Advanced Wireless Power Transfer Vehicle and Infrastructure Analysis

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National Renewable Energy Laboratory

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Project ID # VSS130

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.

Overview

Timeline

- **Project Start Date: October 2013**
- **Project End Date: September 2014**
- **Percent Complete: 50%**

Budget

- **Total Project Funding: $200K (all DOE FY14)**
- Project also builds on $250K FY13 Interstate Electrification Modeling & Simulation effort

DOT = Department of Transportation
NREL = National Renewable Energy Laboratory
ORNL = Oak Ridge National Laboratory

Barriers

- **Risk Aversion**
- **Cost of Vehicle Electrification**
- **Infrastructure**

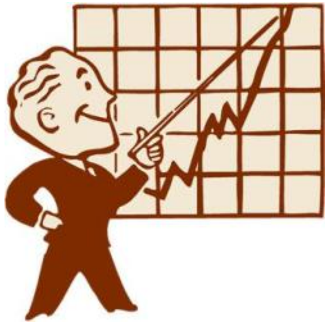
Partners

- ORNL – technology development, feasibility study collaborator
- Industry – inputs on technology capability/costs, modeling tools and assumptions
- DOT – complementary analysis under the Clean Transportation Sector Initiative
- Project Lead – NREL

Relevance to DOE Fuel-Saving Mission

- **Increased electric energy available to a vehicle → Increased fuel displacement**
- **Potential BEV enabler**
  - Recharging while driving would mitigate range anxiety
  - Could improve market penetration and aggregate fuel savings

- **Opportunity to improve electrification cost effectiveness**
  - For BEVs, PHEVs and HEVs
  - Smaller, more affordable energy storage configurations may realize fuel displacement similar to a large-battery plug-in vehicle
  - Improve sales and total fuel savings



BEV = battery electric vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle

Photo from iStock/7579060

Relevance to Addressing Barriers

- **Risk aversion**
  - Very much an emergent area with significant uncertainties and risks
  - Manufacturers therefore are unlikely to pursue aggressively
  - DOE investment is warranted, given potentially large national benefits if successful (this project is helping quantify benefits/impacts)
- **Cost**
  - Remains a barrier to widespread penetration of electrified vehicles
  - WPT may improve the cost vs. benefit and marketability of electrified vehicle technologies
- **Infrastructure**
  - Critical to coordinate R&D and analyze potential issues in parallel with vehicle and component investigations

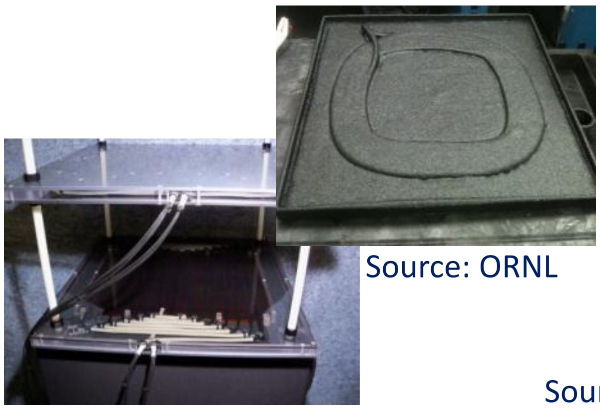
WPT = wireless power transfer

Milestones

Date	Milestone or Go/No-Go Decision	Description	Status (as of April 2014)
12/31/2013	Milestone	Progress update.	Completed
3/31/2014	Milestone	Progress update.	Completed
6/30/2014	Milestone	Progress update.	On track
9/30/2014	Milestone	Report on cost vs. benefit comparison of WPT systems optimization scenarios.	On track

Approach/Objective: Conduct Broad Vehicle Impact Assessment, Independent of WPT Technology

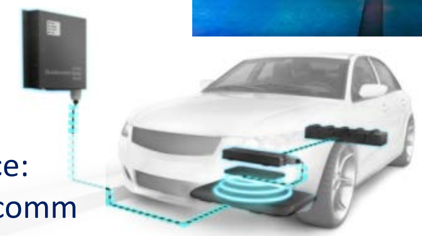
- **Assume various infrastructure penetration scenarios**
  - Consider both quasi-stationary & (farther out) in-motion implementations
  - Could be satisfied by a variety of technologies



Source: ORNL

Source: Utah State University

Source: KAIST



Source: Qualcomm

Source: WiTricity WT-3300 Data Sheet

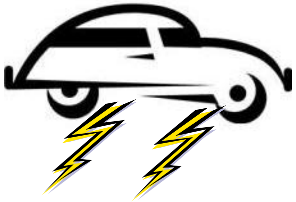
Source: Momentum Dynamics

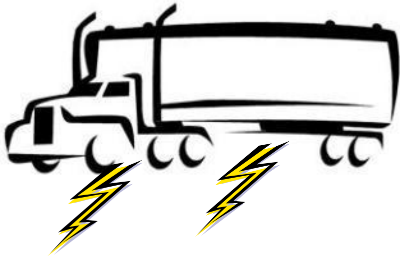
Source: Volvo Group

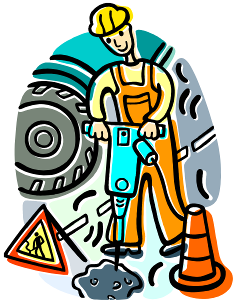
Source: Siemens

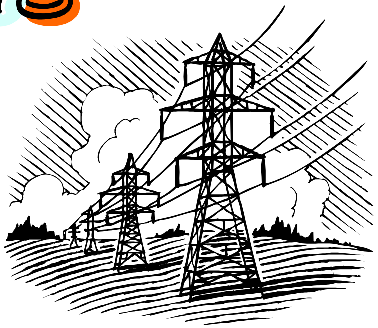
Approach: Consider Range of Vehicle Vocations, Powertrains, and Impact Areas

