NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Mobility Patterns Informing V2X Research Projects:

## Eco-Routing and Electrified Roadway Project Examples


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**National Renewable Energy Laboratory**

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Task 28 Workshop
Home Grids and V2X Technologies

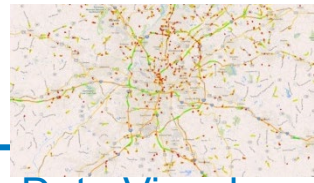
**NREL/PR-5400-66467**

# Outline

- **NREL real-world mobility pattern data**
- **V2X *communication connection* application example**
  - V2X-enabled fuel savings via green routing and adaptive control for the Chevy Volt
- **V2X *electrical connection* application examples**
  - WPT-enabled roadway electrification
    - Static (stationary)
    - Quasi in-motion
    - Fully in-motion

V2X = vehicle connected to “X”
WPT = wireless power transfer

# Transportation Data Centers at NREL



Data Visual
www.nrel.gov/tsdc

## Real-World Data and Analysis to Support Decision Making

Alternative Fuels Data Center (AFDC)
*Public clearinghouse of information on the full range of advanced vehicles and fuels*

National Fuel Cell Technology Evaluation Center (NFCTEC)
*Industry data and reports on hydrogen fuel cell technology status, progress, and challenges*

Transportation Secure Data Center (TSDC): *Detailed individual travel data, including GPS profiles*

Fleet DNA Data Collection
*Medium- and heavy-duty drive-cycle and powertrain data from advanced commercial fleets*

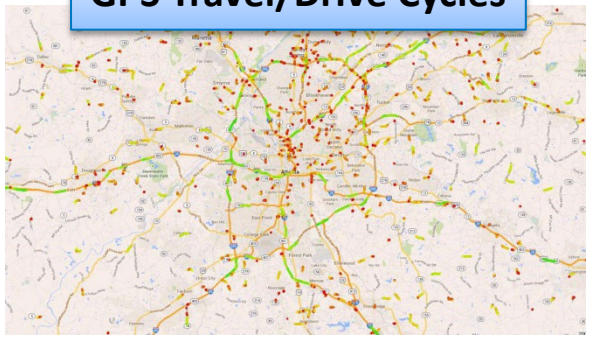
FleetDASH: *Business intelligence to manage Federal fleet petroleum/alternative fuel consumption*

| Features | AFDC | NFCTEC | TSDC | Fleet DNA | Fleet DASH |
|---|---|---|---|---|---|
| Securely Archived Sensitive Data | | Y | Y | Y | Y |
| Publicly Available Cleansed Composite Data | Y | Y | Y | Y | |
| Quality Control Processing | Y | Y | Y | Y | Y |
| Spatial Mapping/GIS Analysis | Y | Y | Y | Y | Y |
| Custom Reports | | Y | | Y | Y |
| Controlled Access via Application Process | | | Y | | |
| Detailed GPS Drive-Cycle Analysis | | | Y | Y | |

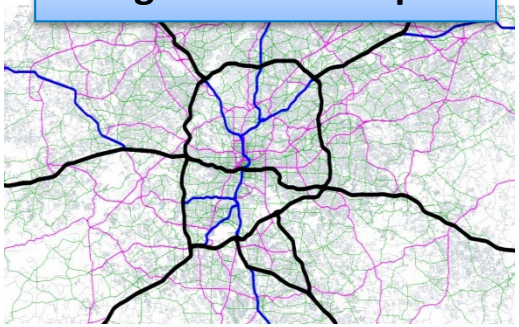
Transportation Secure Data Center

# Integration with Other Large Data Sets

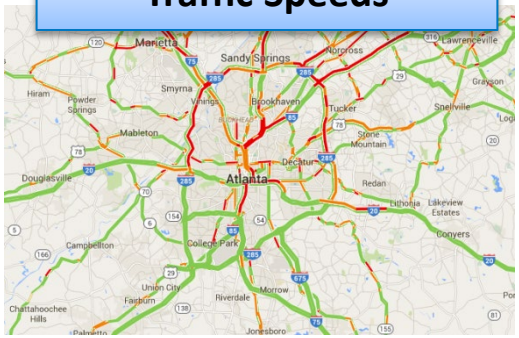
## GPS Travel/Drive Cycles



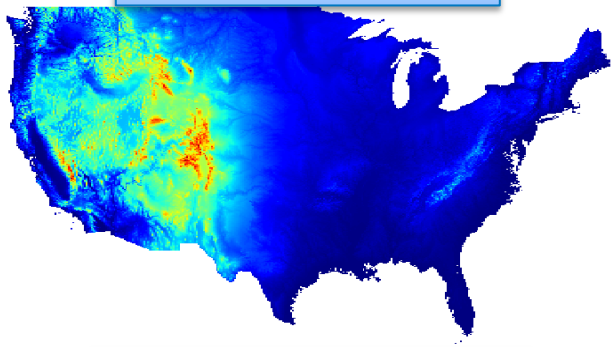
## Digital Street Maps



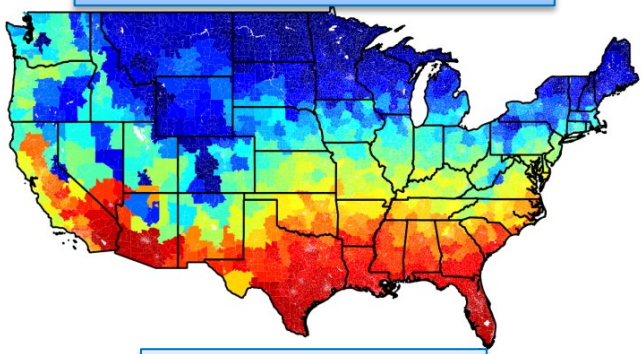
## Traffic Speeds




## Elevation / Grade

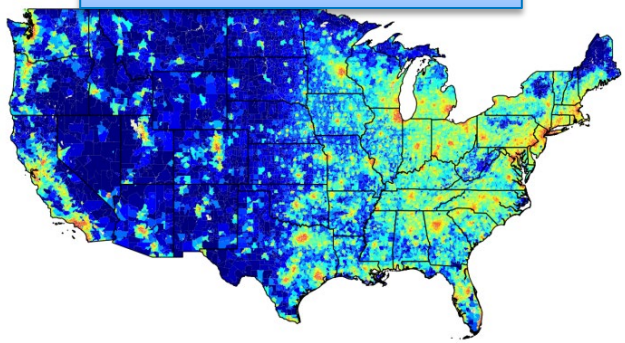


## Ambient Temperature

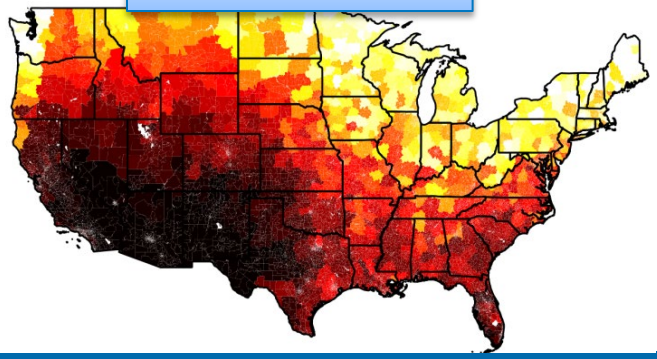


## Freight Volumes

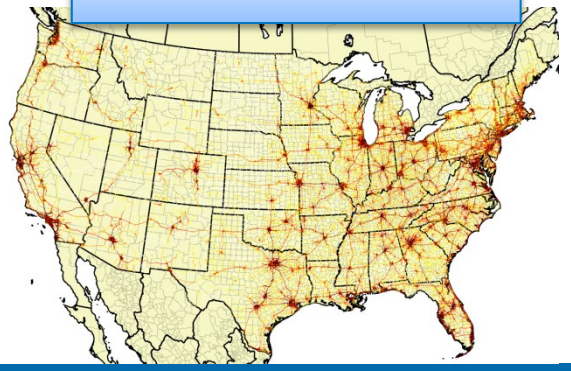
## Vehicle Registrations



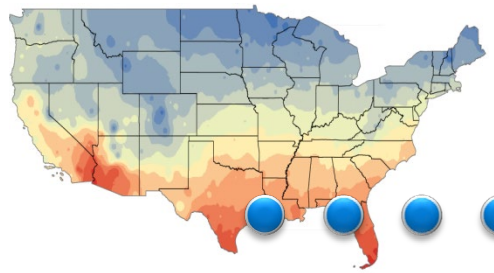
## Solar Intensity



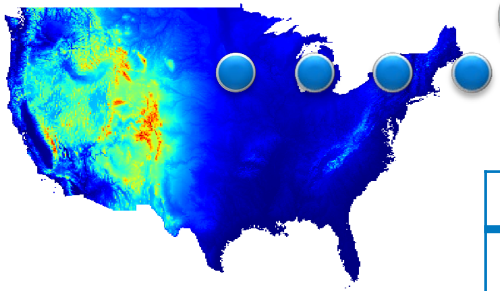
## Overall Road Volumes

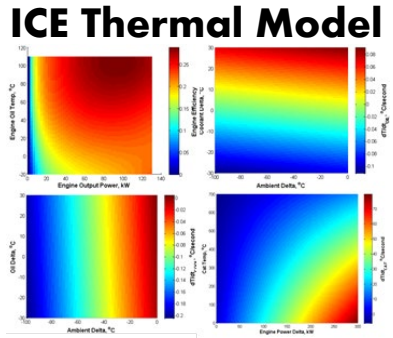


# Merging Data and Models to Support Real-World Analyses

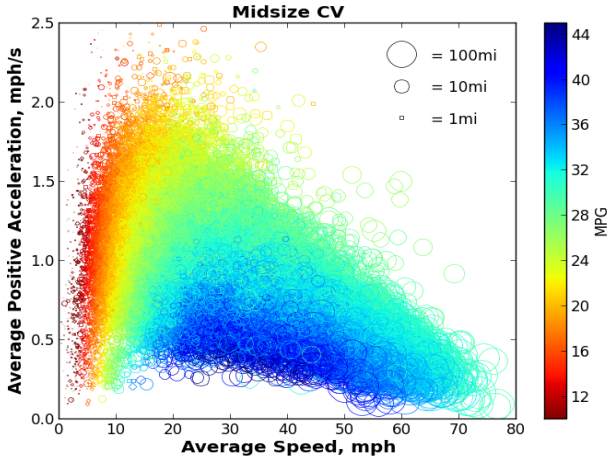


Transportation
Secure Data Center




**Vehicle use conditions from disparate datasets can be merged in a common environment to investigate the interplay of conditions (thermal, drive cycle/ routing, grade, etc.)**



