



CAVs and Shared Mobility Potential Energy and GHG Impact

Chris Gearhart, Director

NREL Transportation and Hydrogen Systems Center

Clean Air Act Advisory Committee

Mobile Sources Technical Review Subcommittee

October 18, 2016

National Renewable Energy Laboratory



Photo by Dennis Schroeder, NREL 17613

NREL at a Glance

- Only U.S. National Laboratory dedicated to renewable energy and energy efficiency research
- Established in 1979 as Solar Energy Research Institute
- About 2,400 employees with world-class facilities
- Owned by the Department of Energy, operated by the Alliance for Sustainable Energy

National Renewable Energy Laboratory

Sustainable Transportation RD&D

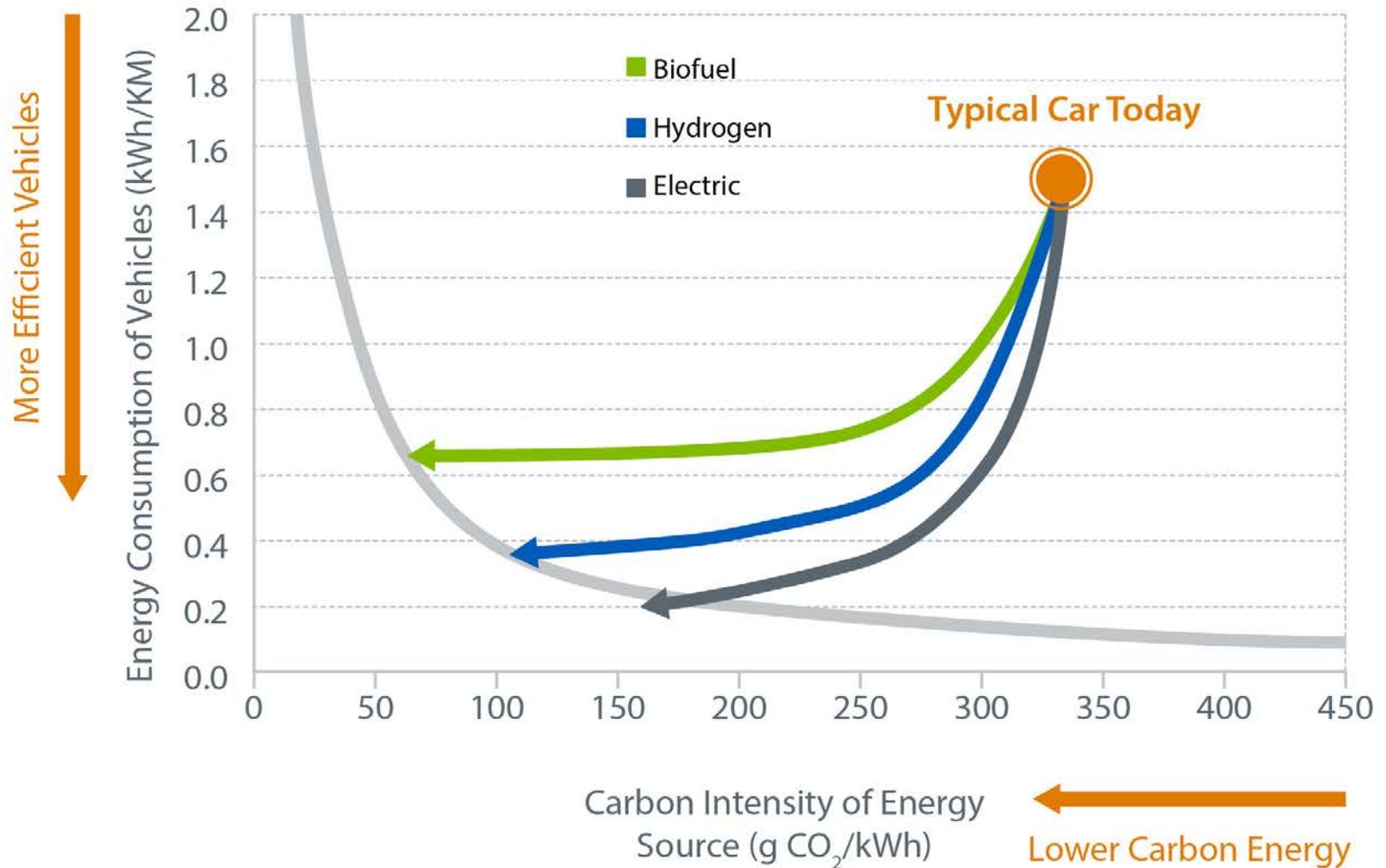
NREL has led U.S. clean-energy transportation innovation for 35 years