- **Potential vehicle sizes/vocations**
  - Light-duty (LD)
  - Heavy-duty (HD) Class 8 truck
  - Medium-/heavy-duty (MD/HD) delivery vehicle and transit bus
    - Particularly for quasi-stationary
- **Potential vehicle powertrains**
  - Conventional (CV) baseline
  - E-roadway enabled HEV, PHEV or BEV
- **Areas of impact for different approaches/penetration levels**
  - Vehicle performance and capital/operating cost
  - Road infrastructure
  - Electrical/grid infrastructure



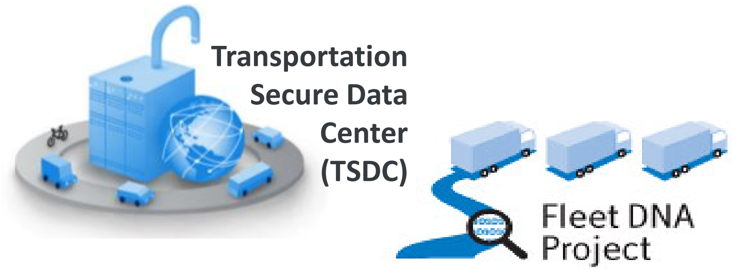


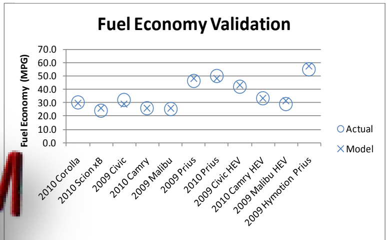


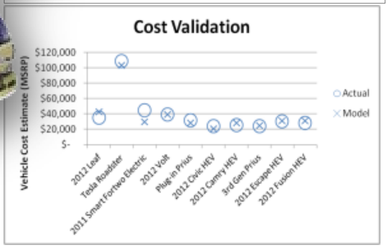


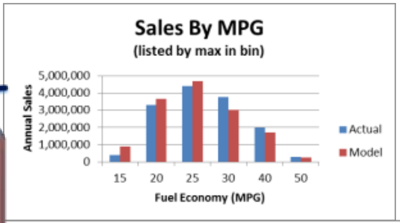
Approach: Factor Together Operating Behavior, Powertrain Performance and Adoption Estimates

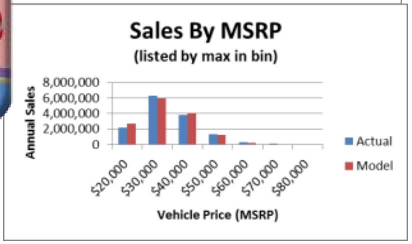
- **Analyze real-world operating profiles, linked to road infrastructure**
  - Databases with ≈3.5M driving miles from ≈12K LD, MD & HD vehicles
- **Powertrain simulations over profiles**
  - Validate baseline models against test data
  - Add WPT capability; simulate fuel use and electricity consumption
- **Aggregate impacts analysis**
  - Estimate LD market adoption
  - Calculate commercial vehicle net present cost