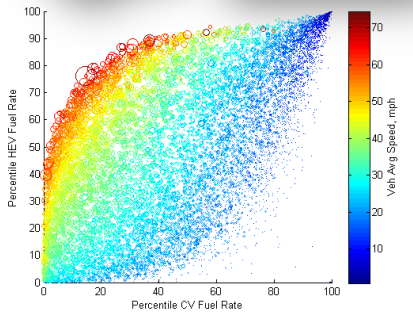

USGS = United States Geological Survey
TDSC = Transportation Secure Data Center
TMY = Typical Meteorological Year
FASTSim = Future Automotive Systems Technology Simulator

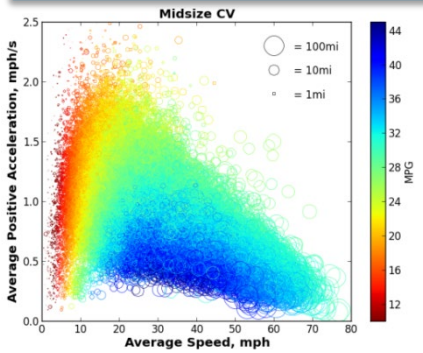
| Data Element | Source | Notes |
|---|---|---|
| Drive Cycles/ Trip Distributions | NREL Transportation Secure Data Center | The TSDC houses hundreds of thousands of real-world drive cycles from vehicles across the country. |
| Climate Data | NREL National Solar Radiation Database | Home to TMYs from hundreds of U.S. locations, each containing hourly climate data. |
| Elevation/ Road Grade | USGS National Elevation Dataset | Raw USGS elevations are filtered to remove anomalous data and produce smooth road grade curves. |

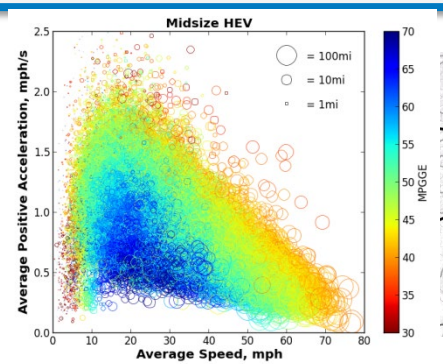
# Example TSDC-Enabled Studies

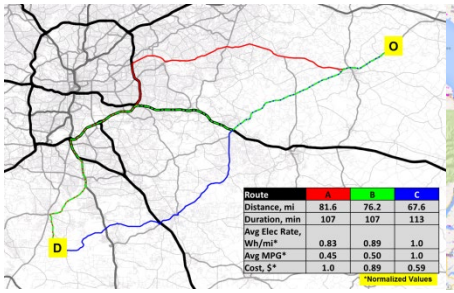
- **Extensive NREL analyses working with large GPS datasets**
  - Multi-powertrain real-world fuel economy distributions/sensitivities
  - Comparing real-world driving and standardized test profile results
  - Enabling road grade simulation and quantifying impacts
  - Synthesis with national climate data for thermal technology evaluation
  - Investigating PEV charging and alternative fuel station locations
  - Developing green routing and adaptive control algorithms
  - Assessing fuel saving opportunities from driver feedback…

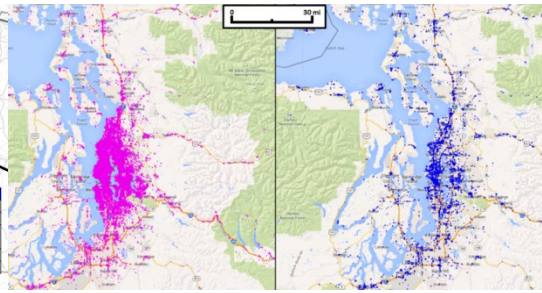


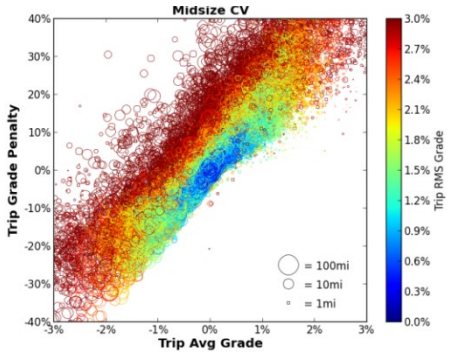


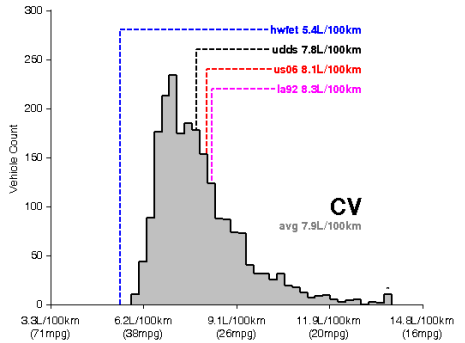



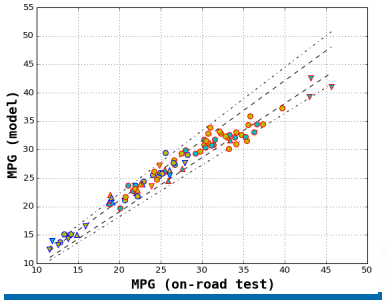



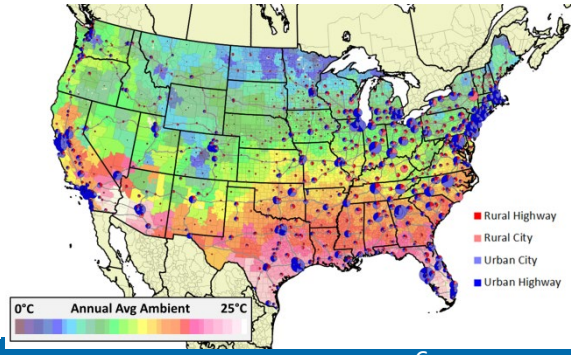





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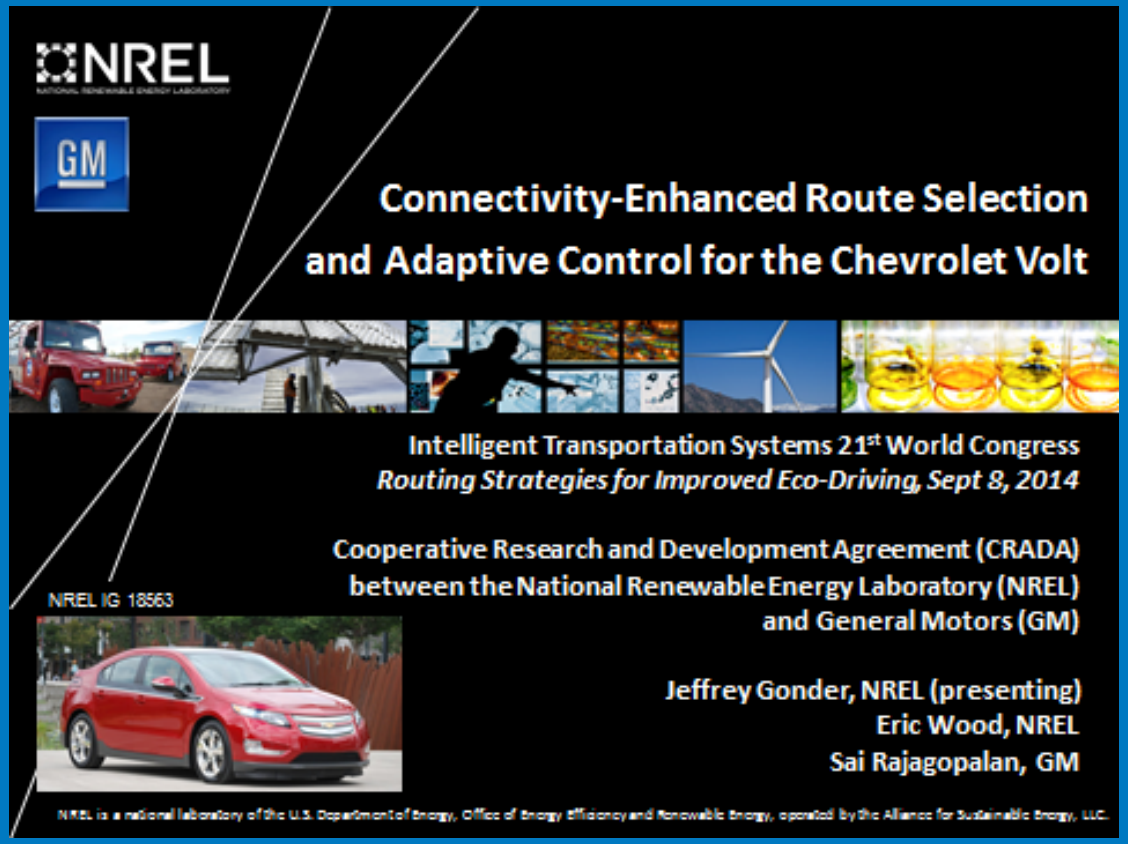
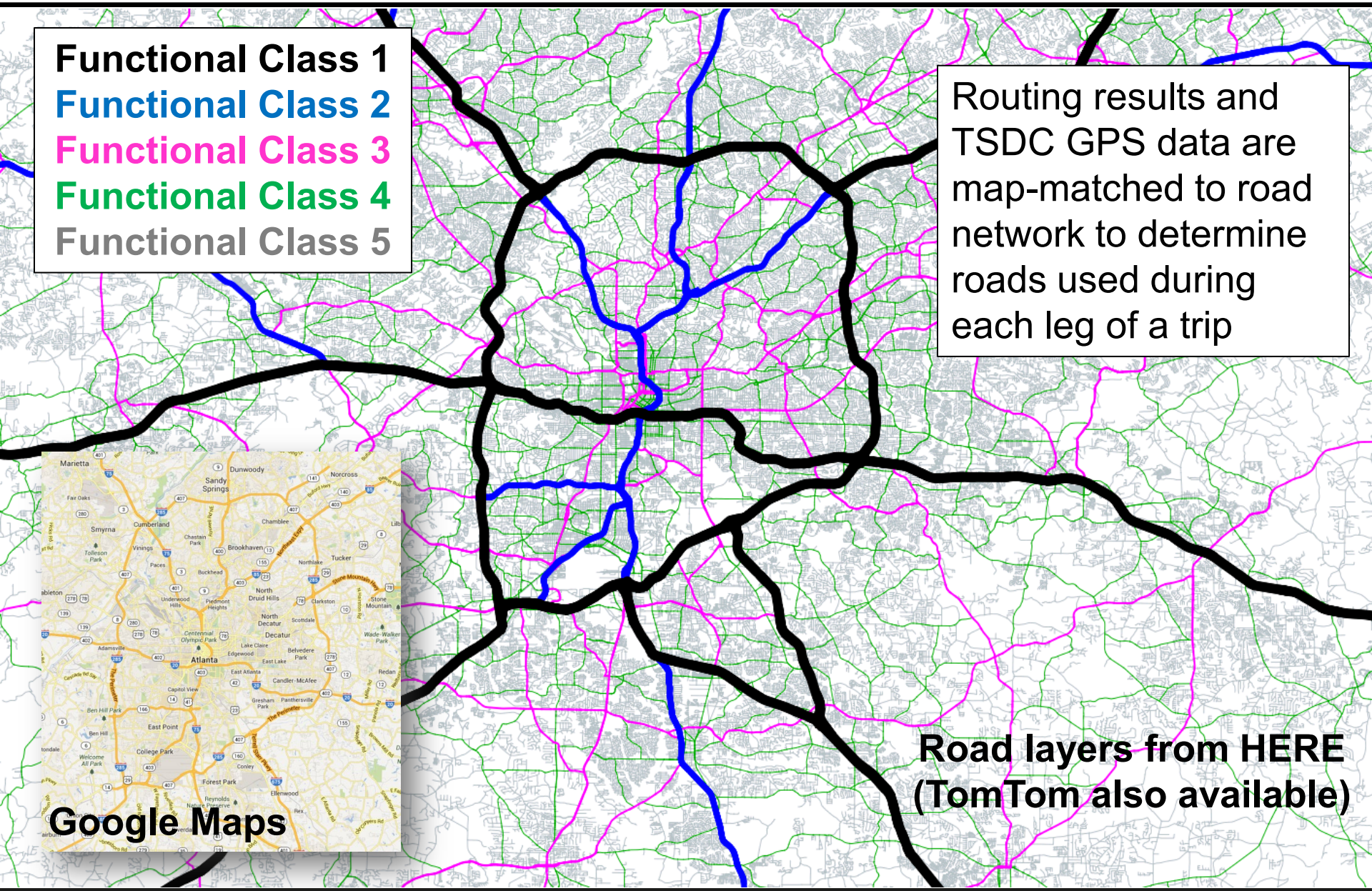
# Excerpt from study of V2X-enabled green routing and adaptive control applied to the Chevy Volt



