Analysis of In-Motion Power Transfer for Multiple Vehicle Applications




PI: Jeff Gonder (NREL)
Team: Aaron Brooker, Evan Burton, and Tony Markel

DOE Vehicle Technologies Annual Merit Review
May 15, 2013

Project ID #: VSS105

Overview

Timeline

Project Start Date: Sept 2012

Project End Date: Oct 2013

Percent Complete: 50%

Budget

Total Project Funding: $415k

Funding Received in FY12: $165k

Funding for FY13: $250k

Barriers Addressed

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

Partners (more on later slide)

- ORNL – Lead for dynamic WPT feasibility study; input on WPT device assumptions
- ANL & INL – Input on light-duty PEV lab and field test data
- Industry – Additional input on WPT device and vehicle/ implementation assumptions

WPT = wireless power transfer; ORNL/ANL/INL = Oak Ridge/Argonne/Idaho National Laboratories

Relevance for DOE Fuel-Saving Mission

- **Increased electric energy available to a vehicle → Increased fuel displacement**

- **Potential BEV enabler**
  - In-motion recharging 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

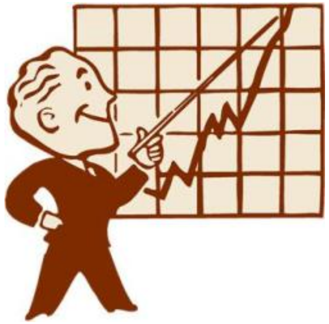


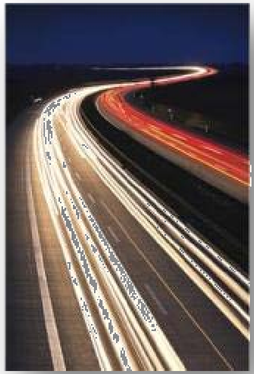
Photo from iStock/7579060

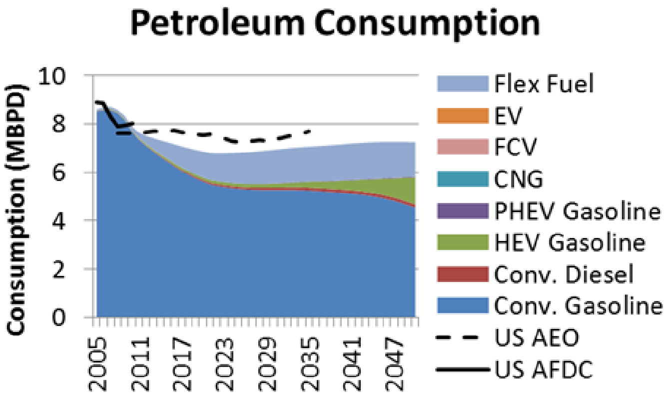
Relevance for Addressing Barriers

- **Risk aversion**
  - Very much an emergent area with significant uncertainties and risks
  - Manufacturers therefore unlikely to pursue aggressively
  - DOE investment warranted, given potentially large national benefits if successful (this project will help better quantify benefits)
- **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

Objectives

- **Establish/apply a comprehensive analysis methodology**
- **Quantify petroleum consumption and GHG emission impacts**
  - Capture interaction between input assumptions
  - Evaluate marketability and resulting aggregate impact potential
  - Consider multiple vehicle and implementation approaches
- **Coordinate efforts with ORNL and other partners**





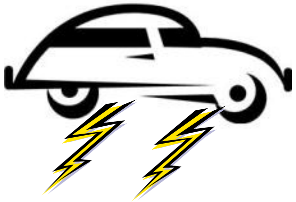
GHG = greenhouse gas

Milestones

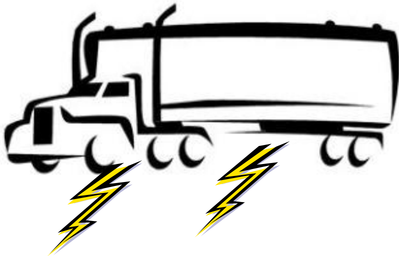
Date	Description	Status (as of March 2013)
May 2013	Dynamic Wireless Power Transfer Technology Report	On track
Sept 2013	Report on Cost/Benefit Analysis of Interstate Electrification with Commercial Trucks	On track

Approach: Overview

- **Analyze technology potential**
  - In coordination/collaboration with partners
  - Baseline modeling supported by validation data
  - Informed by real-world vehicle usage and market drivers
  - Considering multiple road, vehicle, drive cycle scenarios
    - With and without roadway electrification
    - Including system integration analyses
- **For passenger vehicles**
  - Real-world driving data from travel surveys
  - Consumer choice model predicts market penetration, aggregate petroleum, and GHG impacts

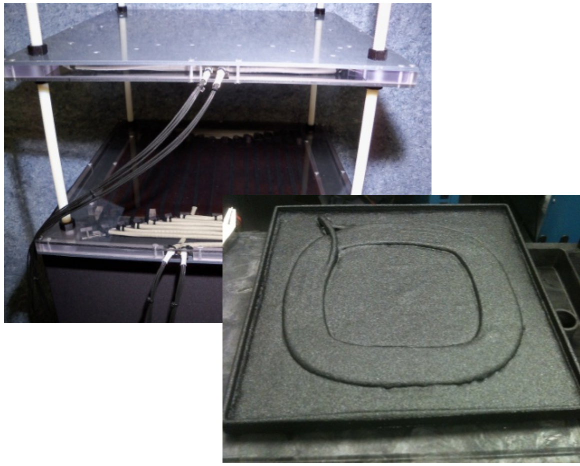


- **For commercial vehicles**
  - Draw from fleet driving data
  - Net present value/payback analysis for economic viability
  - Particular focus on Class 8 trucks (large fuel user)

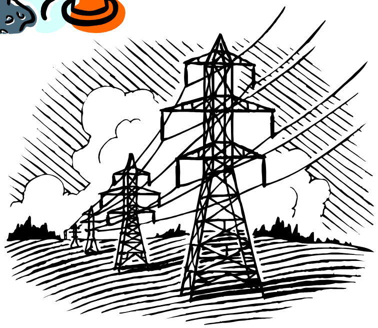


Approach: Technology Analysis

- **Coordinate with partners (ORNL & others)**
  - Device power, efficiency, and costs
  - Impact of separation gap and misalignment
  - Commercial system comparisons
- **Consider fuel savings and cost sensitivities**
  - Infrastructure type and penetration
  - Device power, spacing, efficiency, and alignment
  - Different vehicle classes and powertrain types
- **System integration analysis**
  - Construction and maintenance implications
    - Leverage DOT interactions
  - Magnitude and timing of additional grid load
  - Rough assessment of V2I communications
    - Correlation with DSRC attributes