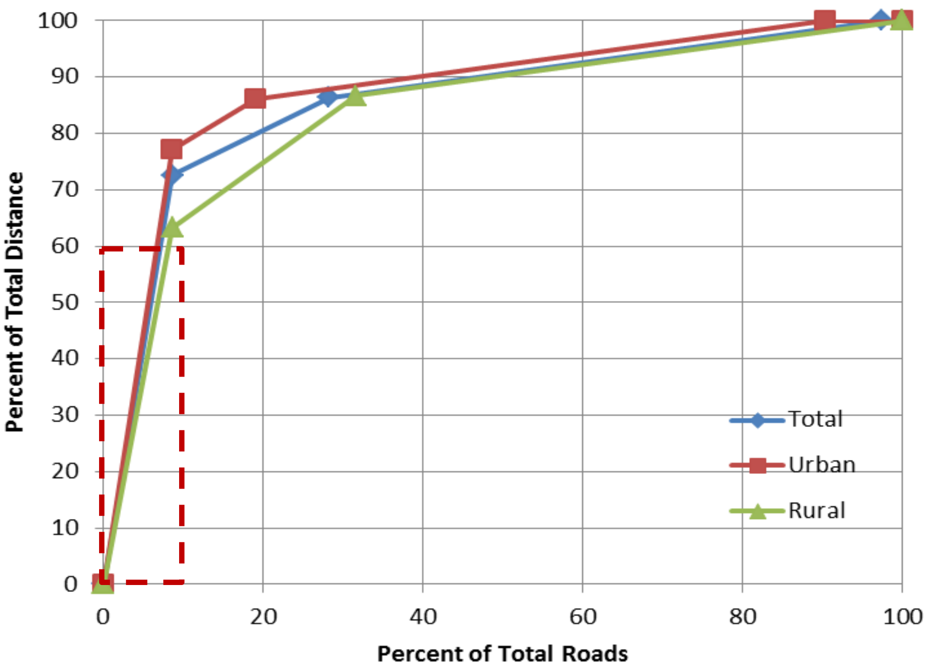


Leveraging extensive data and well-validated analysis tools

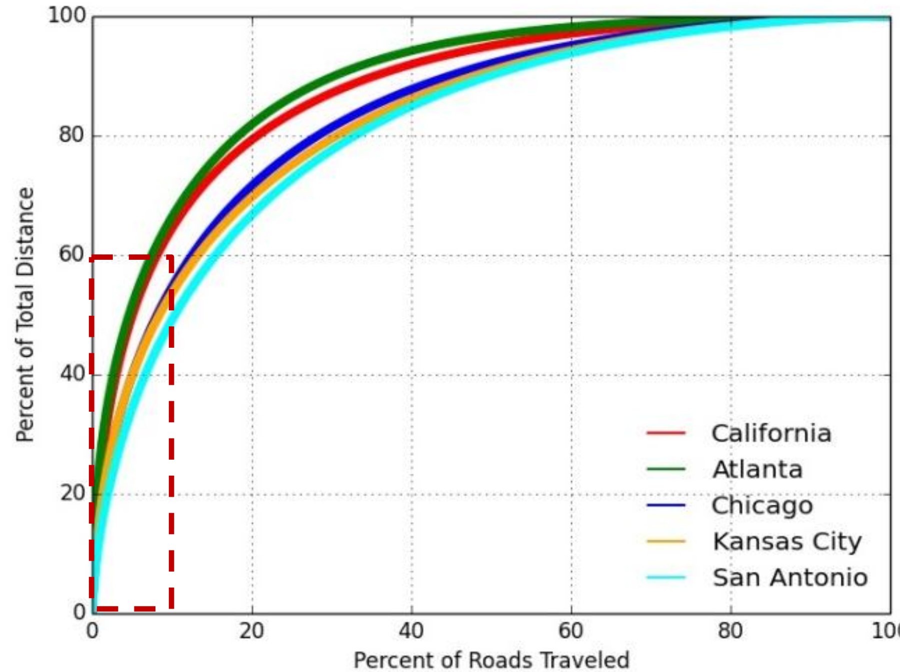
ADOPT = Automotive Deployment Options Projection Tool
FASTSim = Future Automotive Systems Technology Simulator

Accomplishments: Examined Road Infrastructure Utilization Across Geographies

National Level



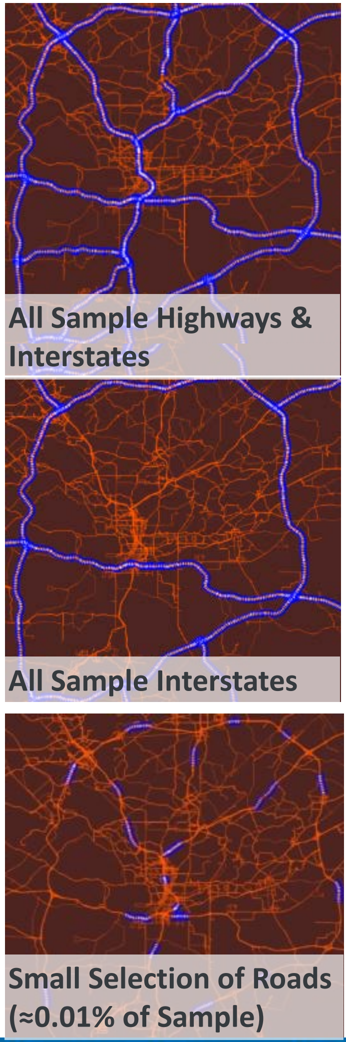
State/Metro Area Level

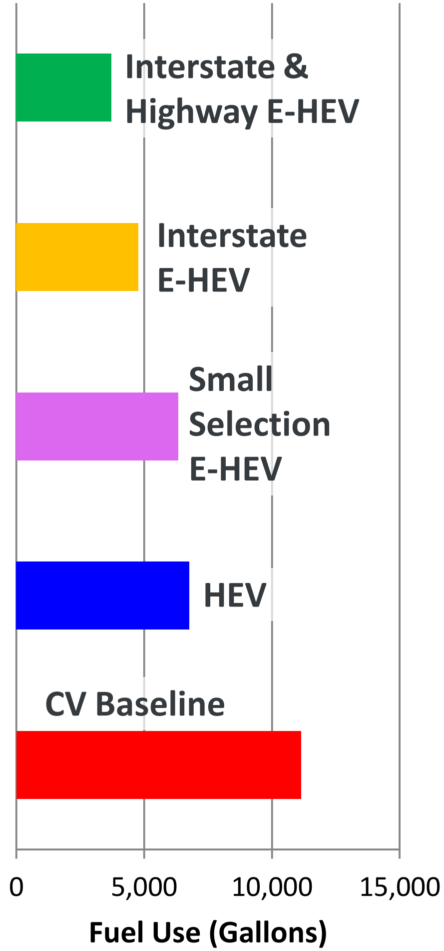


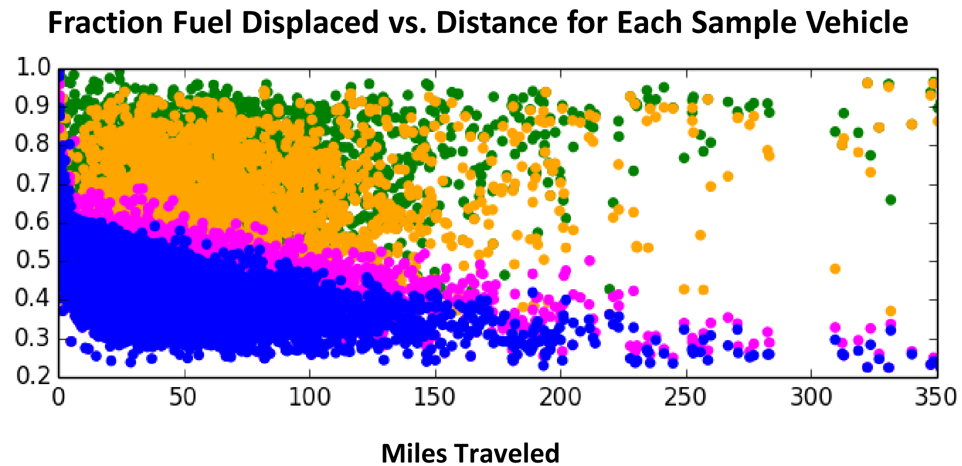
- **Identified potential for small fraction of in-motion WPT infrastructure to cover significant amount of travel**
  - Opportunity to maximize benefit/cost ratio
  - 1% of infrastructure would cover 15%–20% of travel
  - 10% of infrastructure would cover ≈60% of travel

Accomplishments: LD Fuel and Electricity Consumption Assessment for Various Scenarios

E.g., Atlanta vehicle sample simulations for different powertrains and WPT coverage cases







- **Very large savings from interstate coverage**
  - Still a relatively small fraction of roads in the sample
  - Savings maintained for long distances
- **Working to optimize incremental rollout strategy**