# Route-Connected Energy Prediction

- Drive Cycle Prediction
- Powertrain Modeling
- **Application to Green Routing**
- Control Mode Scheduling

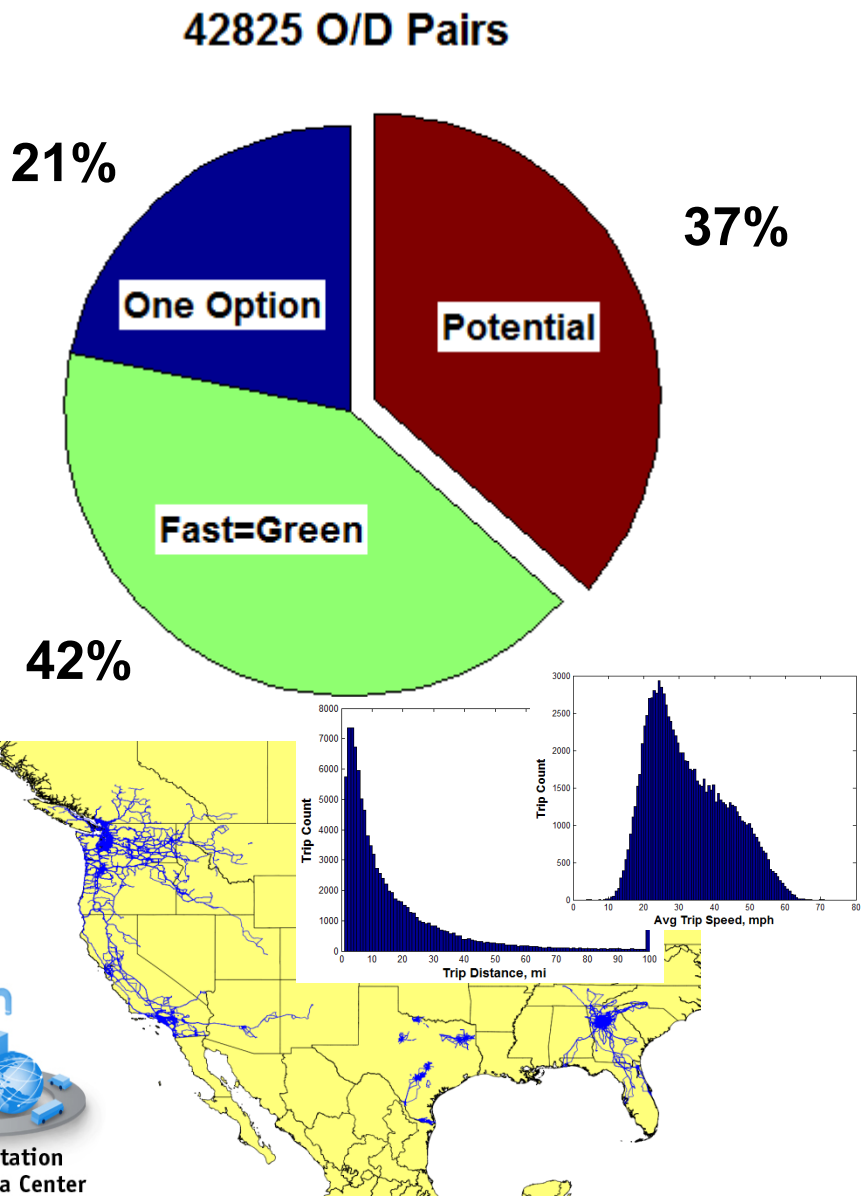
# Base Maps + Routing API



# Routing Analysis

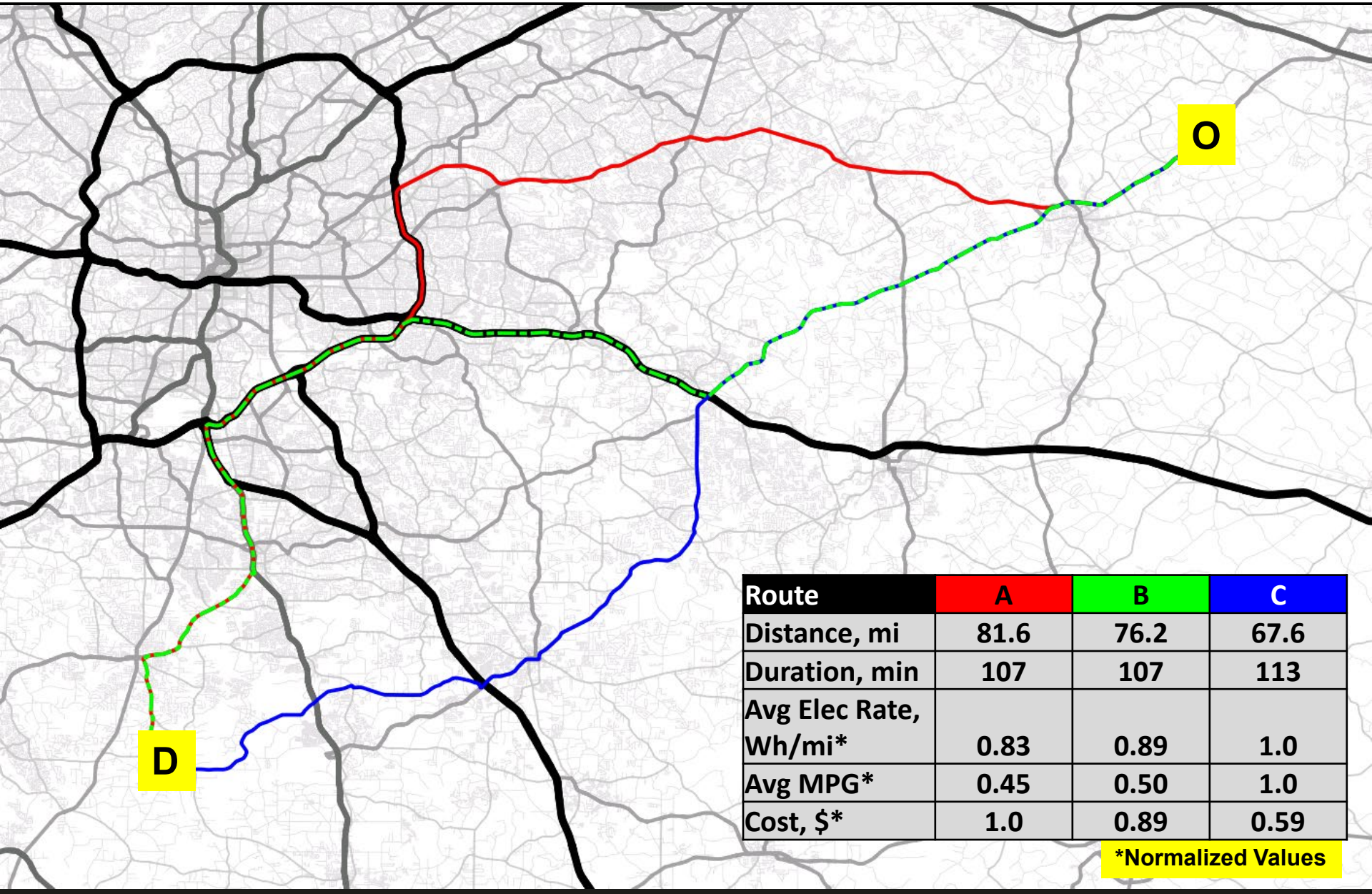
***Consider the route with the shortest estimated travel time to be the default.**

