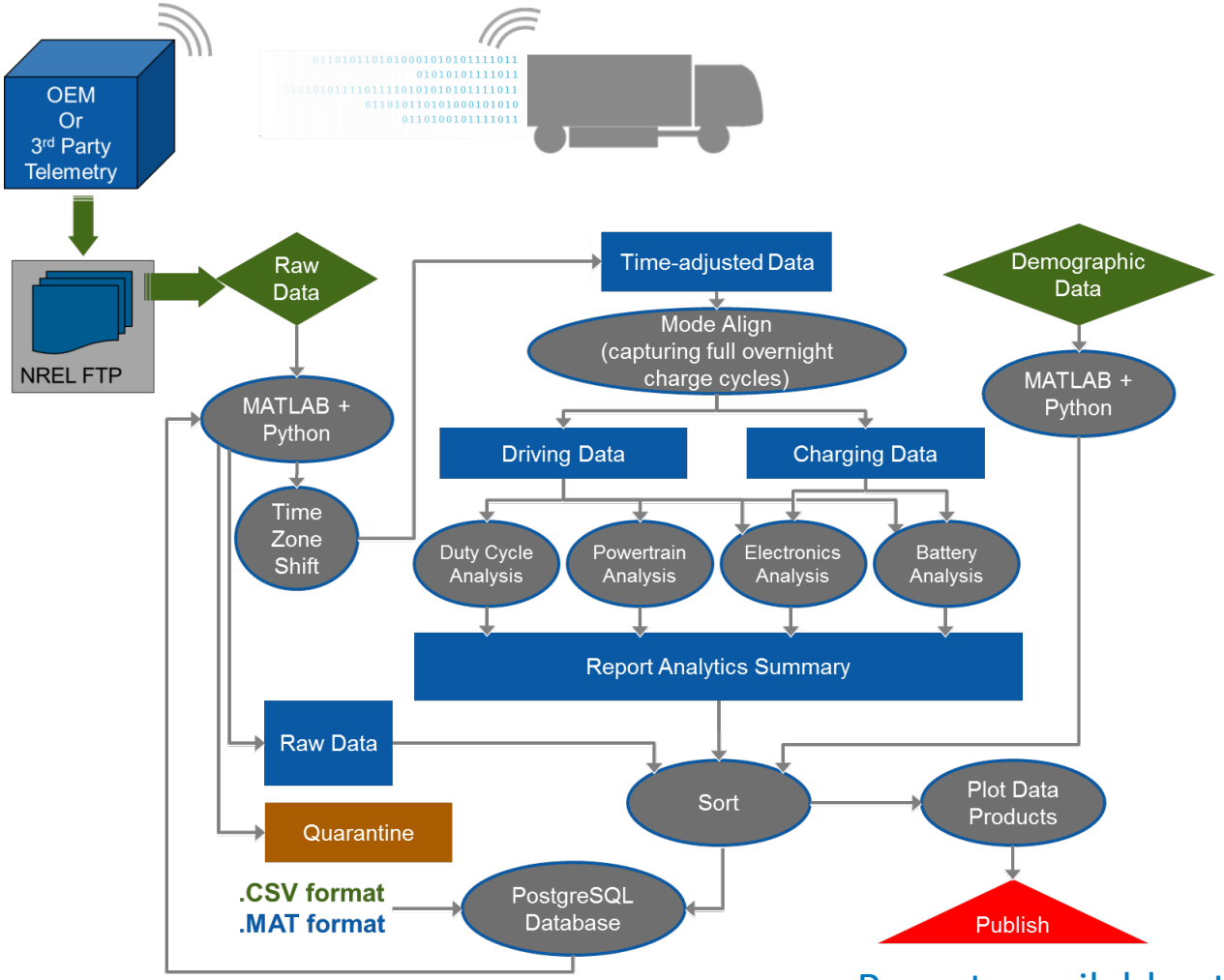
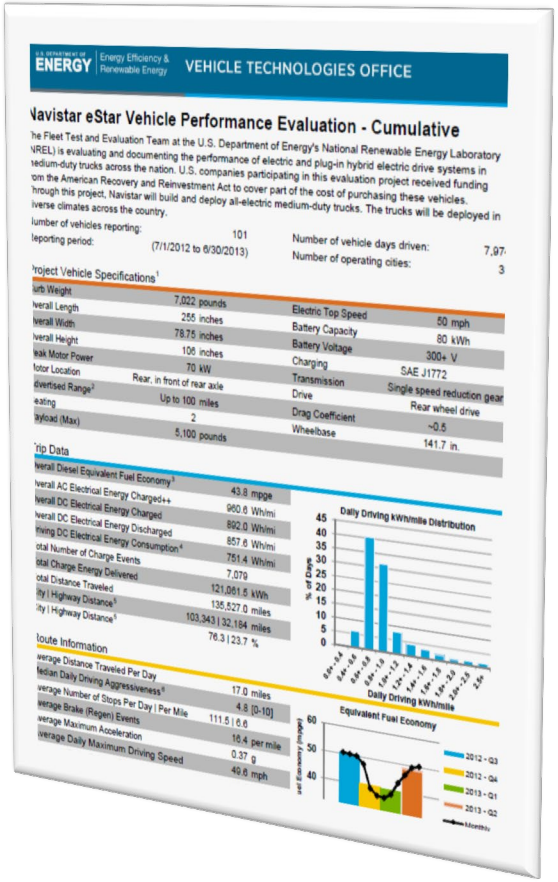
Approach/Strategy

Data Processing Routine – Receive, Filter, Analyze





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