E-HEV = electric roadway enabled HEV

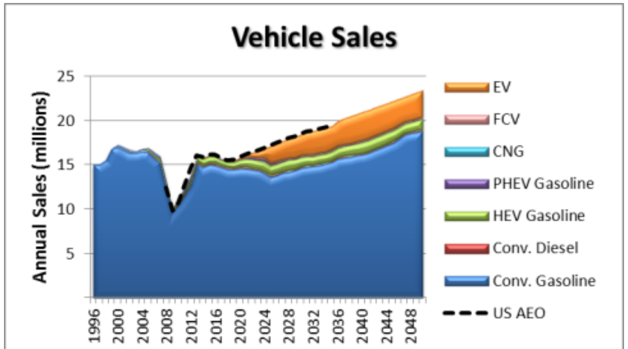
Initial Results

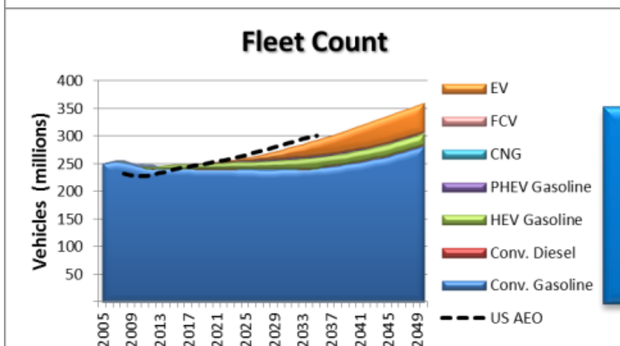
Further refinement ongoing

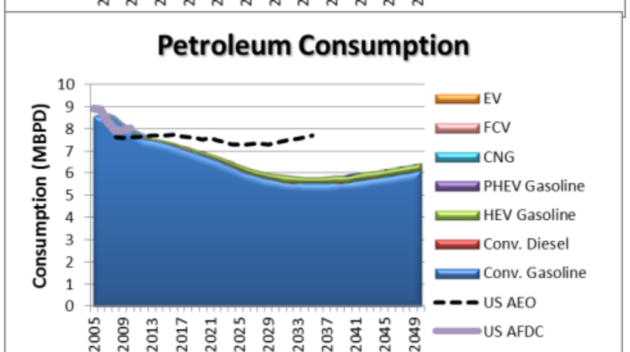
Accomplishments: Estimating Impact on LD Vehicle Adoption for Various Market Conditions (Interstate E-HEV)

- **Achieve 10-year battery cost reduction targets**
  - E-roadway helps overcome BEV range limitations

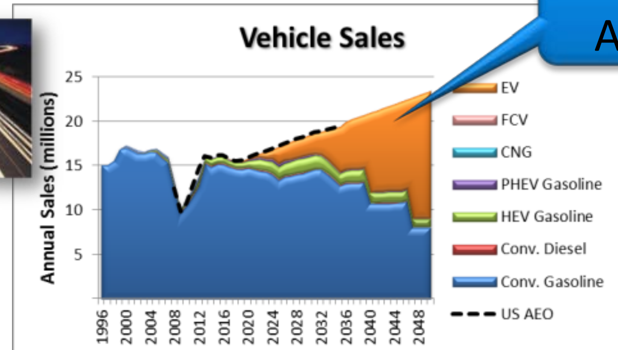
Large BEV Adoption

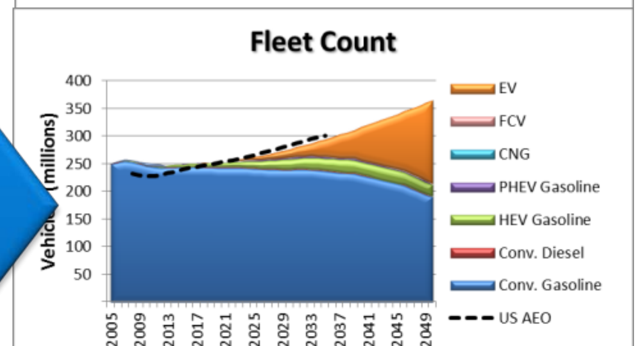


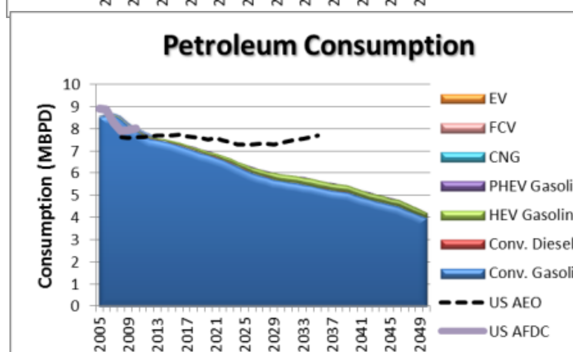




Electric Roadway



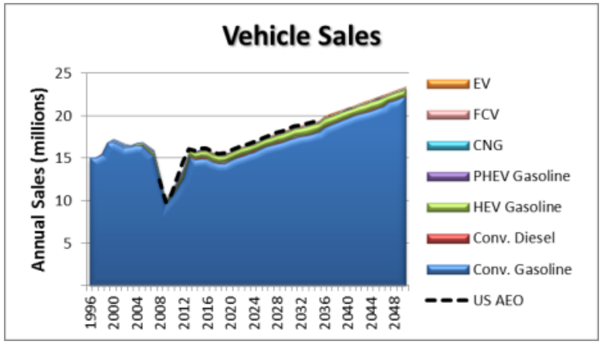


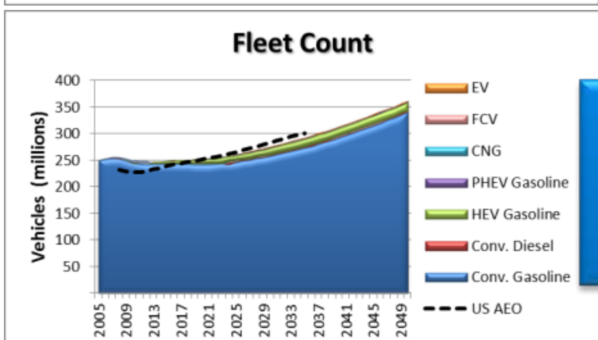


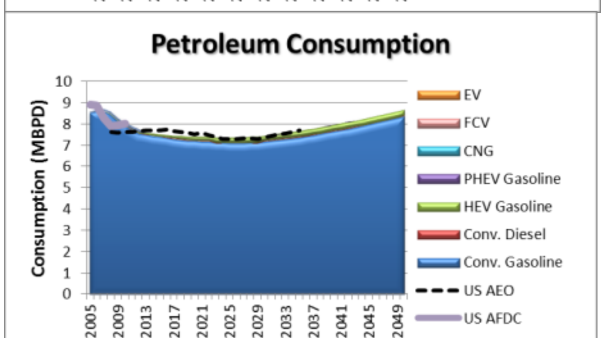
Initial Results
Further refinement ongoing