- Accelerates adoption of new transportation technologies, breaks down market barriers, and demonstrates economic viability
- Understands factors impacting technology commercialization
- Works closely with range of industry partners for real-world solutions; holds one quarter of DOE cooperative research and development agreements (CRADA)
- Integrates transportation RD&D with related renewables and efficiency research in the areas of building design, grid infrastructure, and energy generation.



Photos by NREL

Our Goal is Deep Decarbonization of Transportation



The Biggest Thing in Automotive Technology R&D

Vehicle Connectivity and Automation are Here

Today



Image by NREL

Safety and Convenience Benefits

- Collision aversion
- Park assist
- Limited drive-cycle smoothing
- GPS route mapping
- Dynamic ridesharing

Near-Term



Image courtesy of Ford

Fuel Economy Benefits

- Efficient route selection and improved driving profiles
- Vehicle “platooning”
- Stationary wireless power transfer
- Automated vehicle “valet” parking and retrieval

Long-Term



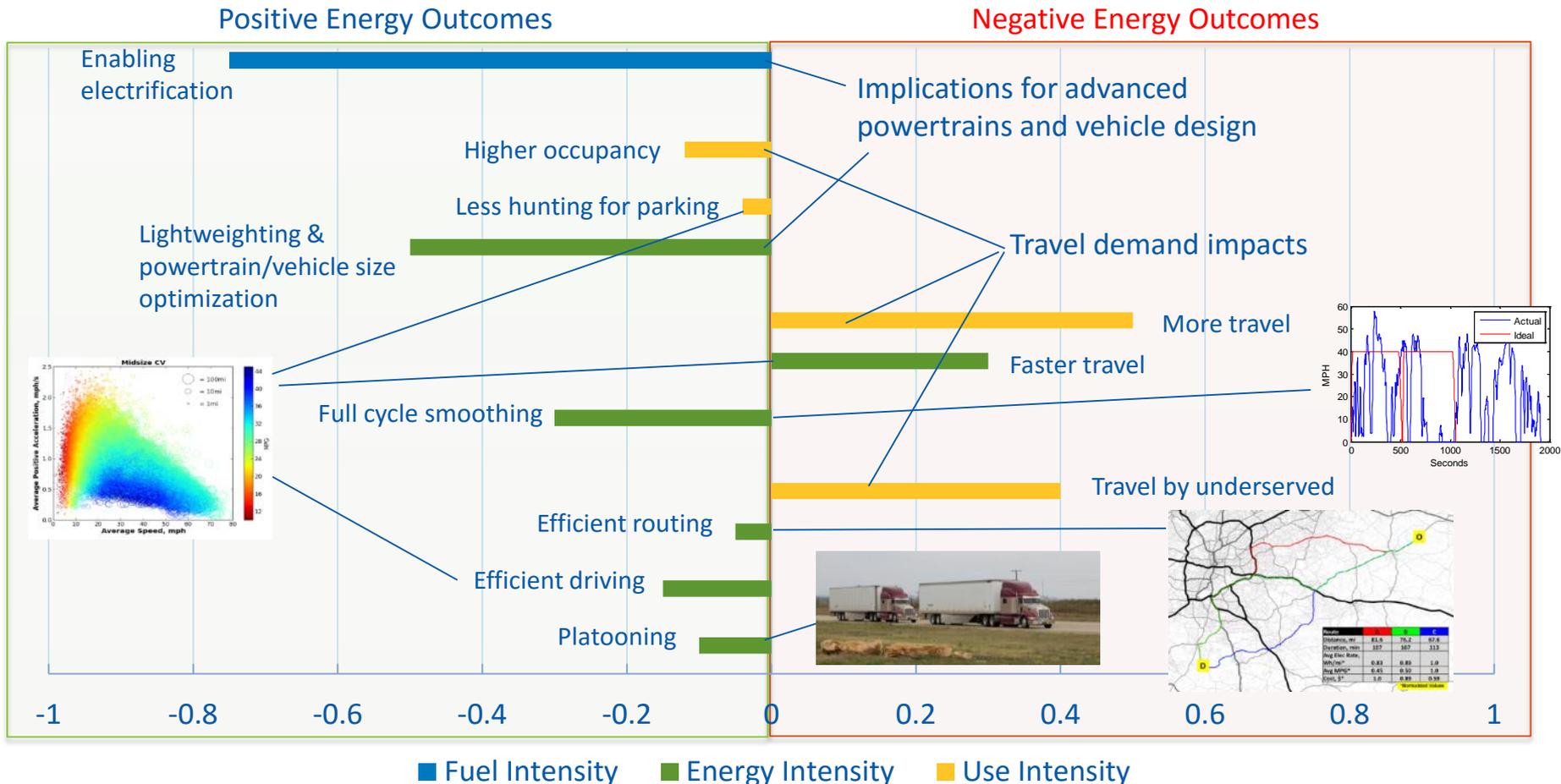
Image Courtesy of GM

System-Wide Benefits

- Fully automated hands-free driving
- Vehicle to vehicle and vehicle to infrastructure communication
- In-motion wireless power transfer