- **One Option**
  - Directions API only provided one route for 21% of O/D pairs
- **Fast = Green**
  - The route with the estimated shortest travel time also required the least amount of estimated energy to complete for 42% of O/D pairs
- **Potential**
  - The remaining 37% of O/D pairs offer the potential for a green routing algorithm to inform an energy saving route selection




O / D = origin / destination

# Green Routing Example

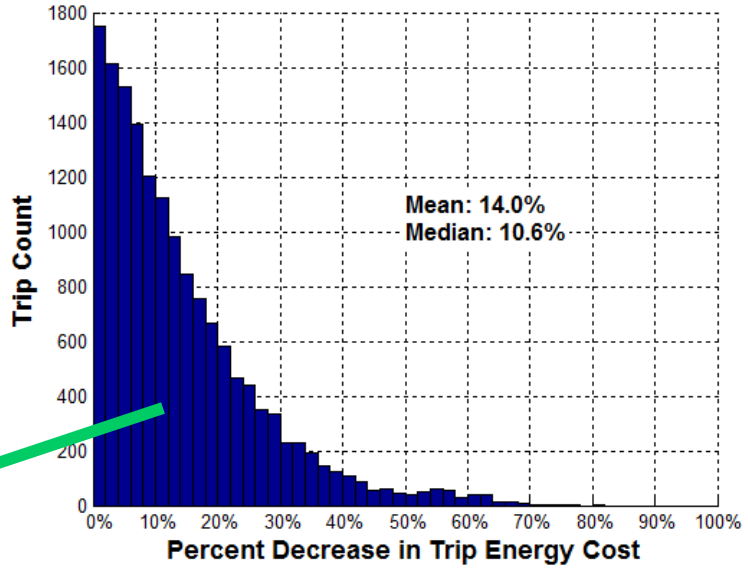


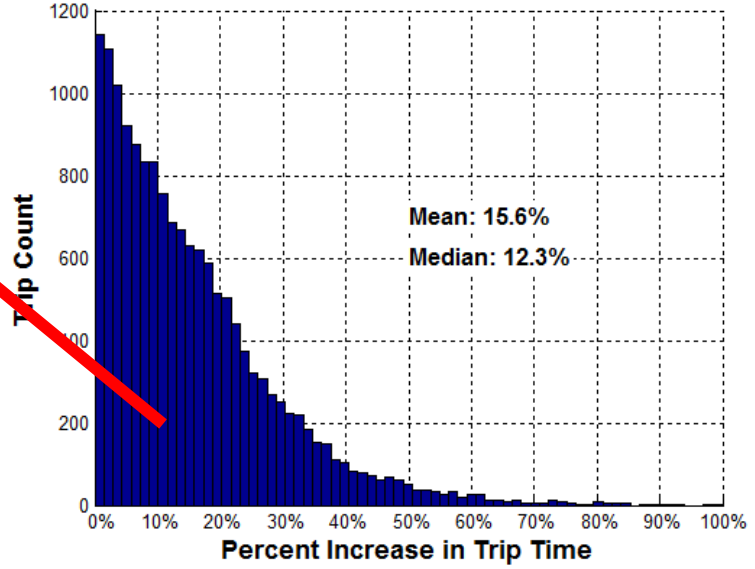

| Route | A | B | C |
|---|---|---|---|
| Distance, mi | 81.6 | 76.2 | 67.6 |
| Duration, min | 107 | 107 | 113 |
| Avg Elec Rate, Wh/mi* | 0.83 | 0.89 | 1.0 |
| Avg MPG* | 0.45 | 0.50 | 1.0 |
| Cost, $* | 1.0 | 0.89 | 0.59 |

*Normalized Values

# Will people select the green route?

- On aggregate the benefits of green routing appear to be significant
- However, in order for green routes to be selected in practice, the incentive of energy savings must be weighed against disincentive of longer travel times

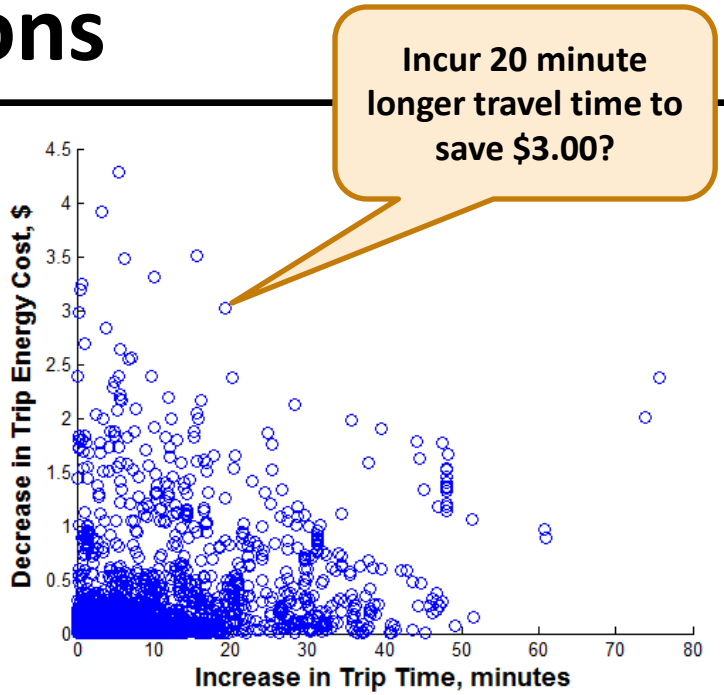


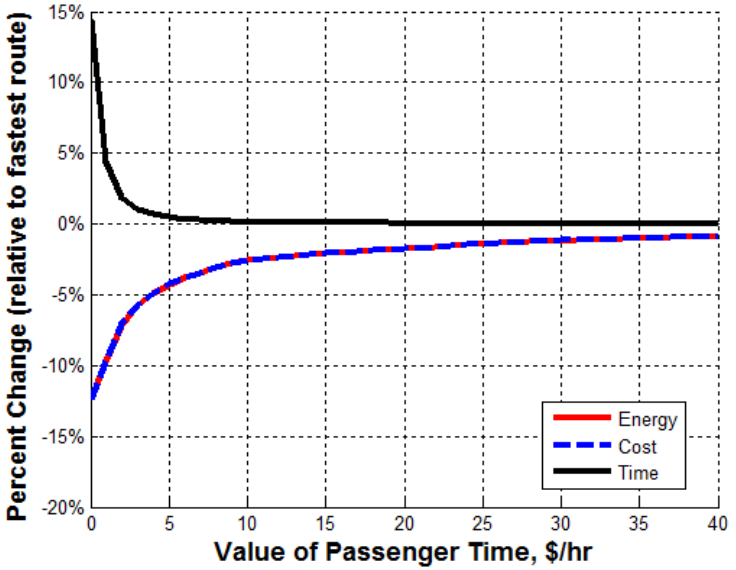



# Value of Time Considerations

- **Energy savings plotted against increase in travel time (selecting green route over shortest duration)**
- **This 2D space is swept versus value of passenger time ($/hr) to show cumulative effects of green routing given a return on investment threshold**
  - **Ex1:** If passenger has no value of time, cost/energy could be decreased by 12.3% and travel time increased by 14.4%
  - **Ex2:** If passenger values time at $35/hr, cost/energy could be decreased by 1.0% and travel time increased by 0.0%

***The data only consider the 37% of O/D pairs previously identified as having green routing potential.**



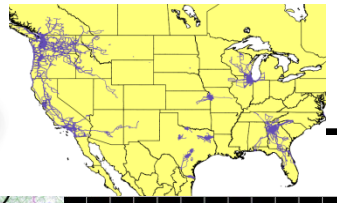



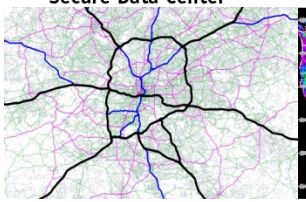
# Summary

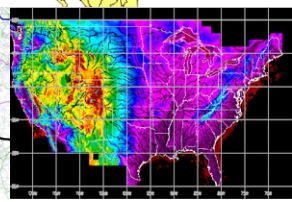
- **Demonstrated ability to model vehicle speed/accel profiles relative to road type**
- **Constructed high-level powertrain model employing cycle metrics and vehicle state as inputs**
- **Applied model using real-world distribution of O/D pairs, demonstrating:**
  - Aggregate energy savings of up to 4.6% for green routing (relative to passenger value of time)
  - Average energy savings of 3.3% for mode scheduling

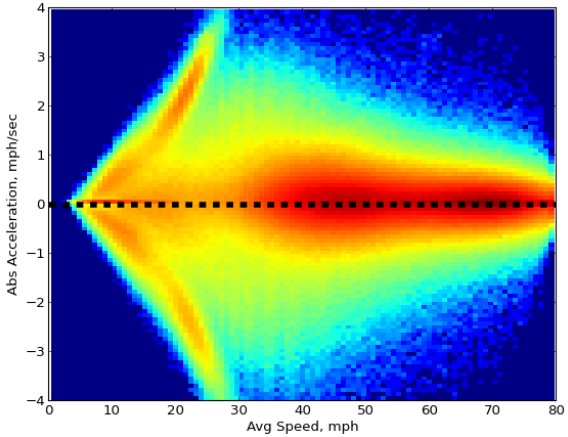
**Modest aggregate savings, but may be cost effective**