Accomplishments: Estimating Impact on LD Vehicle Adoption for Various Market Conditions (Interstate E-HEV)

- **Mild technology improvements** **(absent engine downsizing for CAFE)**
  - E-HEV operating cost advantage spurs adoption

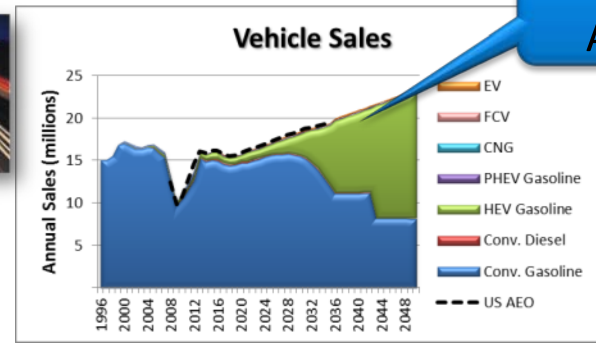


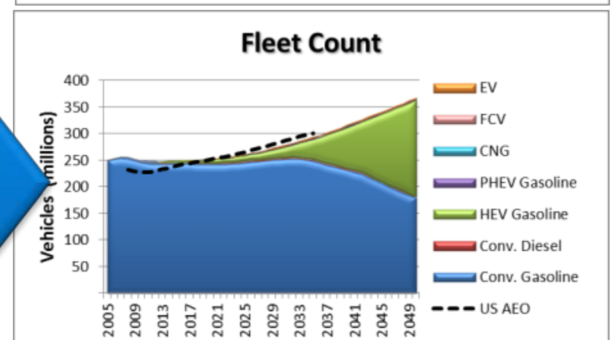


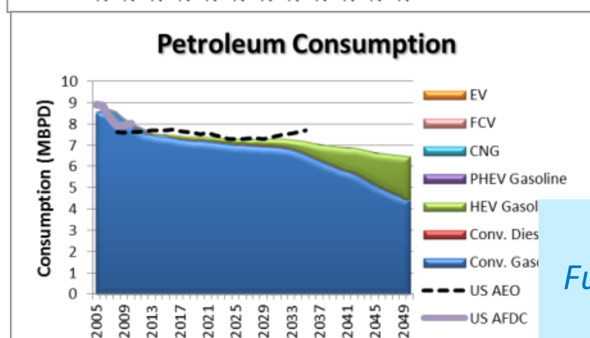


Electric Roadway

Large E-HEV Adoption







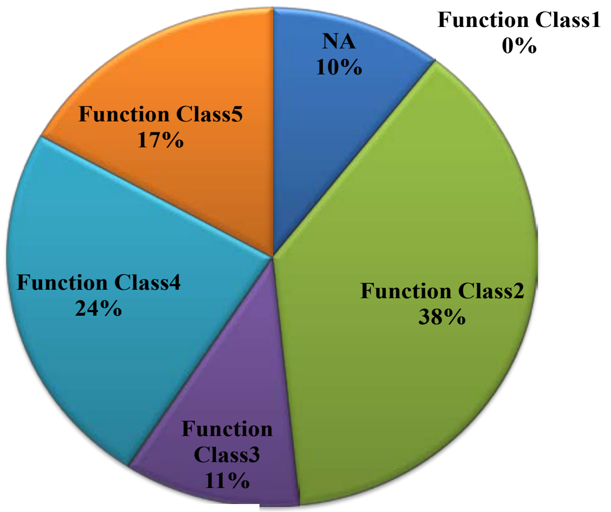
CAFE = Corporate Average Fuel Economy

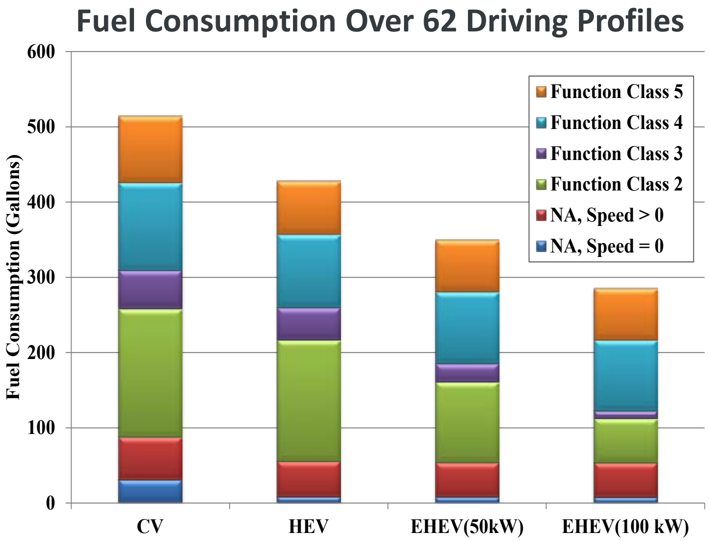
Initial Results

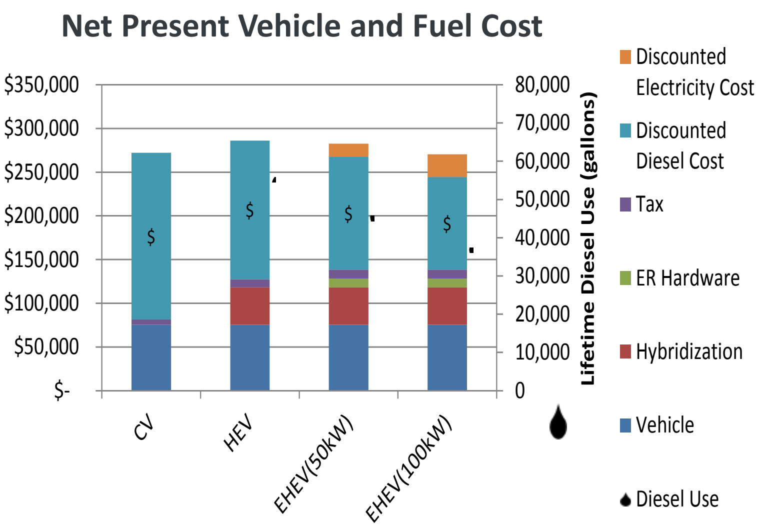
Further refinement ongoing

Accomplishments: Examining Class 8 Truck Operating Behavior, and Potential E-HEV Impacts (regional delivery straight truck)

- **Leveraged Fleet DNA data, CV and HEV truck testing**
  - Half of miles on Functional Class (FC) 2 and 3
- **Consider aggressive FC2 & FC3 E-HEV scenarios**
  - Increasing fuel displacement
    - Also increases with E-roadway power
  - Comparable net present cost





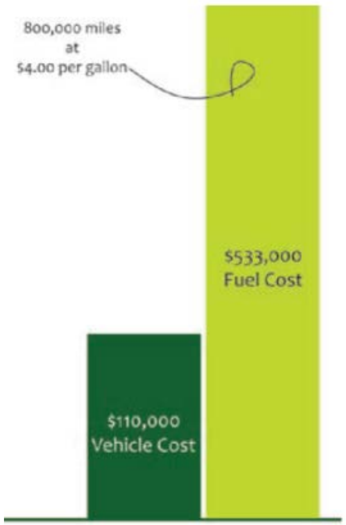