Photos courtesy of ORNL



V2I = vehicle to infrastructure; DSRC = dedicated short-range communication

Approach: LD Vehicle Evaluation Tools and Techniques

- **Real-world GPS data**
  - Multiple cities in NREL's TSDC
  - Driving type and location/road overlap
- **Powertrain model for costs vs. fuel use**
  - Rapidly evaluate many scenarios
  - Range of inputs and considerations
    - Driving distribution, battery life, component costs, and efficiency characteristics
    - Vehicle performance and fuel economy
    - Conventional, HEV, PHEV, BEV powertrains
- **Consumer choice model for market prediction**
  - Consider vehicle characteristics, fuel prices, income distribution, infrastructure availability
  - Additional details in back-up slide section

LD = light-duty; GPS = global positioning system; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle

Transportation Secure Data Center

Future Automotive Systems Technology Simulator

Automotive Deployment Options Projection Tool

Approach: Link for Aggregate Impact Estimation

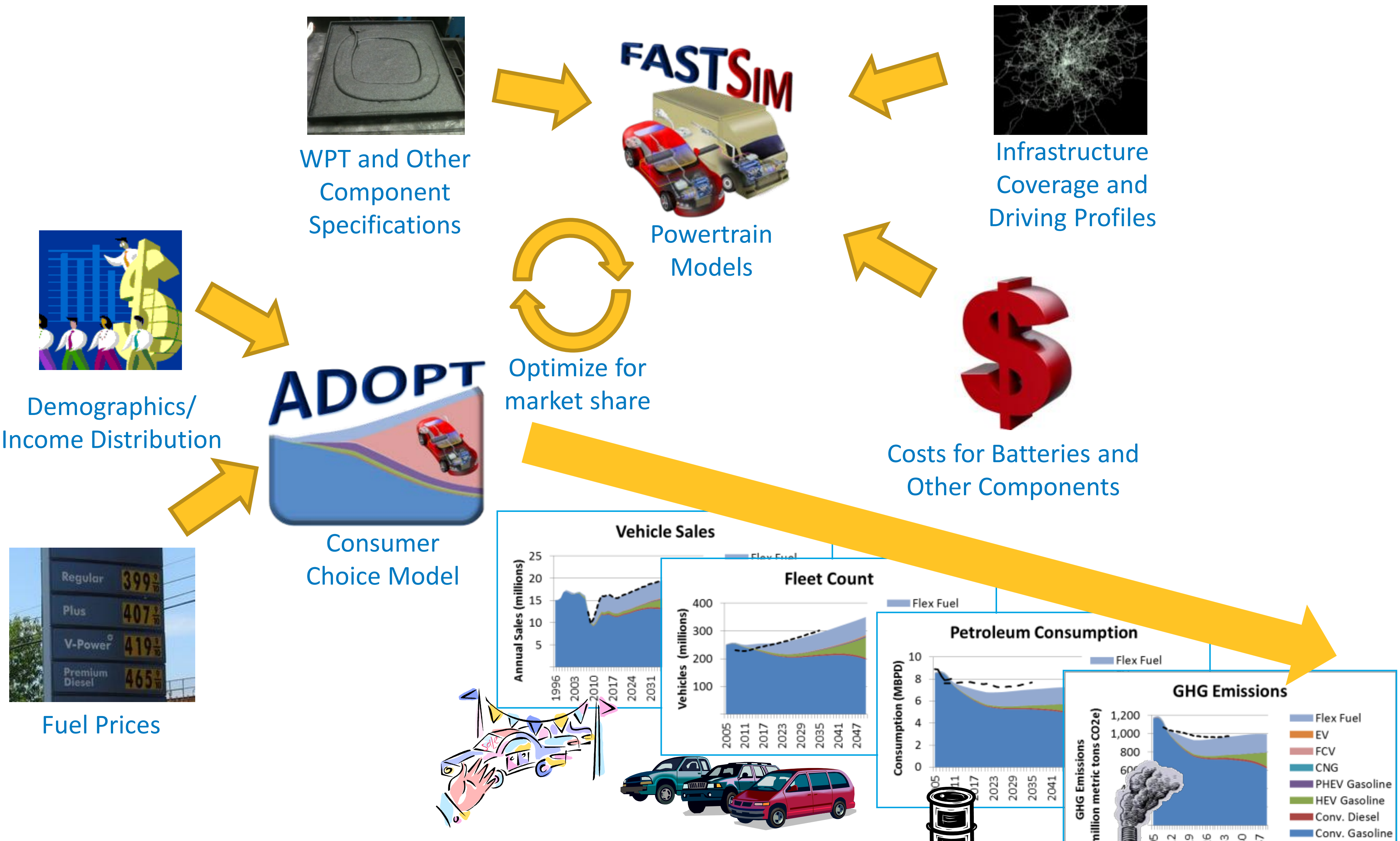
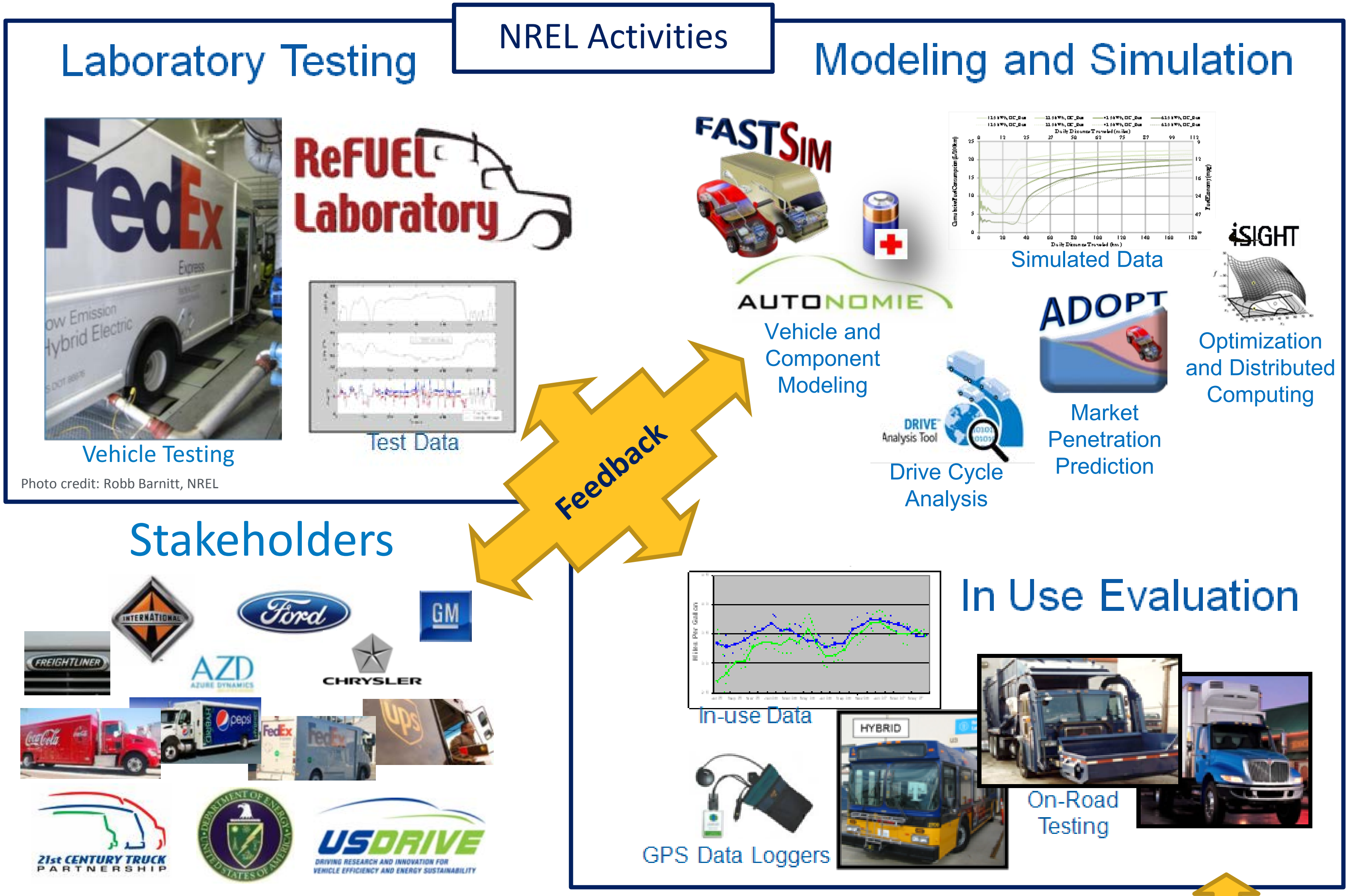