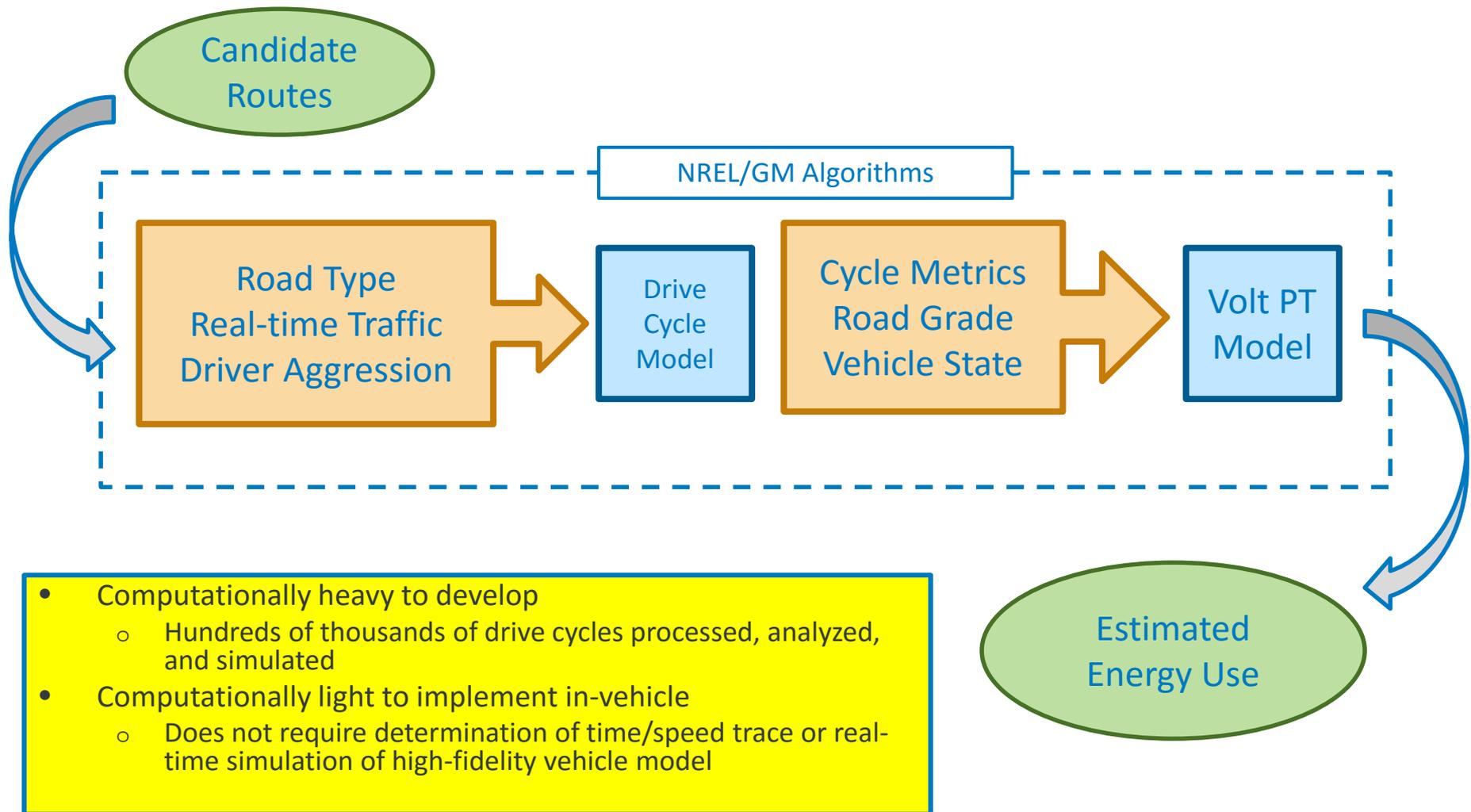
“Bookending” CAV Energy Impact Analysis

- Identified dramatic potential energy impacts (across automation levels)
 - Informed by related NREL work and literature review
 - Significant uncertainties remain; further research warranted/on-going