FC1 = High-capacity Interstate; FC5 = Low-capacity neighborhood streets

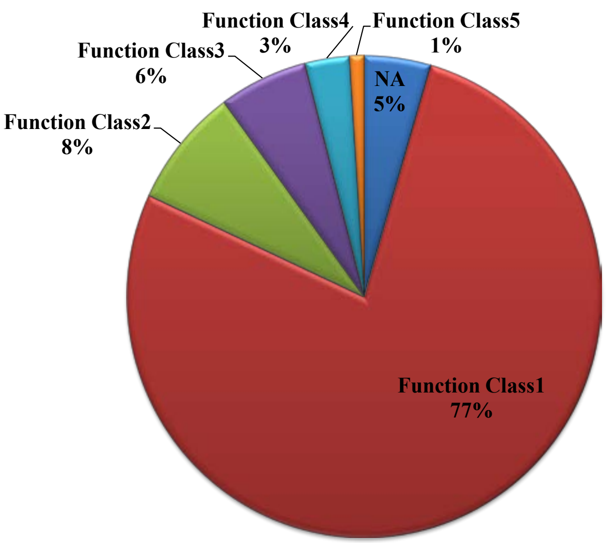
Initial Results
Further refinement ongoing

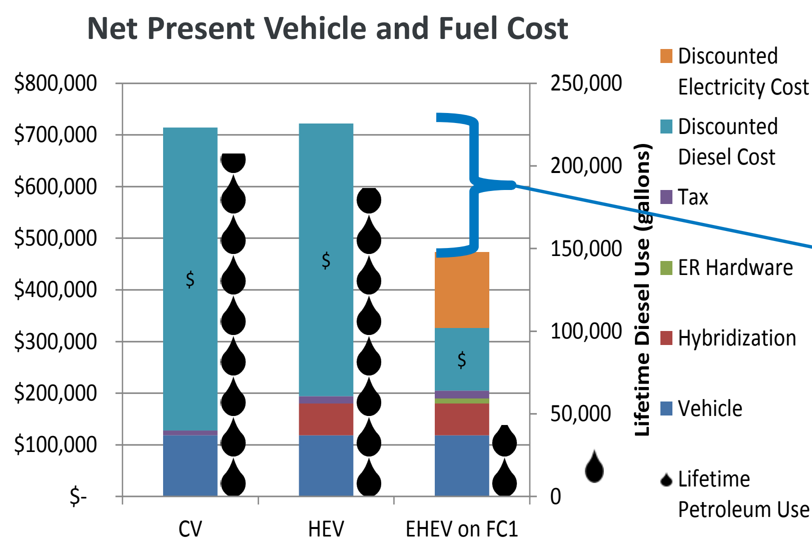
Accomplishments: Examining Class 8 Truck Operating Behavior, and Potential E-HEV Impacts (long-haul tractor-trailer)

- **High miles, operating costs and specific infrastructure usage**
- **Consider high-power FC1 E-HEV scenario**
  - Leveraging long-haul hybridization enhancements
  - Results in major fuel and cost savings



From DOE Report on Class 8 Truck R&D*





Potential margin each vehicle could contribute to infrastructure cost (and still pay back)

* See https://www1.eere.energy.gov/vehiclesandfuels/pdfs/truck_efficiency_paper_v2.pdf

Initial Results
Further refinement ongoing

Collaboration and Coordination

- **Industry**
  - OEMs and WPT developers such as Volvo, Qualcomm, WAVE, OLEV, etc.
- **ORNL**
- **DOT Clean Transportation Sector Initiative**
  - Supporting analysis by NREL's Electric Vehicle Grid Integration team—exploring incremental generation costs, reduced renewable energy curtailment, etc.