Photo by Keith Wipke, NREL 15986

Approach: Coordinate with Industry, Lab and Field Testing for Commercial Vehicle Modeling → Cost vs. Benefit Analysis

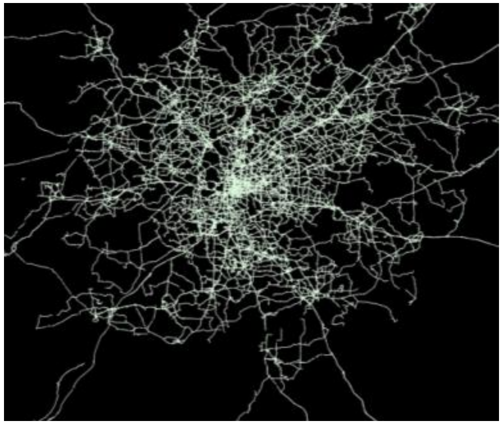


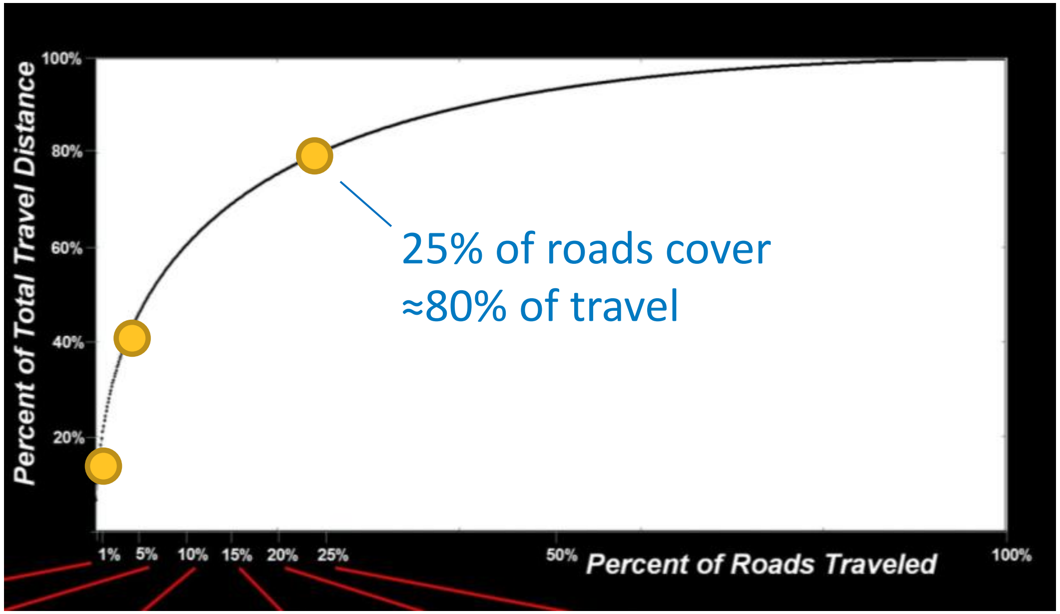
- **Additional ORNL collaboration (Class 8 truck data)**

Accomplishment:
Explored Travel Distribution Across the Road Infrastructure

- **Evaluated GPS data**

Atlanta Dataset





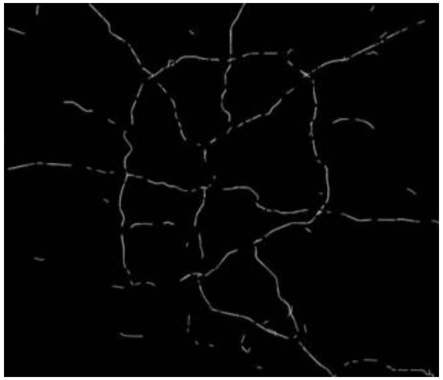
- **Found that a significant amount of travel occurs on a small fraction of roads**
  - If 1% of roadways electrified, 17% of travel would be covered
  - At 5%, ≈40% of travel would be covered
  - At 25%, ≈80% of travel would be covered

Significance

- **Shows that relatively little infrastructure can cover a significant amount of travel (minimizes costs and maximizes benefits)**

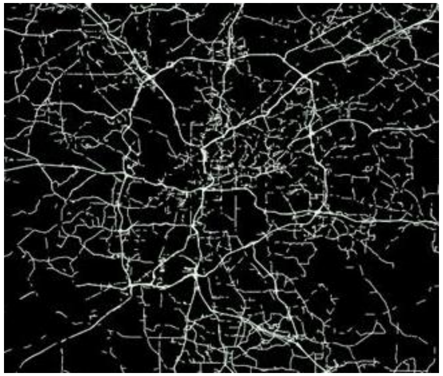
Accomplishment: Examined Infrastructure Placement

- **Evaluated spatial coverage of most heavily-traveled roads**
  - Match between heavy travel and high-utility roads, e.g., Interstate highway
  - Interstate electrification would enable BEVs to travel beyond a roughly 50-mile radius to anywhere across the country