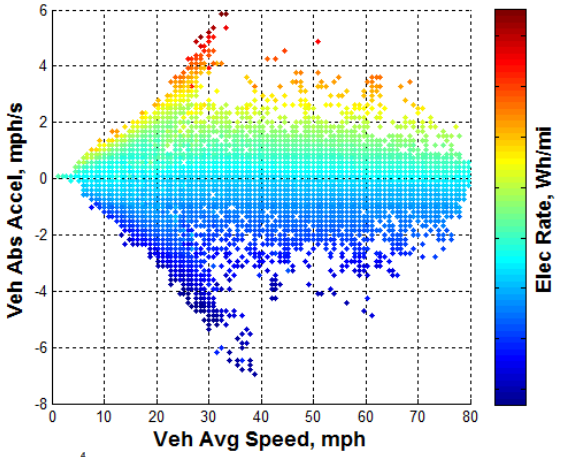

NREL 18563

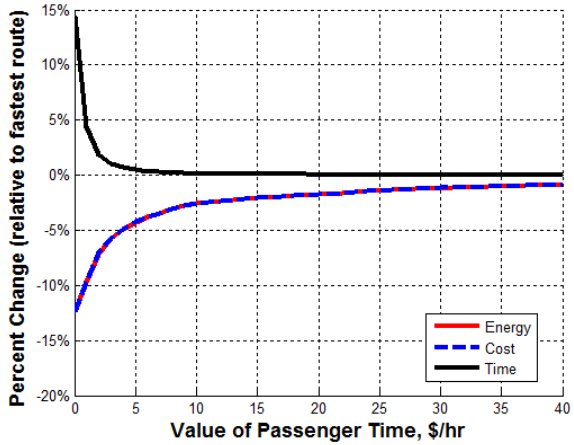



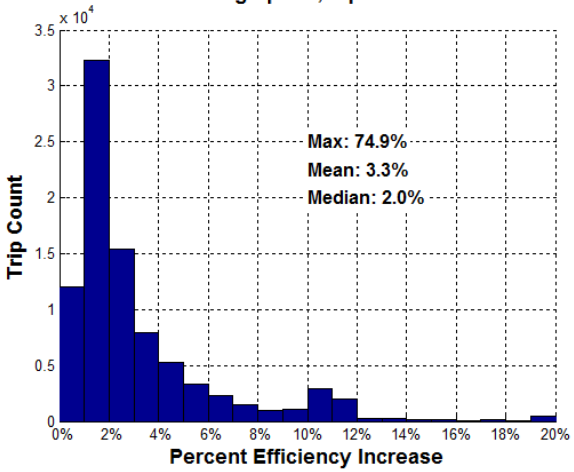






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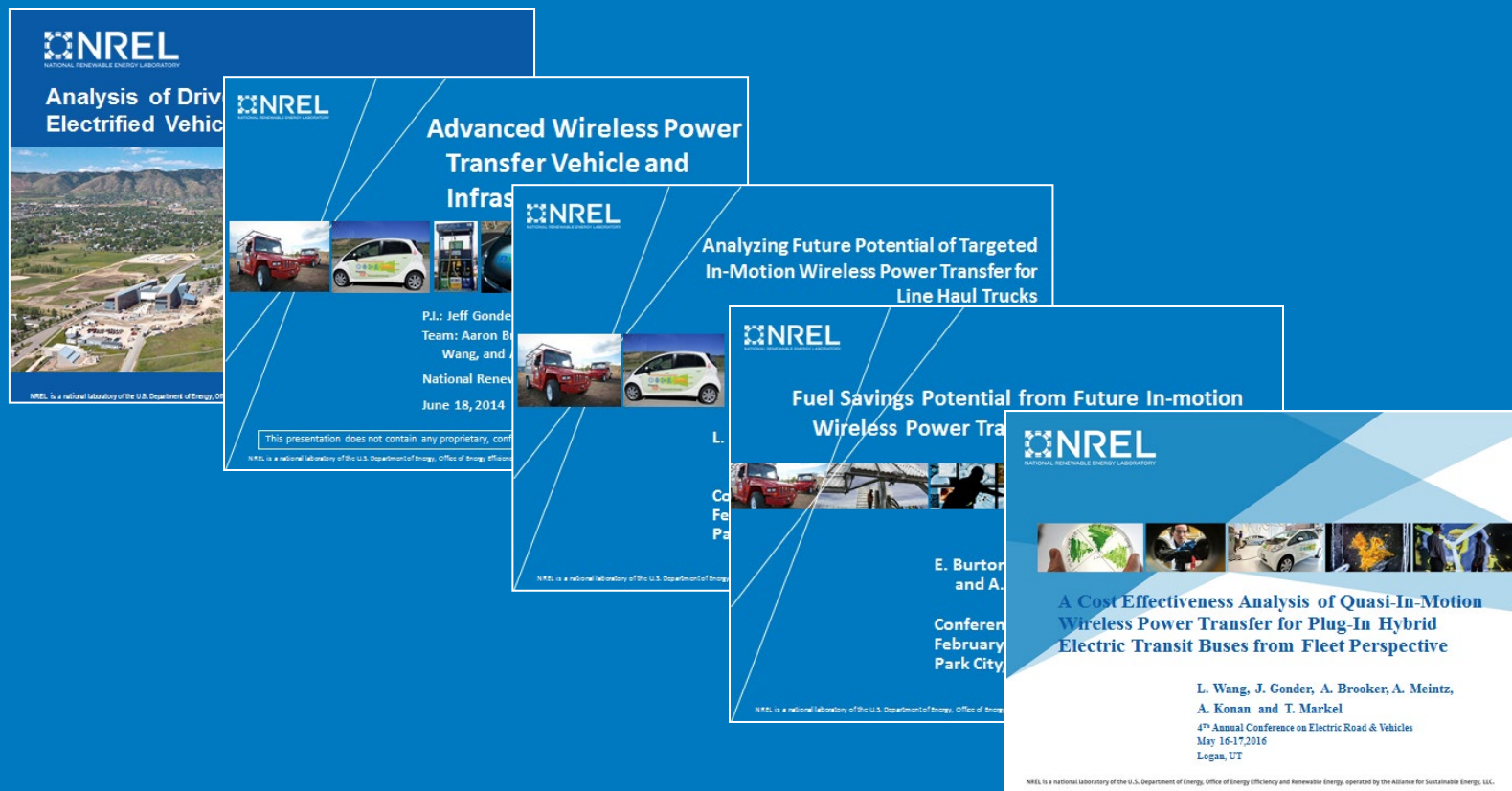
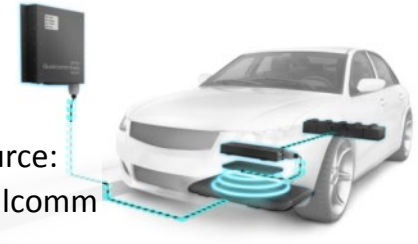
# Highlights from studies on potential fuel savings and relative cost effectiveness from roadway electrification



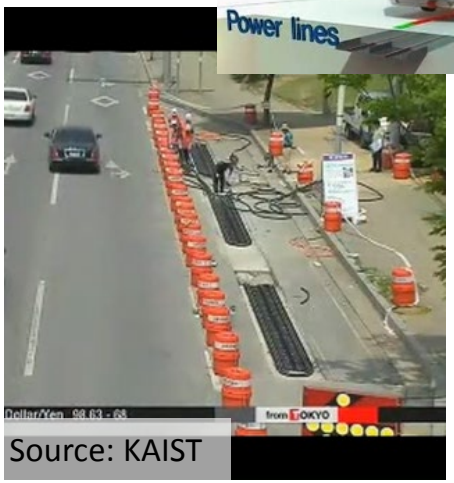
# Wireless Power Transfer (WPT) Technology Advancements

- **Potential to maximize electrified miles and resulting fuel savings**
  - Static charging when parked; quasi in-motion at brief stops
  - Farther out: fully in-motion