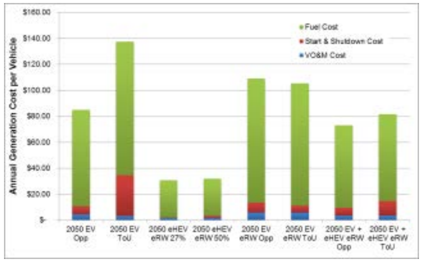
WPT Technology Costs; Feedback on Analysis Tools and Assumptions; Information from Standards Development

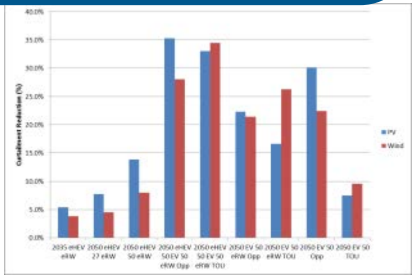
Comparing Market Adoption Estimates; Contributed Line-Haul Truck Data into Fleet DNA

Road/Grid Infrastructure Impacts and Costs

Additional collaboration with DOE VTO Analysis Program on ADOPT

OEM = original equipment manufacturer





Responses to Previous Year Reviewers' Comments

Comments	Responses
"…expand on stakeholders to include U.S. DOT efforts on electrified roadways"; "…take into account the changes in the future brought about with the DOE SuperTruck program with the development of hybridization for long haul, over-the-road trucks."	These have been done and are explicitly included in the presentation.
"…should check impact of EVs on GHG, or state assumption that EV energy source is 100% renewable."	Default assumption is average grid mix; will be clarified when presenting GHG results.
"…important project …builds on the substantial database that NREL has available, which makes them uniquely positioned to do this work."; "…all topical aspects appear to be covered: consumer preference modeling, dynamometer test data, Class 8 truck duty cycles, and passenger car GPS profiles."	Retain these elements for the work completed since the last review period.

GHG = greenhouse gas (emissions)

Remaining Challenges and Barriers

- **Need to complete partner and internal review on initial results**
  - Refine as needed
  - Address gaps from still-to-be-completed scenario analyses
- **Need to consider potential transition paths from zero infrastructure to one of the favorable scenarios**
  - Where to build first?
- **Having answers prepared for stakeholders who would make future implementation decisions**
  - What would the expected total implementation costs be?
  - How would these compare to the potential benefits?
  - How might the analysis change when applied to a specific location under consideration?

Proposed Future Work

- **Refine analyses and evaluate additional scenarios**
  - Including quasi-stationary (bus stop/truck loading dock WPT)
- **Complete incremental roll-out analyses**
  - Identify optimal initial locations to maximize benefits
  - Use in-motion WPT to enable MD/HD HEV engine downsizing?
    - E.g., installing in high power demand hill climb locations
- **Conduct rigorous cost/benefit analysis across scenarios**
  - Collaborating with partners on road/grid infrastructure costs
- **Perform case study with interested municipality or other partner**
  - Apply information learned from scenario analyses to assess the viability of specific early pilot locations

Summary

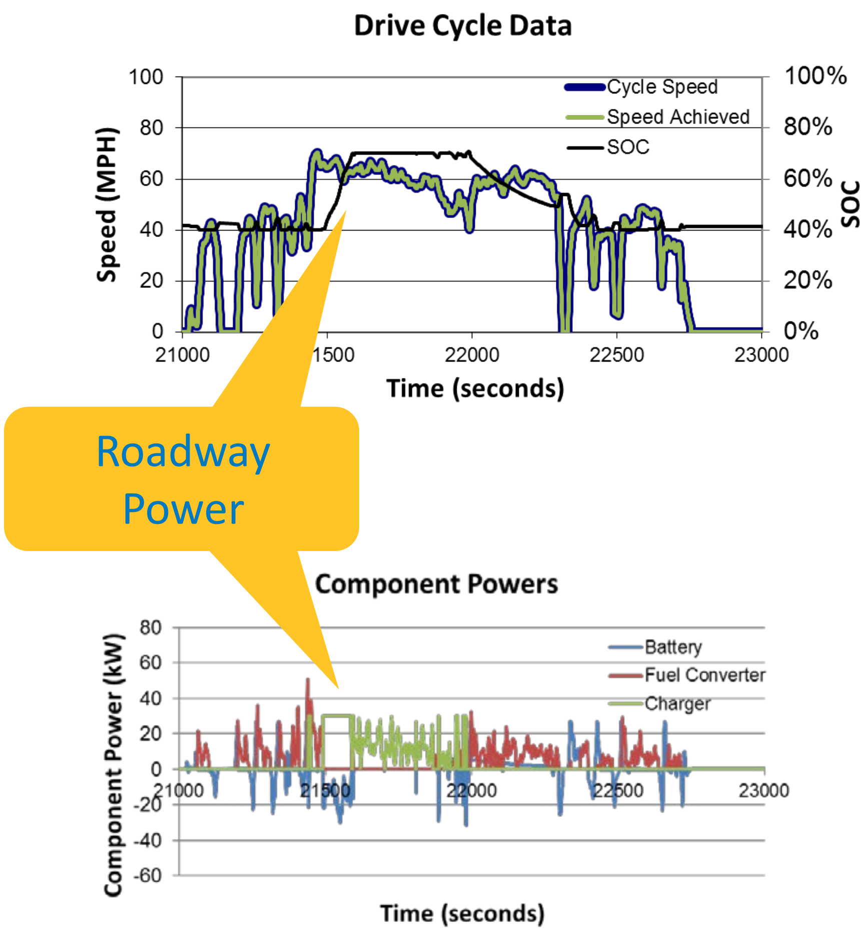
- **Analysis project looking beyond stationary WPT**
  - Considering long-term potential for quasi-stationary and in-motion WPT to increase electrified vehicle viability and aggregate fuel savings
- **Integrating multiple techniques and scenario dimensions**
  - Real-world travel data
  - Test data and partner inputs
  - Powertrain modeling
  - Market adoption estimates
  - WPT type and penetration level
  - Powertrains from CV & HEV to BEV
  - Vocations (LD, MD & HD)
  - Vehicle and infrastructure impacts
- **Initial results show potential long-term in-motion WPT considerations**
  - Large utilization from small fraction of infrastructure
  - Large individual and aggregate fuel displacement under certain scenarios
- **Many factors influence results, will be further explored**
  - Market conditions, evolution of the baseline fleet in response to CAFE
  - Optimal roll-out (e.g., from 0%–1% infrastructure coverage) for WPT?
  - Complete analyses of quasi-stationary/lower-speed scenarios

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.)