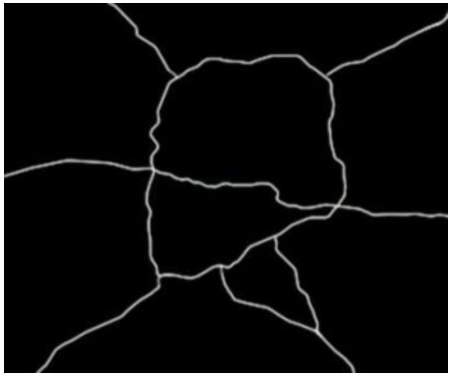


1% Roadway
17% Travel

5% Roadway
≈ 40% Travel



25% Roadway
≈ 80% Travel



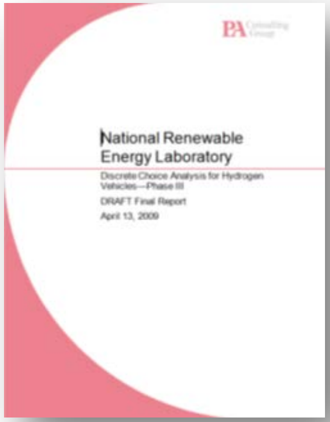
Interstate Highway

Significance

- **Identifies opportunity to improve consumer preference for BEVs**
  - Mitigates low range and slow recharge drawbacks that otherwise prevent long-distance trips

Accomplishment: Incorporated Model Enhancement for Infrastructure Rollout

- **Added infrastructure rollout impact on consumer preferences**
  - Based on research from PA Consulting
  - Survey refined three times to ensure best possible results
  - Preference based on three parameters:
    - Metro area coverage
    - Medium distance coverage (within 150 miles of metro area)
    - Long distance coverage


PA

National Renewable Energy Laboratory

Discrete Choice Analysis for Hydrogen Vehicles—Phase III

DRAFT Final Report

April 13, 2009

Significance

- **Key to estimating a city-by-city approach to rolling out electric roadway infrastructure**

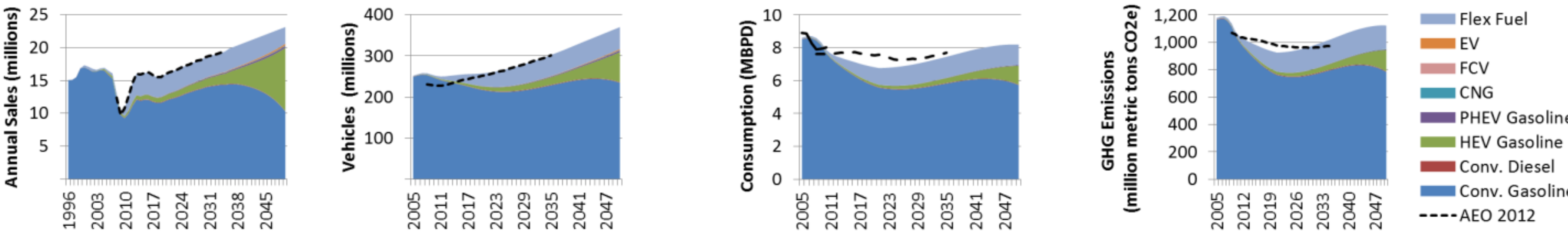
- **Enables electric roadway rollout impact analysis to help determine**
  - The best approach
  - The corresponding impact on market adoption

Accomplishment: Initial Estimates of Electric Roadway Impact on Petroleum Use and GHG Emissions

Draft results from integrated passenger vehicle modeling and market approach

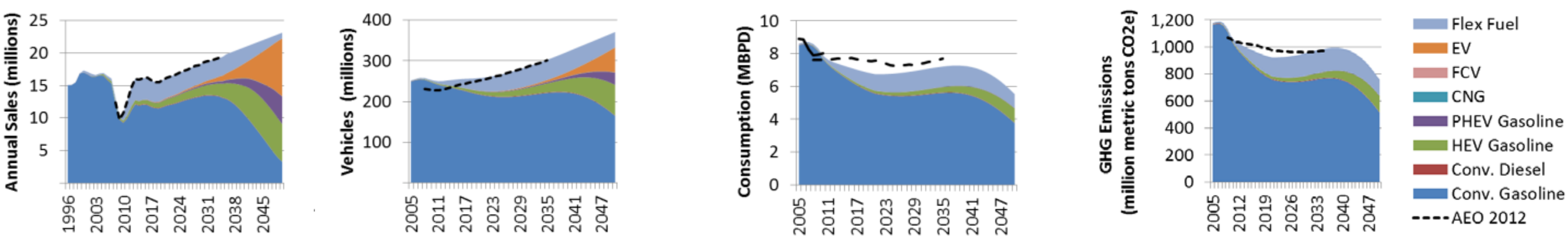
Assumptions: No electric roadway, gasoline price based on trend from last 10 years, no battery cost reductions

Vehicle Sales | Fleet Count | Petroleum Consumption | GHGs



Assumptions: Same except electric roadway installed on 5% of roads (≈40% of travel, 7 year rollout starting in 2015)

Vehicle Sales | Fleet Count | Petroleum Consumption | GHGs



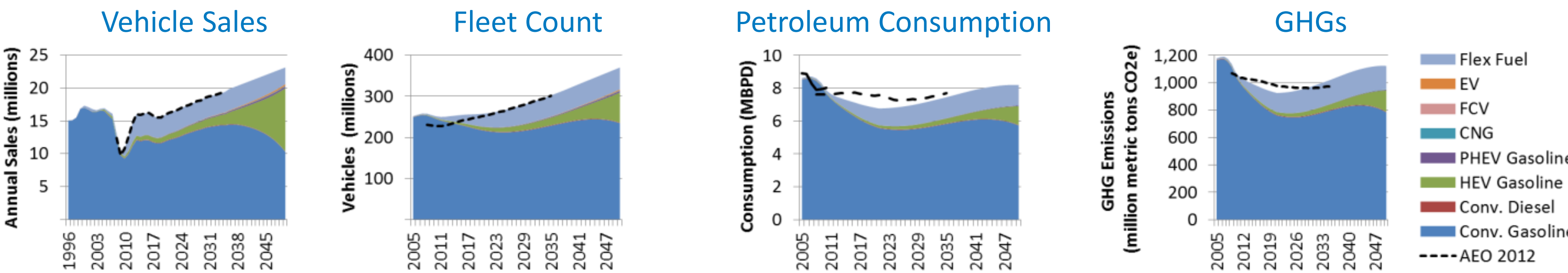
Significance

- Evaluates the potential impact of electric roadway infrastructure on vehicle electrification and DOE's end goals