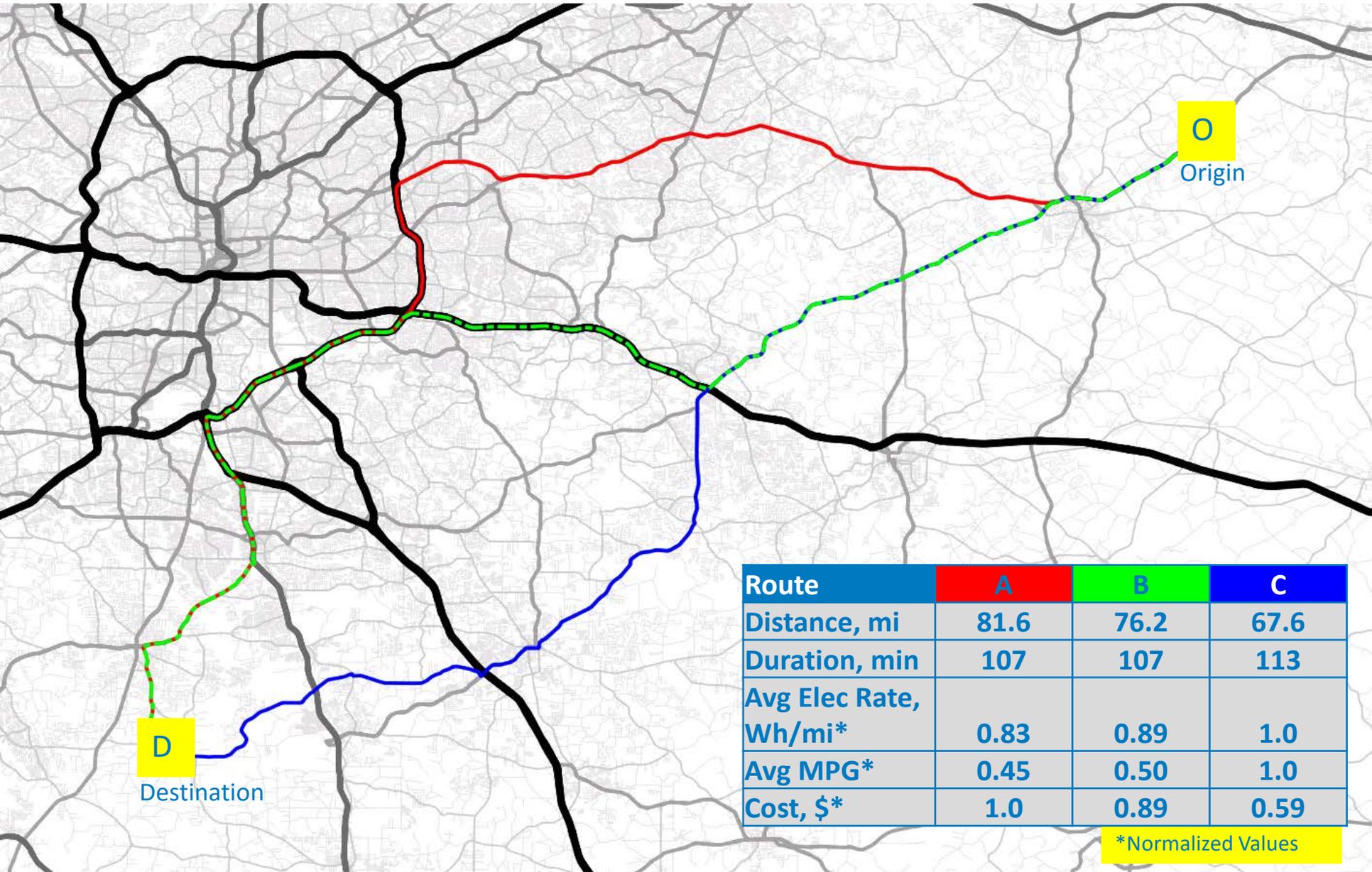
Brown, A.; Gonder, J.; Repac, B. (2014). “An Analysis of Possible Energy Impacts of Automated Vehicles.” Chapter 5, Societal and Environmental Impacts. Meyer, G., ed. *Lecture Notes in Mobility: Road Vehicle Automation*. Berlin: Springer.

Example from Collaborative Project with GM on Green Routing and Adaptive Control for the Chevy Volt



Gonder, J.; Wood, E.; Rajagopalan, S. "Connectivity-Enhanced Route Selection and Adaptive