Source: ORNL

Source: Qualcomm

Source: KAIST

Source: NREL

Source: WiTricity WT-3300 Data Sheet

Source: Momentum Dynamics

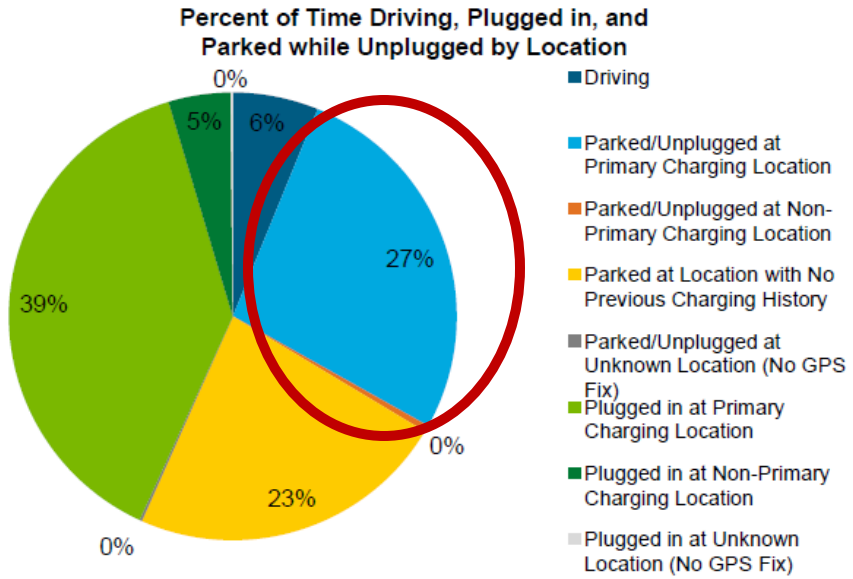

Source: Volvo Group

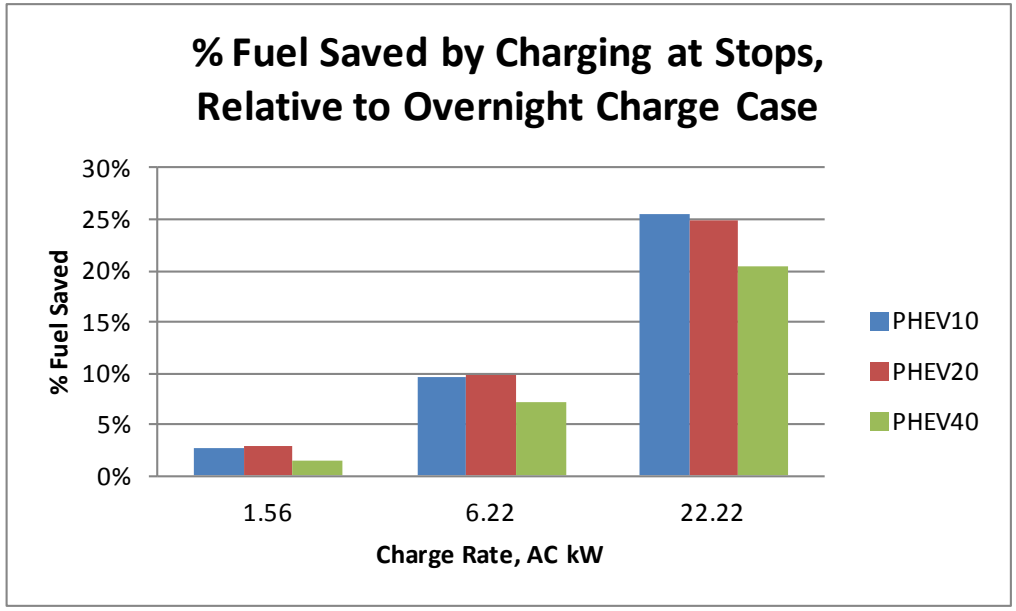
Source: Siemens

# Analyses of Static and Quasi In-Motion Applications

- **Increasing convenience avoids missed charging**
  - People do not always plug in PHEVs (avt.inel.gov/pdf/phev/HymPriusPersonal-useChAndDrSept08-Mar10.pdf)
- **Charging at stops could provide even further fuel savings**
  - Chart reflects outer bound assumption of charging at every stop

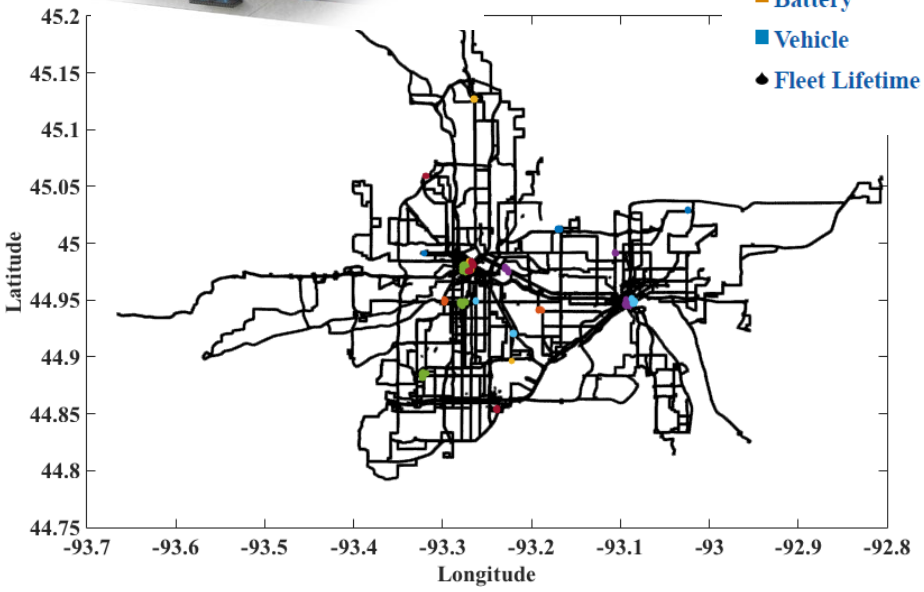
PHEV = plug-in hybrid electric vehicle

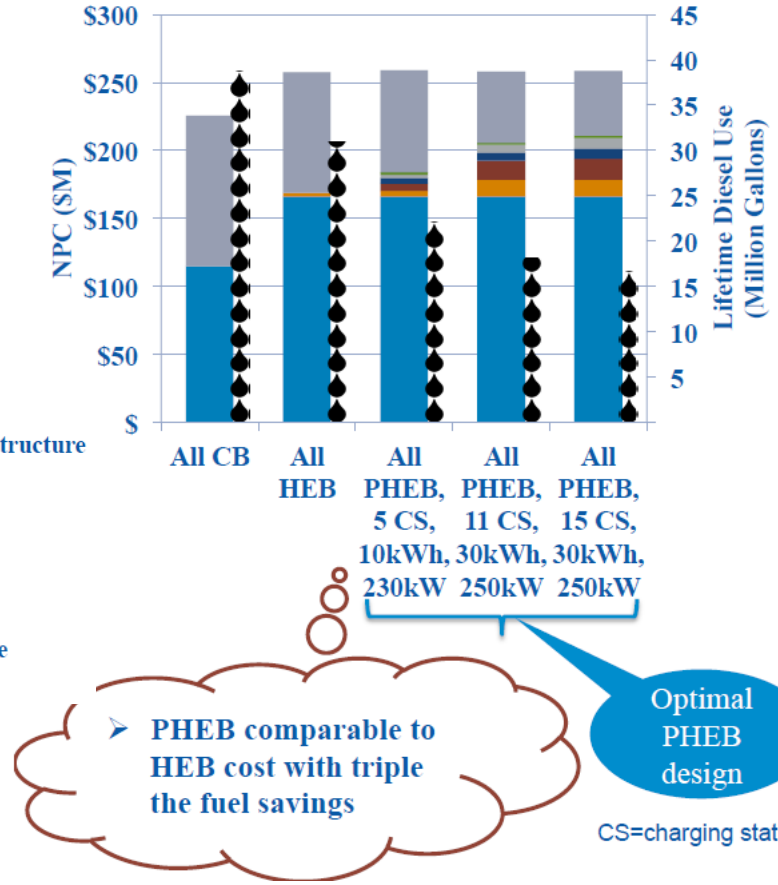


# Analyses of Static and Quasi In-Motion Applications

- **Transit bus application using fleet data**
  - Co-optimize number of charging stations and PHEBs, charging power and battery energy

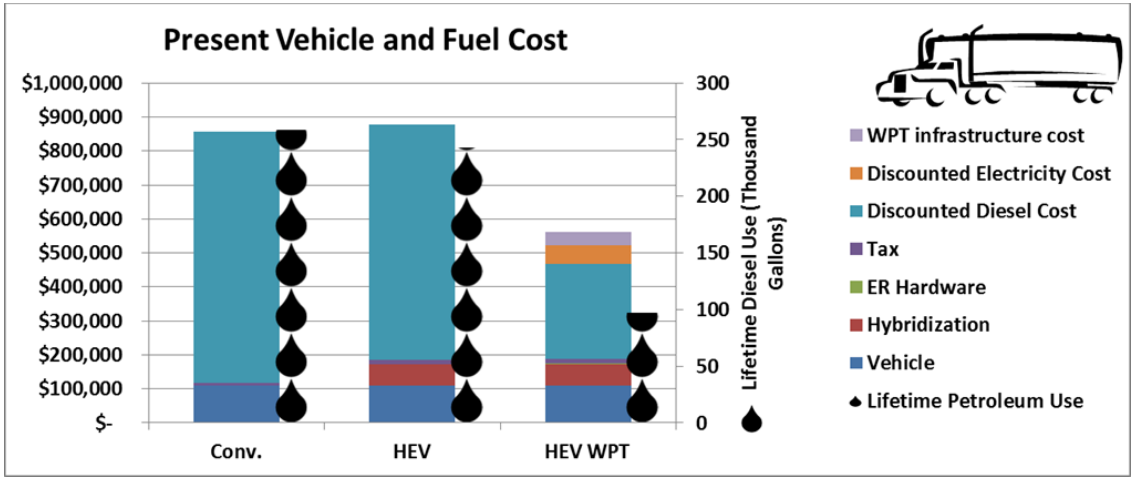


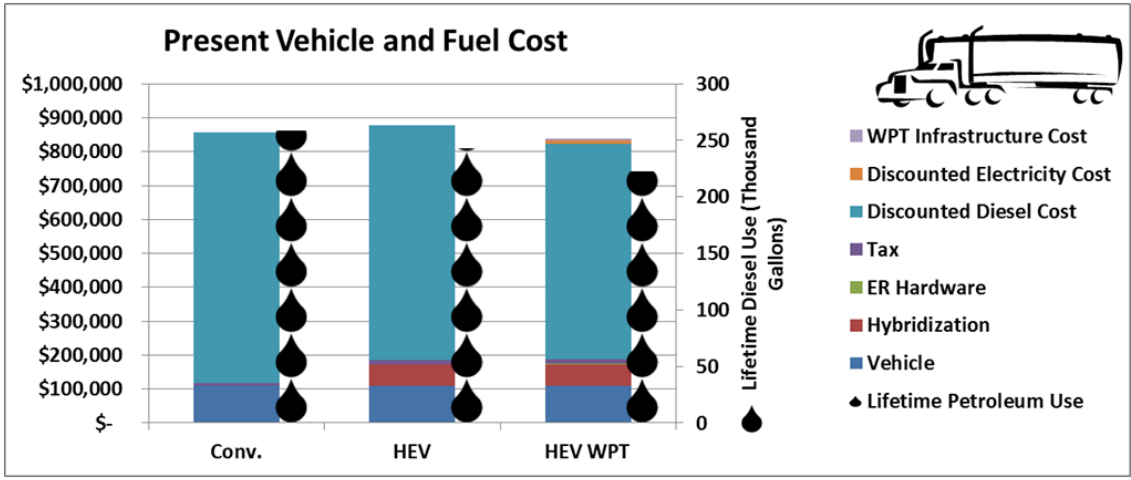

CS = charging station; HEB = hybrid electric bus
PHEB = plug-in hybrid electric bus
CB = conventional bus; NPC = net present cost

# Analyses of In-Motion Applications for Heavy Trucks

- **Aggressive deployment on entire interstate/ highway system**
  - Saves a lot of fuel with margin for higher cost assumptions ($3M / mile, 100 kW, used by all)