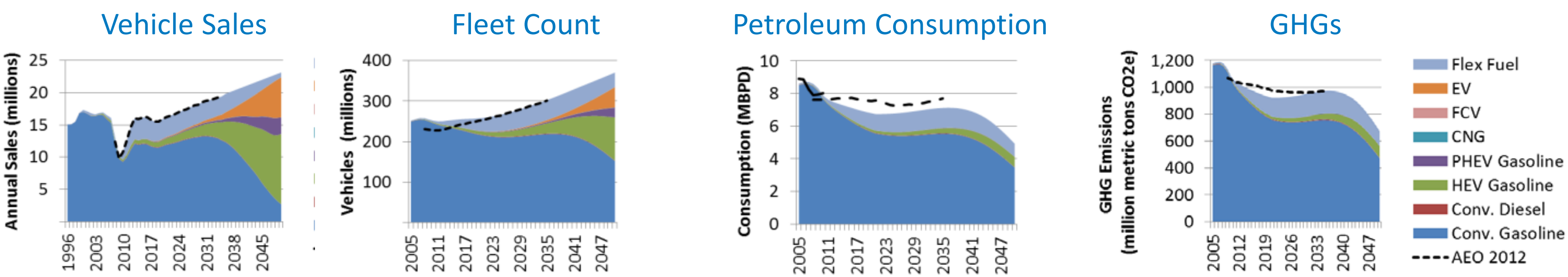
Accomplishment: Initial Estimates of Electric Roadway Impact on Petroleum Use and GHG Emissions

Draft results from integrated passenger vehicle modeling and market approach

Assumptions: No electric roadway, gasoline price based on trend from last 10 years, no battery cost reductions



Assumptions: Same except electric roadway installed on 25% of roads (≈80% of travel, 7 year rollout starting in 2015)



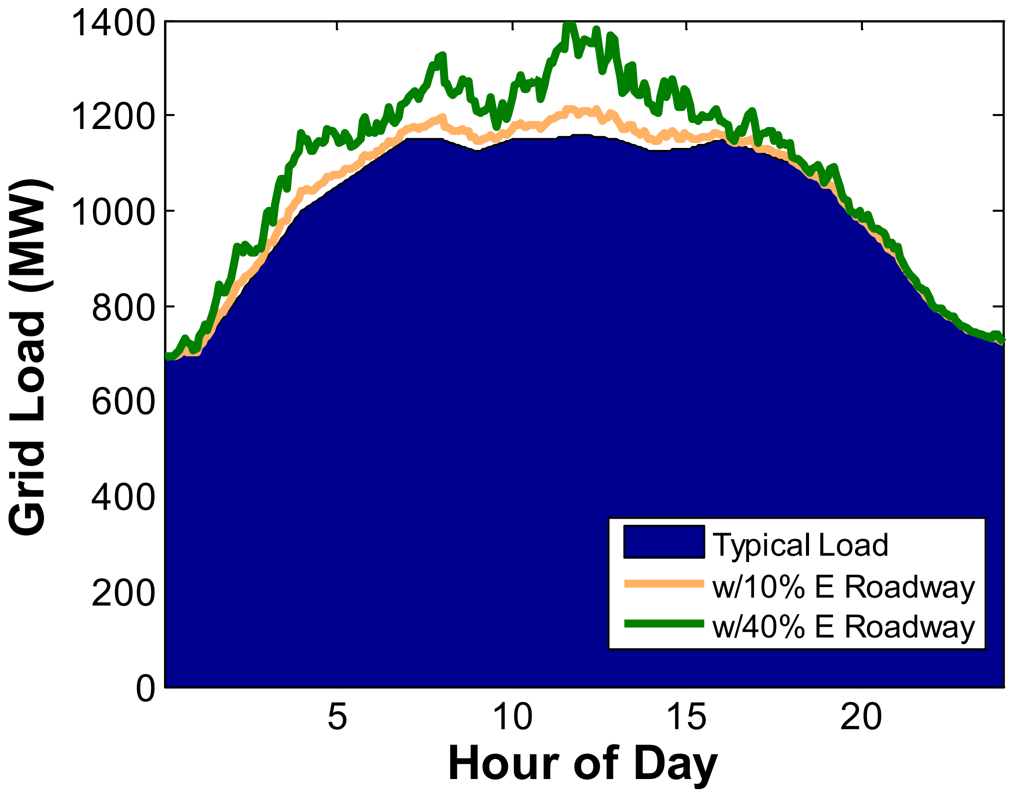
Significance

- **Evaluates the potential impact of electric roadway infrastructure on vehicle electrification and DOE's end goals**

Accomplishment: Initial Estimates of Roadway Electrification Contribution to Existing Grid Loads

Draft results using GPS driving profiles

- **Starts with typical grid load for a metropolitan area**
- **Overlays added load if given percentage of vehicles pull from the grid in real time for all power requirements (worst case assumption)**

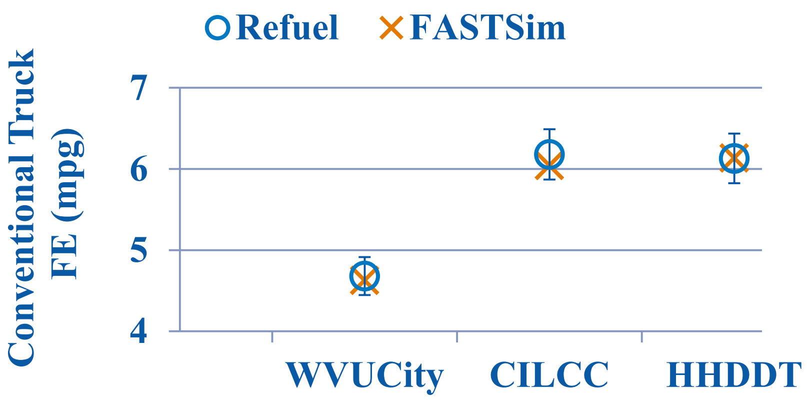


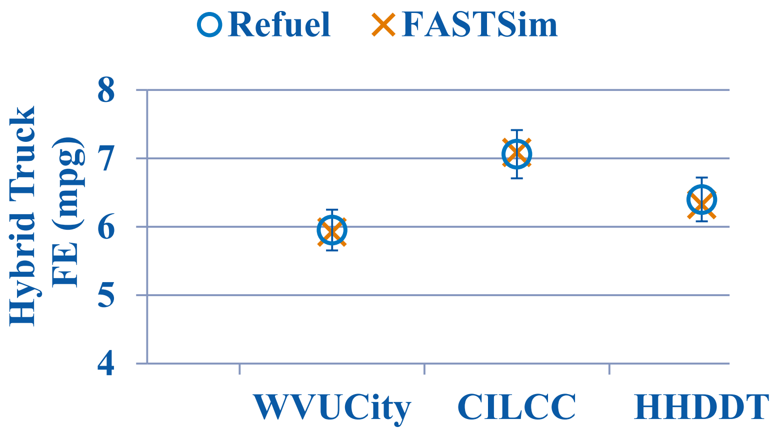
Significance

- **Illustrates that incremental load may be significant relative to the base load, and that alignment with midday peak will likely need to be addressed**
  - Could require infrastructure to vehicle communication to manage (e.g., draw from vehicle battery instead of electrified roadway when grid at peak load)