Control for the Chevrolet Volt." *Proceedings of the 21st World Congress on Intelligent Transport Systems*, Sept 2014. www.nrel.gov/docs/fy14osti/60960.pdf

Green Routing Example

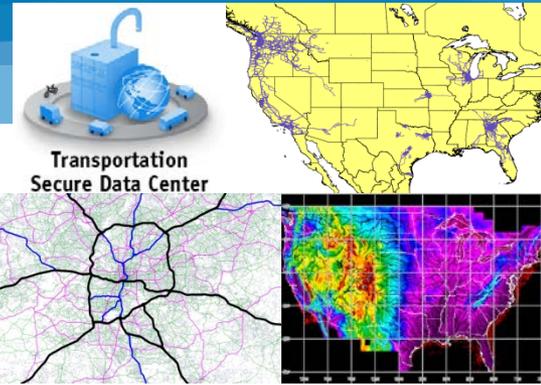


| Route | A | B | C |
|-----------------------|------|------|------|
| Distance, mi | 81.6 | 76.2 | 67.6 |
| Duration, min | 107 | 107 | 113 |
| Avg Elec Rate, Wh/mi* | 0.83 | 0.89 | 1.0 |
| Avg MPG* | 0.45 | 0.50 | 1.0 |
| Cost, \$* | 1.0 | 0.89 | 0.59 |