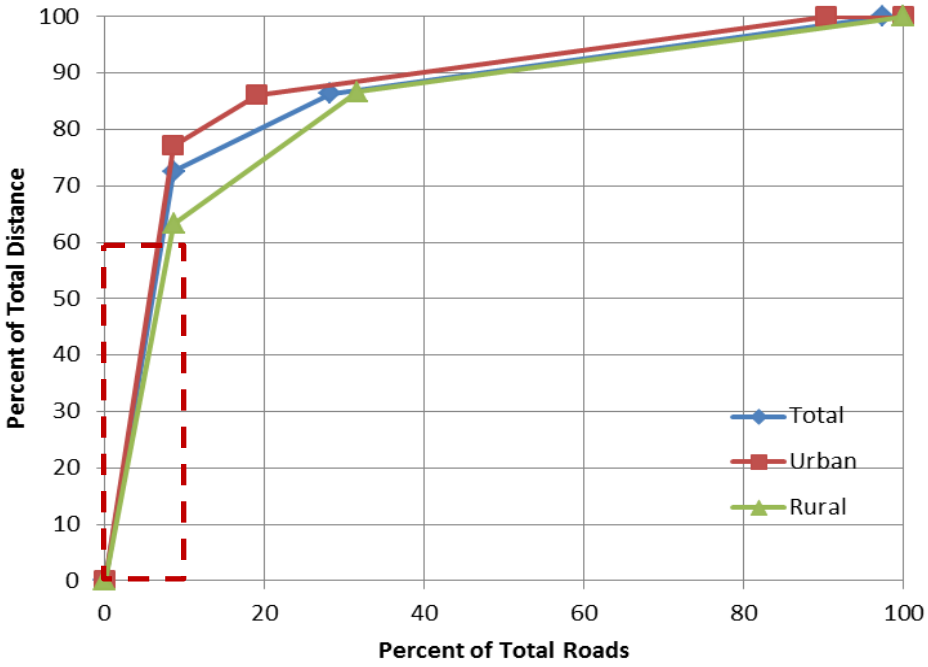



- **Initially deploy where road grade >1.5%**
  - Still attractive for fuel and cost savings
  - Potential hybridization (and engine downsizing) enabler

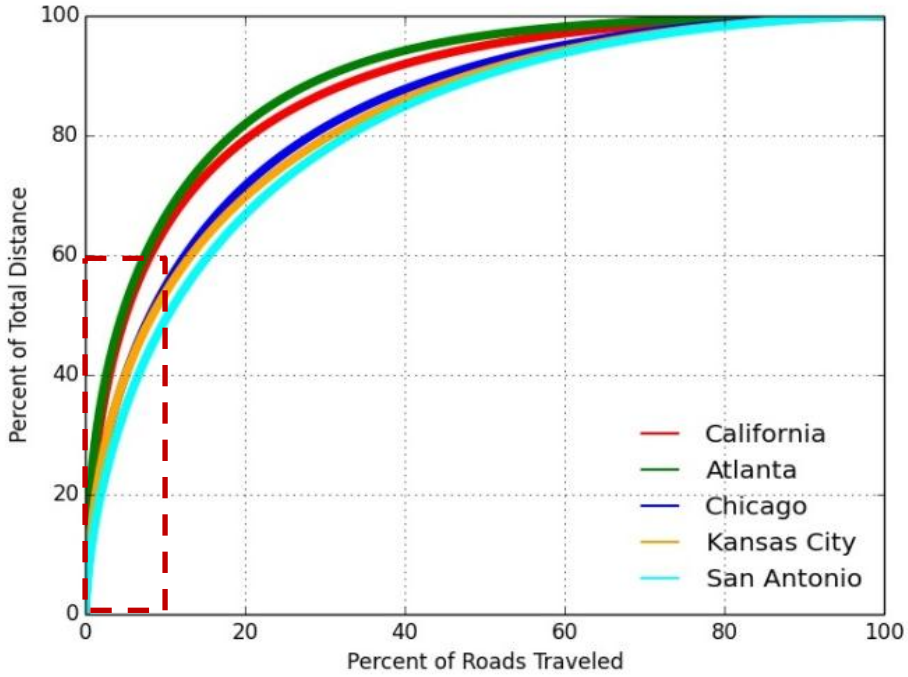


# Analyses of In-Motion Applications for Light-Duty Vehicles

## National Level



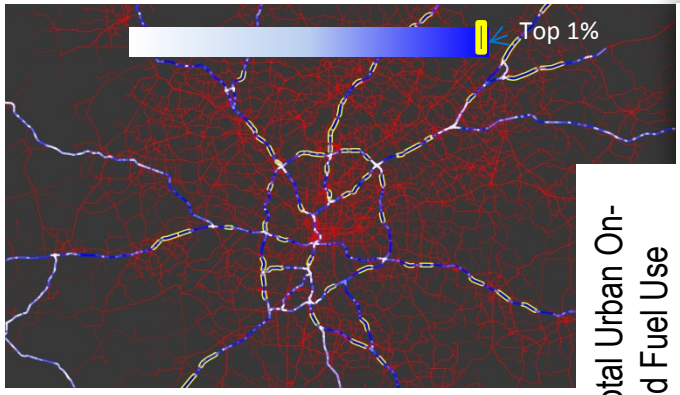

## State/Metro Area Level

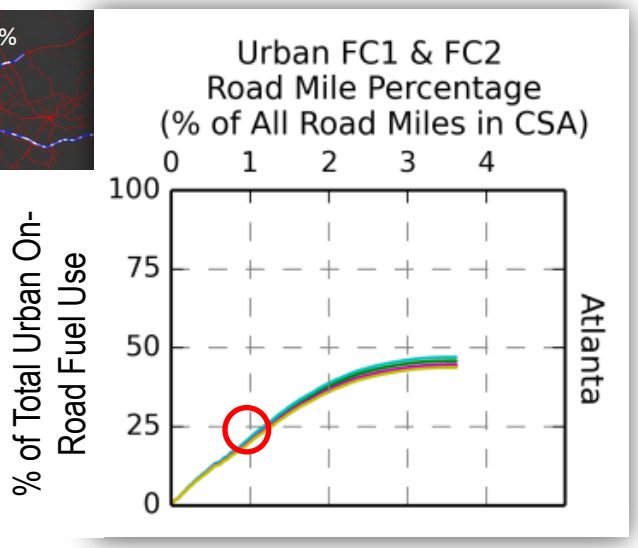



- **Identified potential for small fraction of in-motion WPT infrastructure to cover significant amount of travel**
  - Opportunity to maximize benefit/cost ratio
  - 1% of infrastructure would cover 15%–20% of travel
  - 10% of infrastructure would cover ≈60% of travel

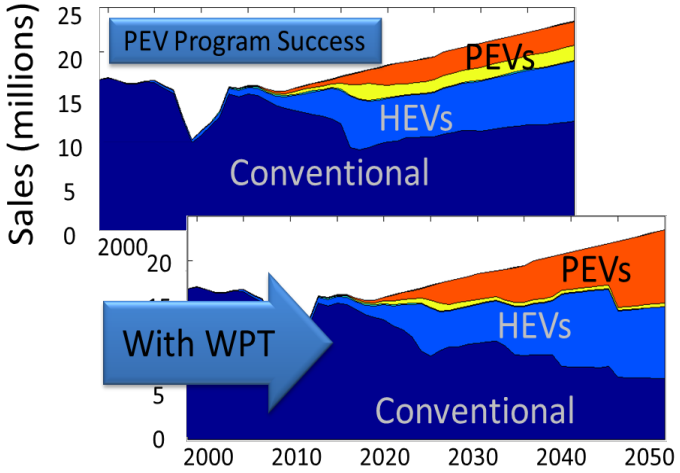
# Analyses of In-Motion Applications for Light-Duty Vehicles

- **Analyzed incremental roll out within urban areas**
  - Electrifying 1% of urban freeways consistently displaces ~25% of urban fuel use