Integrated Electric Roadway Powertrain Modeling

- **Added electric roadway to FASTSim**
- **Power availability/level is designated by road class**
- **Benefits: FASTSim captures**
  - Real world driving
  - Component power limits
  - Regenerative braking
  - Charging by roadway type
  - Fuel cost
  - Vehicle cost
  - Acceleration
  - Battery life



SOC = state of charge

Assumptions for Draft Class 8 Truck Cost vs. Benefit Analysis

Inputs	Straight-Truck Assumption	Tractor-Trailer Assumption
Vehicle life (years)	19	19
Beginning of life annual miles	30,000	120,000
End of life annual miles travelled	7,000	30,000
Conventional vehicle cost	$70,000	$110,000
Hybridizing cost increment	$42,900	$61,450
Additional E-HEV cost increment	$10,000	$10,000
Diesel cost	$3.98/gal	$3.98/gal
Electricity cost	$0.12/kWh	$0.12/kWh
Discount rate	4.2%	4.2%
Sales tax	7.8%	7.8%

Additional Details on the Transportation Secure Data Center (TSDC)

- **Secure Archival of and Access to Detailed Transportation Data**
  - Travel studies increasingly use GPS → valuable data
  - TSDC safeguards anonymity while increasing research returns
- **Validation, Analysis, and Reporting Functions**
  - Advisory group supports procedure development and oversight
  - Original data are securely stored and backed up
  - Processing assures quality and creates downloadable data
  - Cleansed data are made freely available for download
  - Secure portal provides access to detailed spatial data

Sponsored by the U.S. DOT Federal Highway Administration and the U.S. DOE Vehicle Technologies Office
Operated by the NREL Transportation and Hydrogen Systems Center (THSC)
Contact: Jeff.Gonder@nrel.gov

www.nrel.gov/tsdc

Additional Details on the Fleet DNA Project

Captures and quantifies drive cycle and technology variation for the multitude of <u>medium and heavy duty</u> vocations

For Government: Supplies information for drive cycle development, R&D programs, and rule making

For OEMs: Provides better understanding of customer use profiles

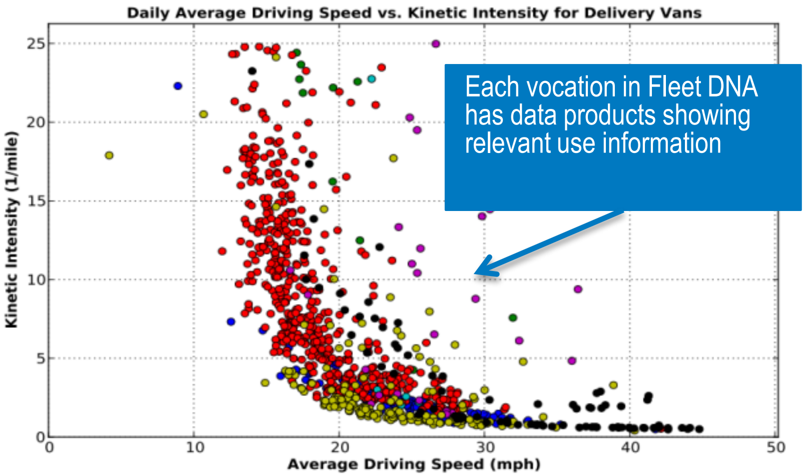
For Fleets: Explains how to maximize return on vehicle technology investments

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

For Researchers: Provides a data source for modeling and simulation

Participants/Partners:

- OEMs, fleets, national labs, federal and state agencies
  - Examples: Paccar, Smith, ORNL, DOT, California Energy Commission, South Coast Air Quality Management District

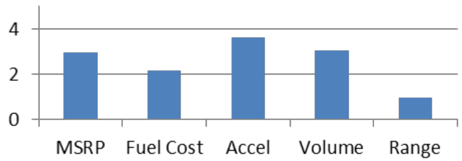


Additional Details on the Automotive Deployment Options Projection Tool (ADOPT)

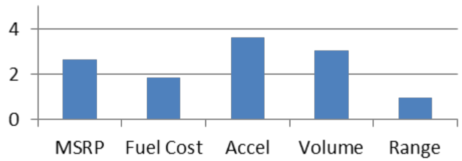
- **Consumer preferences change based on income**

Relative importance by income bin

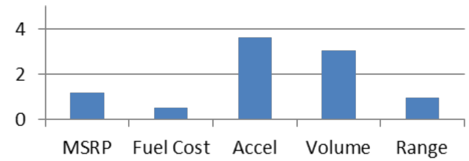
$75-100K



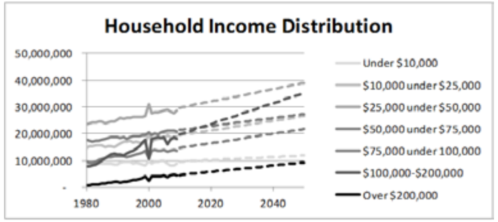
$100-200K

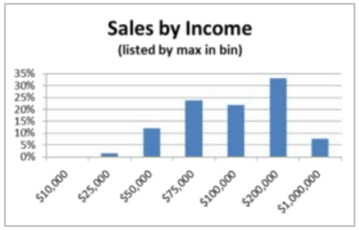


>$200K



- **Income levels change over time, and number of sales vary by income**





- **Competes advanced vehicles with entire existing fleet**
- **Successful models are duplicated (more options for the consumer)**
- **Extensive validation**
  - Multiple years
  - 10 different regions
  - 10 dimensions