*Normalized Values

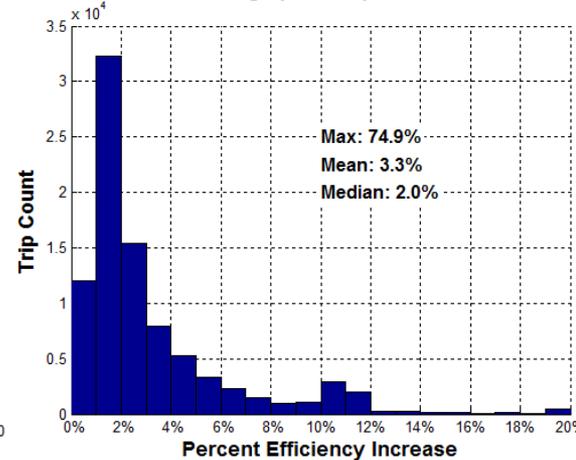
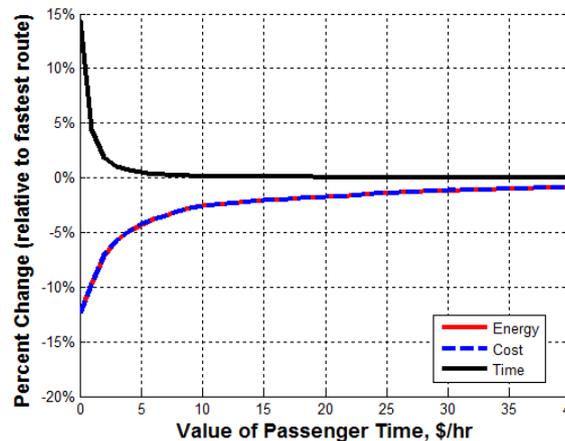
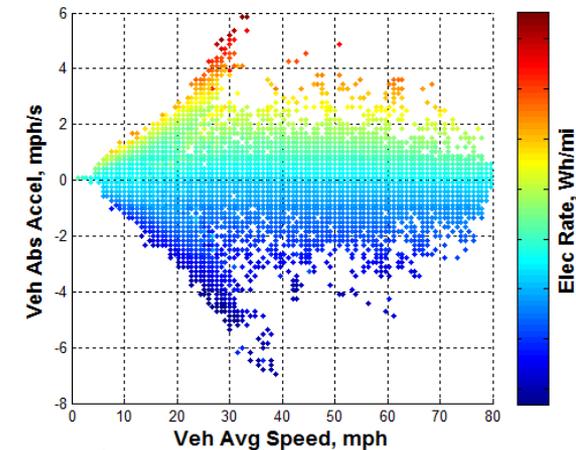
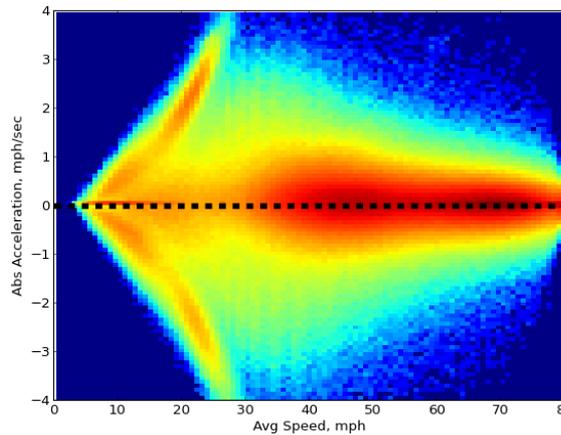
Collaborative Project Summary