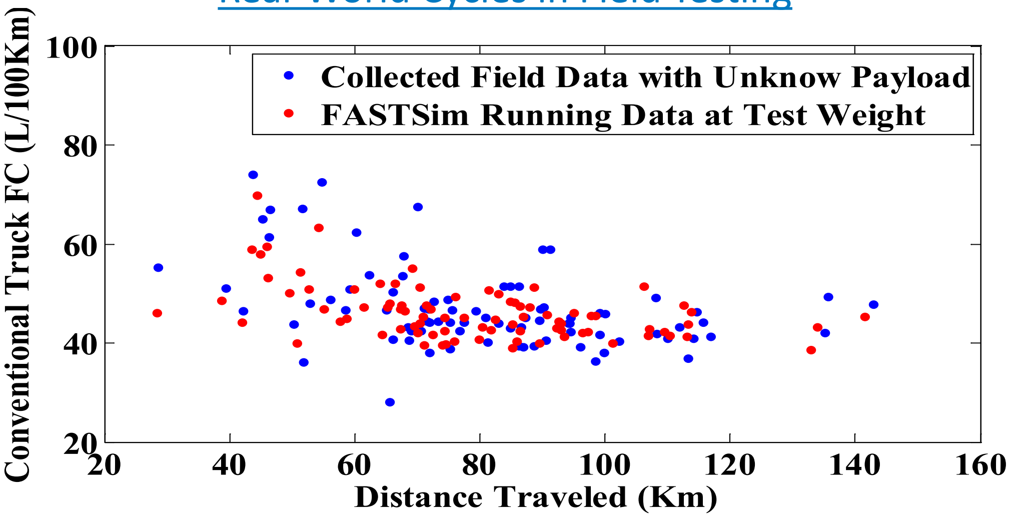
Accomplishment (Class 8 Analysis): Conventional and HEV Truck Model Development & Validation

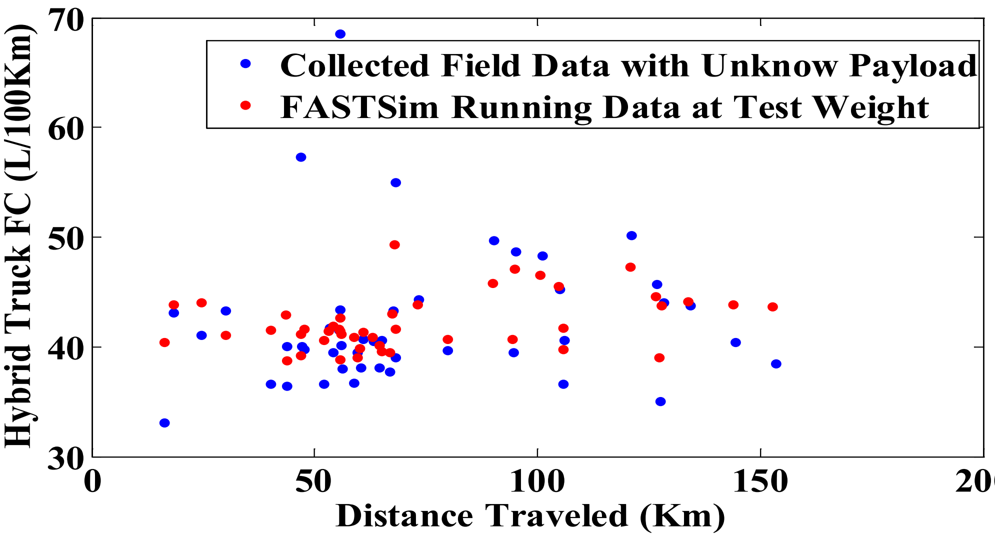
Standard Cycles in Dyno Testing





Real-World Cycles in Field Testing



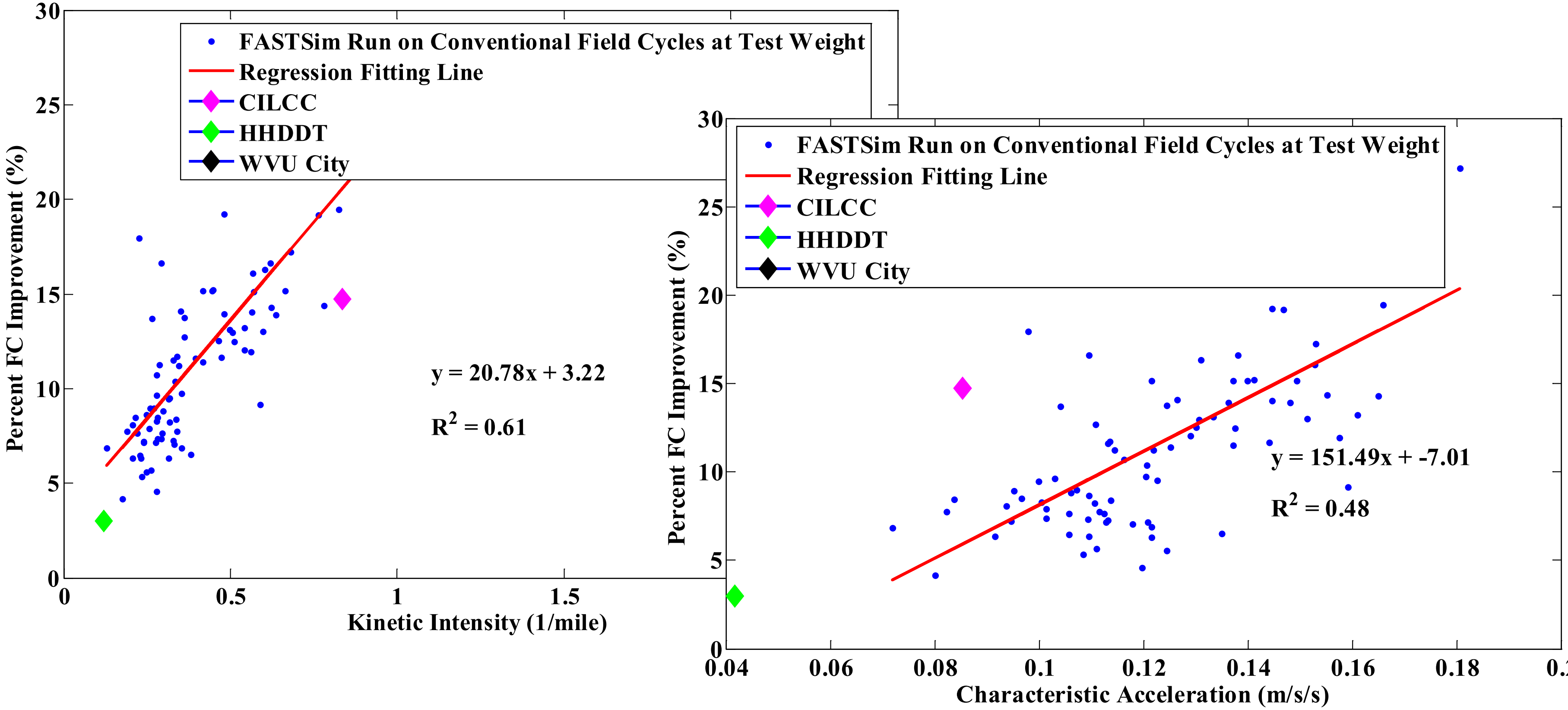


Significance

- Confidence in modeling baseline for electrification evaluation

WVU City/HHDDT/CILCC = West Virginia University City/ Heavy Heavy-Duty Diesel Truck /Combined International Local and Commuter Cycle