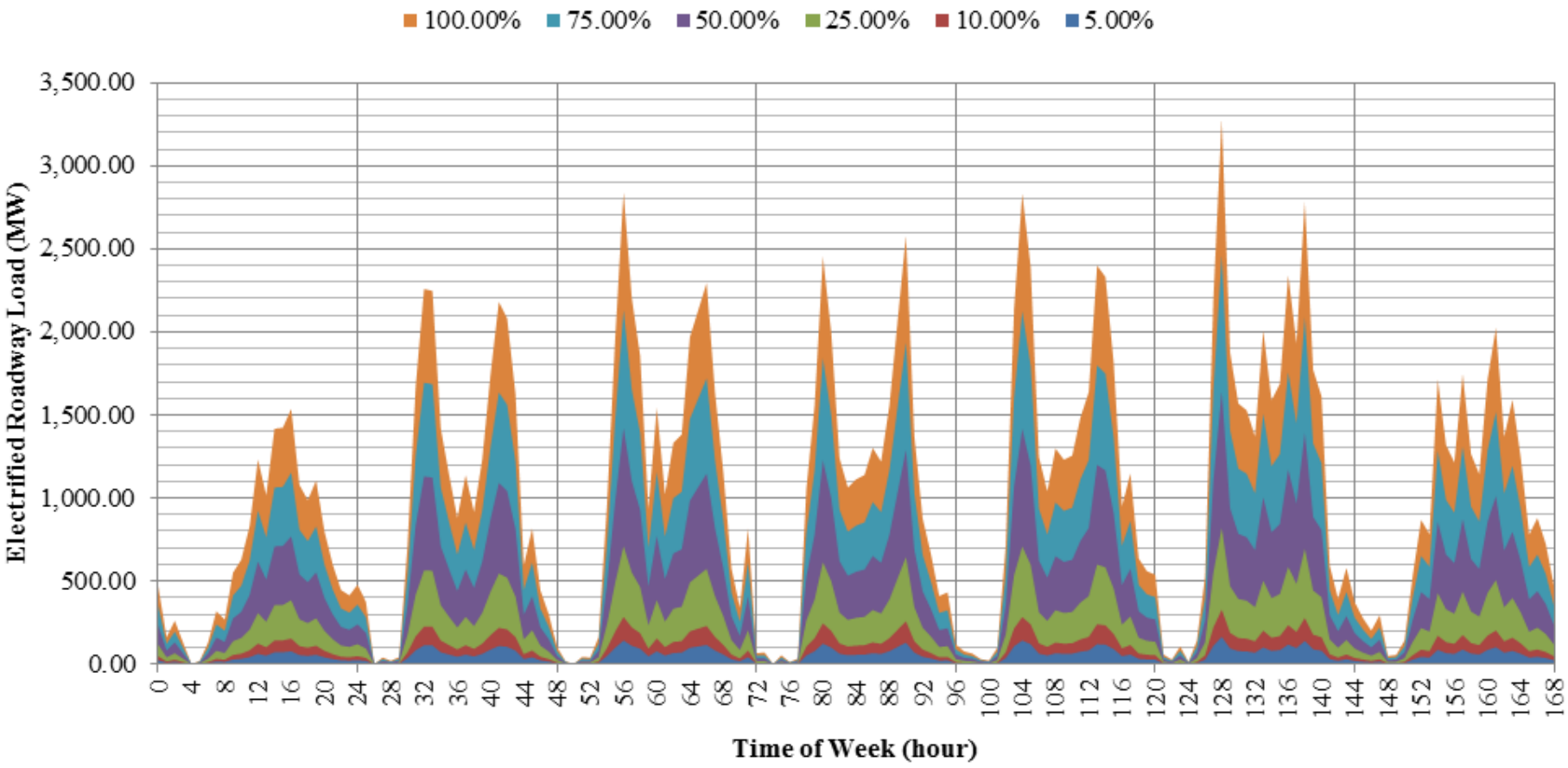

- **Estimated consumer preference impacts for advanced vehicles**
  - Reduced range limitation for PEVs
  - Improved cost effectiveness for HEVs with in-motion WPT


PEV = plug-in electrified vehicle (includes battery electric and PHEVs)

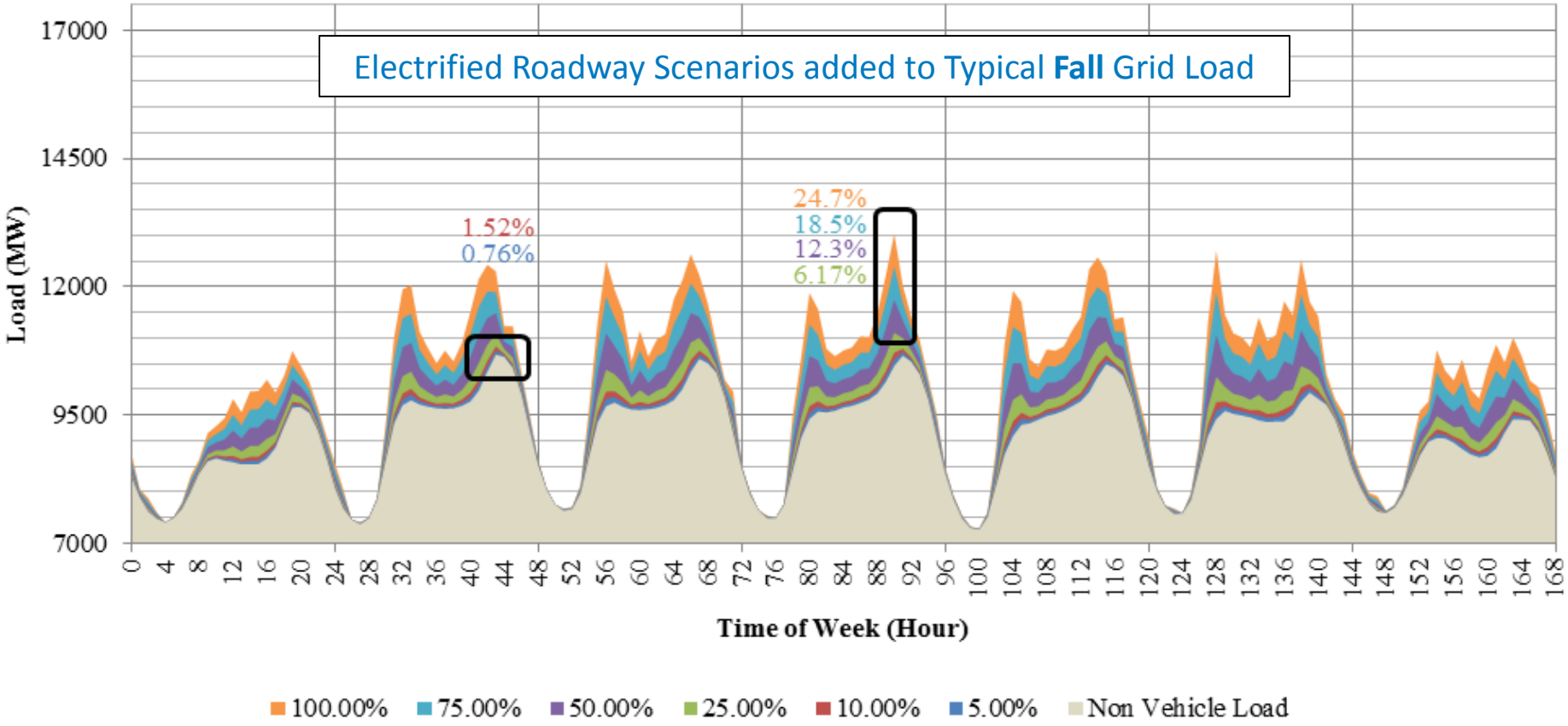
# Analyses of Resulting Load on the Grid

- Assuming different fractions of traveling vehicles draw power from the electrified roadway



# Relative to Typical Grid Loads

- Evaluated for each season (colored text indicates percent load growth over the baseline for each new seasonal average load peak)
- Historic U.S. load growth is ≈2% annually (twice load impact from 5% vehicle penetration, which would take a long time to realize)



# Overall Summary

- **NREL uses real-world data on mobility patterns as a key input into numerous advanced vehicle analyses**
- **Examples include green routing for Chevy Volt**
  - Modest fuel savings from V2X connectivity that could be cost effective and substantially beneficial in aggregate
- **Examples for WPT-enabled roadway electrification**
  - Increase electrified miles for static and quasi in-motion
  - Also displace instantaneous fuel use with fully in-motion
    - High leverage opportunity for travel on interstates/highways
    - Improve value proposition for WPT-connected PEVs and HEVs
    - Grid growth should be able to accommodate, though at high penetrations would need to manage peak alignment and impacts to load shape

# Thanks! Questions?

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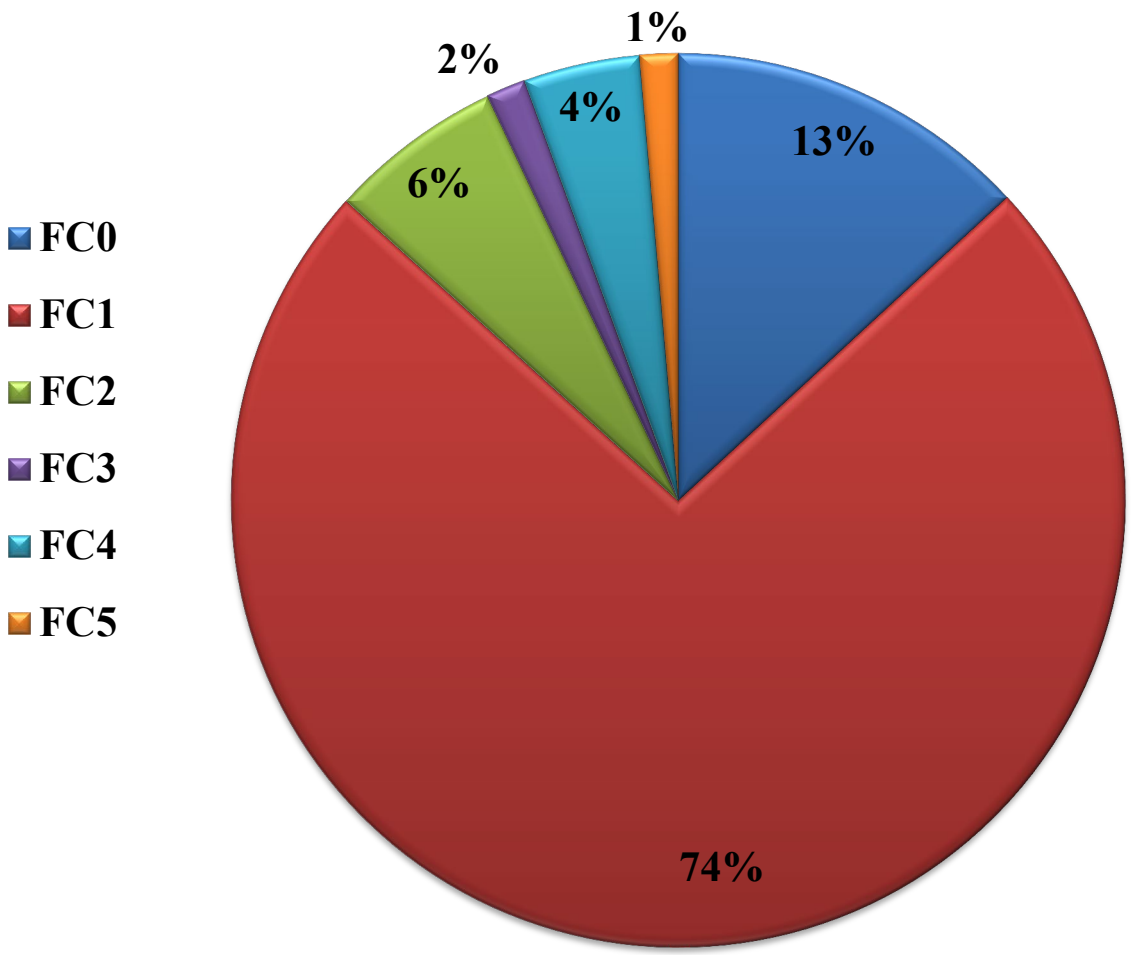
# Appendix

# Class 8 Line Haul Truck Functional Class Distribution




**FC1: Functional Class 1 corresponds to high-speed interstates**


**FC5: Functional Class 5 links to neighborhood streets**