Accomplishment (Class 8 Analysis):
Influence of Cycle Characteristics on Hybridization Fuel Savings



Significance

- Improved understanding of hybridization-only Class 8 benefit potential
- Identified important cycle considerations for HD vehicle WPT analysis

HD = heavy-duty

Collaboration and Coordination

- **Oak Ridge National Laboratory**
  - WPT project coordination, assumptions
  - Class 8 line-haul truck duty cycles
- **Argonne and Idaho national labs**
  - LD dyno and field data
- **ReFUEL Laboratory**
  - HD dyno test data
- **Transportation Secure Data Center**
  - Passenger vehicle GPS profiles
- **DOE Vehicle Technologies Analysis**
  - Consumer preference modeling
- **Utah St. University and KAIST**
  - Additional WPT device assumptions
- **GM, Ford, Chrysler**
  - Input on LD/consumer preference modeling
- **Navistar, Volvo**
  - Past/planned input on HD modeling and analysis

Proposed Future Work

- **Refine and add sensitivity analysis to LD modeling and aggregate market predictions**
- **Assess road construction and maintenance implications**
  - Leverage DOT interactions
- **Refine and expand analysis of load alignment with existing grid demands**
- **Complete assessment of V2I communication requirements and correlation with DSRC attributes**
- **Evaluate cost vs. benefit of various Class 8 truck roadway electrification scenarios against conventional/HEV baselines**
  - Consider payment structures to recover infrastructure cost
  - Assess other commercial vocations (e.g., bus charging at stops)
  - Evaluate shared roadway use by multiple vehicle types

Summary

- **Identified potential for roadway electrification to increase viability and aggregate fuel savings of electric drive vehicles**
- **Integrated multiple techniques to conduct thorough analysis**
  - Partner inputs
  - Powertrain modeling
  - Market forecasting
  - Real-world LD travel profiles
  - Commercial fleet in-use data
  - Chassis dynamometer testing
- **Formulated initial results**
  - Much VMT is supported by a small number of roads (e.g., Interstate)
    - Improved mobility can increase consumer interest in BEVs
    - Electrifying just 5% of roads could double electric drive penetration vs. business as usual case
- **Continued analysis will further explore impacts of**
  - Road coverage
  - Device efficiency
  - Vehicle types
  - Fuel price
  - Construction and maintenance
  - Existing grid loads

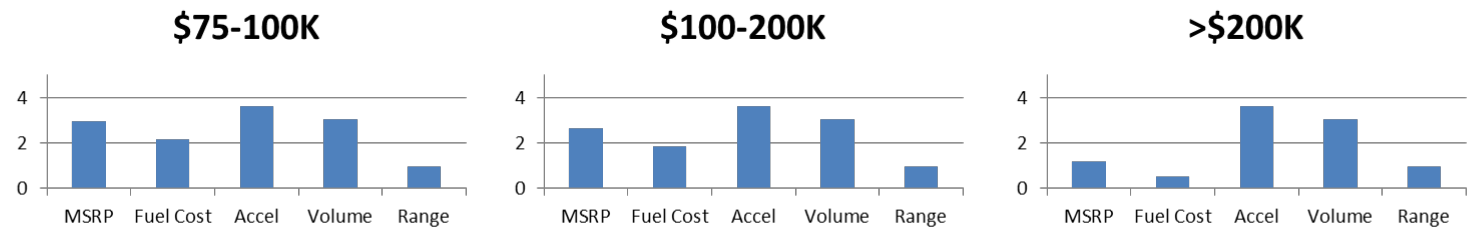
VMT = vehicle miles travelled

Technical Back-Up Slides

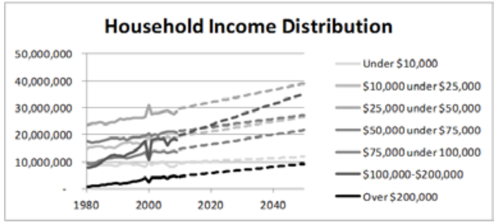
NREL Captures Important Consumer Preference Aspects and Validates Model Predictions

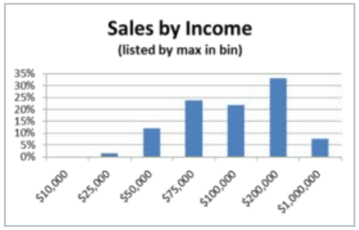
- **Consumer preferences change based on income**

Relative importance by income bin

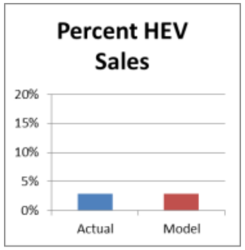


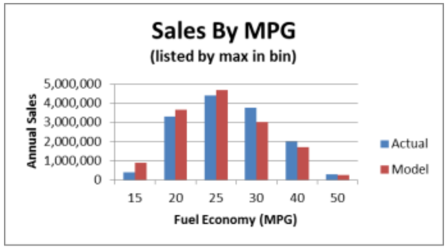
- **Income levels change over time, and number of sales vary by income**

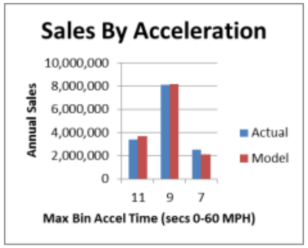




- **Competes advanced vehicles with entire existing fleet**
- **Successful models are duplicated (more options for the consumer)**
- **Extensive validation**
  - Multiple years
  - 10 different regions
  - 10 dimensions







Significance

- **Increased accuracy and confidence in market penetration modeling predictions**

NREL's Transportation Data Centers

Alternative Fuels & Advanced Vehicles Data Center (AFDC) – Clearinghouse of information on advanced vehicles and fuels

Hydrogen Secure Data Center (HSDC) – Tech validation of hydrogen-powered applications and their infrastructure

Transportation Secure Data Center (TSDC) – Secure archival of and access to detailed transportation data (e.g., GPS travel profiles)

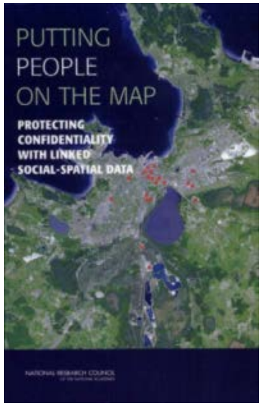
Commercial Fleet Data Center (CFDC) – Detailed MD/HD drive cycle and powertrain data from advanced fleets

Functions	AFDC	HSDC	TSDC	CFDC
Securely archive sensitive data		Y	Y	Y
Provide public/composite data	Y	Y	Y	Y
Quality control processing	Y	Y	Y	Y
Spatial mapping/GIS analysis	Y	Y	Y	Y
Custom reports for providers or DOE		Y		Y
Application process for controlled access			Y	
Detailed GPS drive cycle analysis (including the interactive DRIVE tool and Fleet DNA portion of the CFDC)			Y	Y

GPS = global positioning system; MD/HD = medium-/heavy-duty vehicles; GIS = geographic information system

Transportation Secure Data Center (TSDC)

www.nrel.gov/tsdc



NRC report*

- **Secure archival of, and access to, detailed transportation data**
  - Travel studies increasingly use GPS → valuable data
  - TSDC safeguards anonymity while increasing research returns
- **Various TSDC functions**
  - Advisory group supports procedure development and oversight
  - Original data securely stored and backed up
  - Processing to assure quality and create downloadable data
  - Cleansed data freely available for download
  - Controlled access to detailed spatial data
    - User application process
    - Software tools available through secure Web portal
    - Aggregated results audited before release

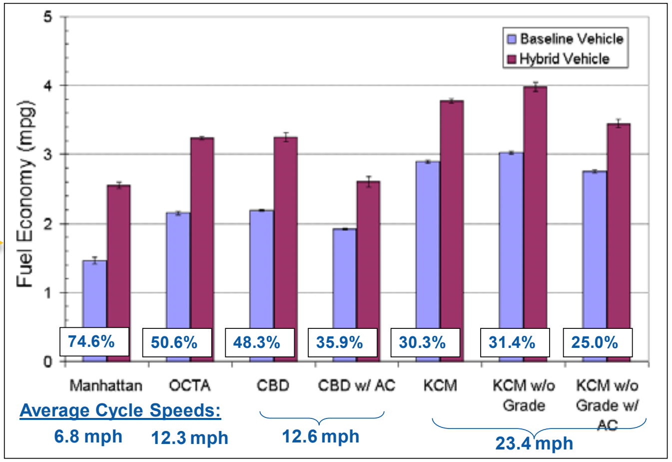
Sponsored by the U.S. Department of Transportation (DOT)
Operated by the NREL Center for Transportation Technologies and Systems (CTTS); Contact: Jeff.Gonder@nrel.gov

GPS = global positioning system
* See recommendations from this 2007 National Research Council report: books.nap.edu/openbook.php?record_id=11865

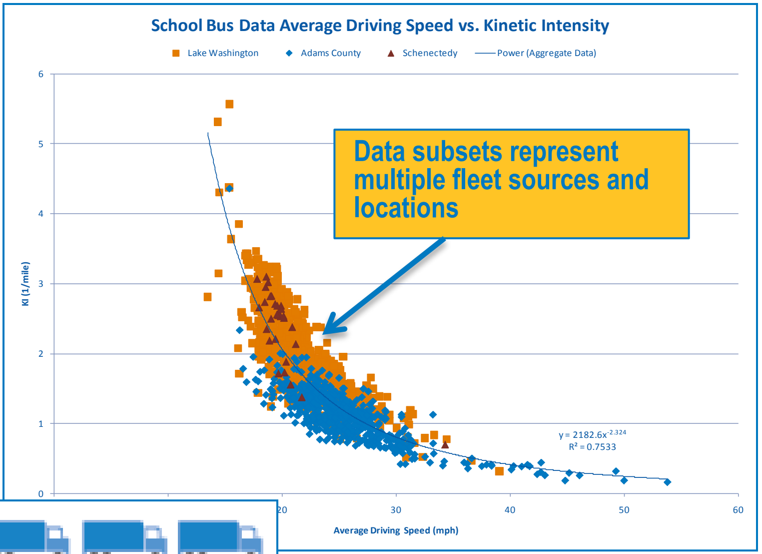
Commercial Fleet Data Center (CFDC): Supporting Transportation Energy Data Collection for the Fleet DNA Project

- **A medium & heavy duty, vocationally-focused, Web-based, drive cycle database of core vehicle usage metrics**

- **Value:**
  - Helps quantify drive cycle Impacts on MD/HD Technology: many, many more vocations than LD
  - Provides reference data for drive cycle development (could support EPA / NHTSA rule making)
  - OEMs: better understanding of customer use profiles.
  - Fleets: information on how to achieve the maximum return from new vehicle technology investments
  - Funding Agencies: optimize impact of financial incentive offers.
  - R&D Activities: data source for modeling and simulation



- **DOE, AQMD, CARB, Calstart, and others participating**
  - NREL partnering with ORNL to acquire data



- **Ongoing field evaluation projects will help to supply data**

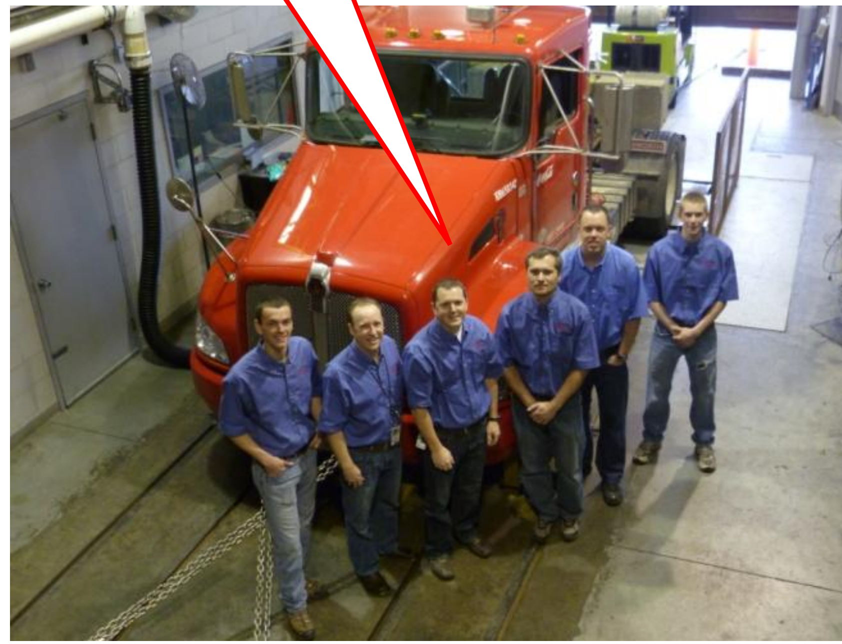
- **10-12 vocations targeted initially – highest fuel usage and/or VMT**

Fleet DNA Project

NREL's Renewable Fuels and Lubricants Laboratory

- **Dynamometer test cells**
  - Chassis dynamometer
  - HD engine dynamometer
  - Single cylinder engine dynamometer
- **Emissions measurement**
- **Portable emissions measurement system**
- **Fuel storage and handling**

The ReFUEL Team



ReFUEL Lab Located at RTD Facility in Denver