NREL IG 18563



- 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

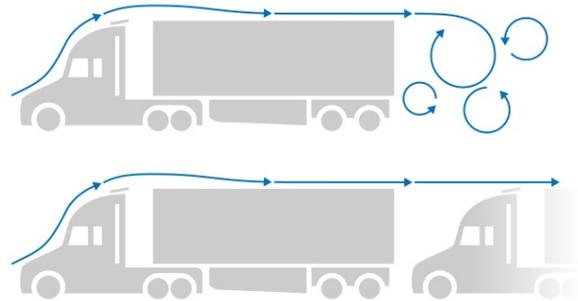
Modest aggregate savings, but may be cost effective



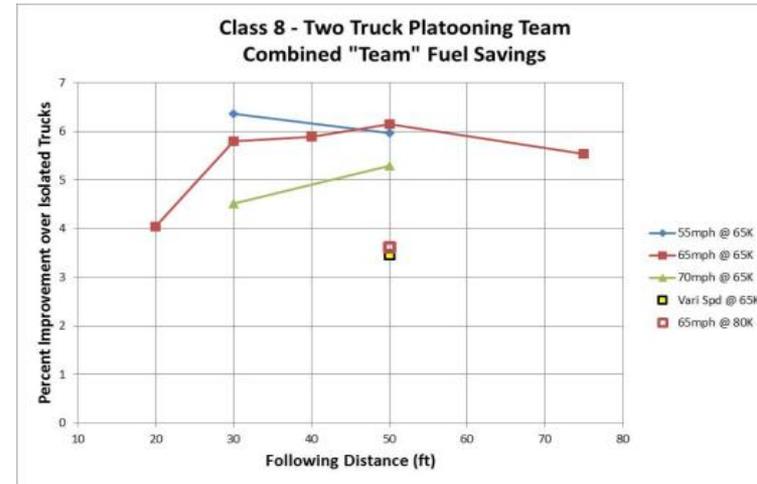
Evaluating Truck Platooning Efficiency Benefits

- Many factors can influence

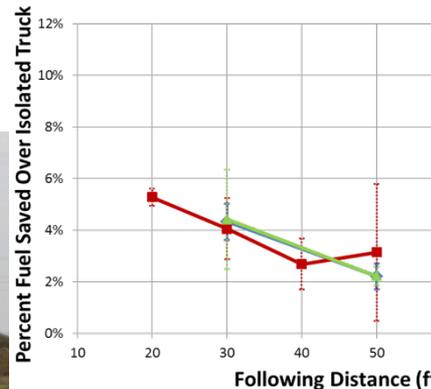
- Vehicle spacing
- Cruising speed
- Speed variation
- Baseline aerodynamics
- Vehicle loading
- Engine loading



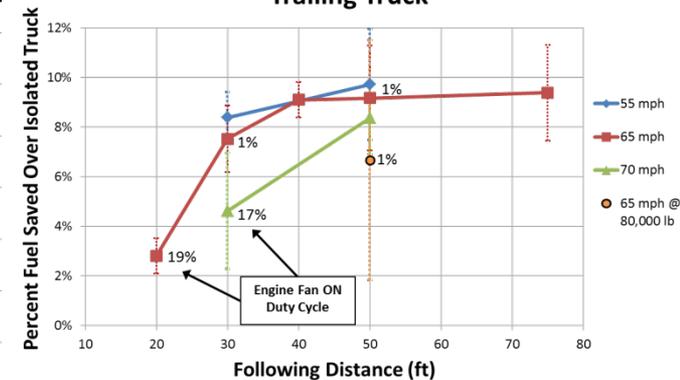
- Also potential safety and comfort benefits



Class 8 Truck Platooning - Lead Truck -



Class 8 Truck Platooning Fuel Savings - Trailing Truck -



Results from SAE Type II track testing of Peloton Technology system over a variety of conditions

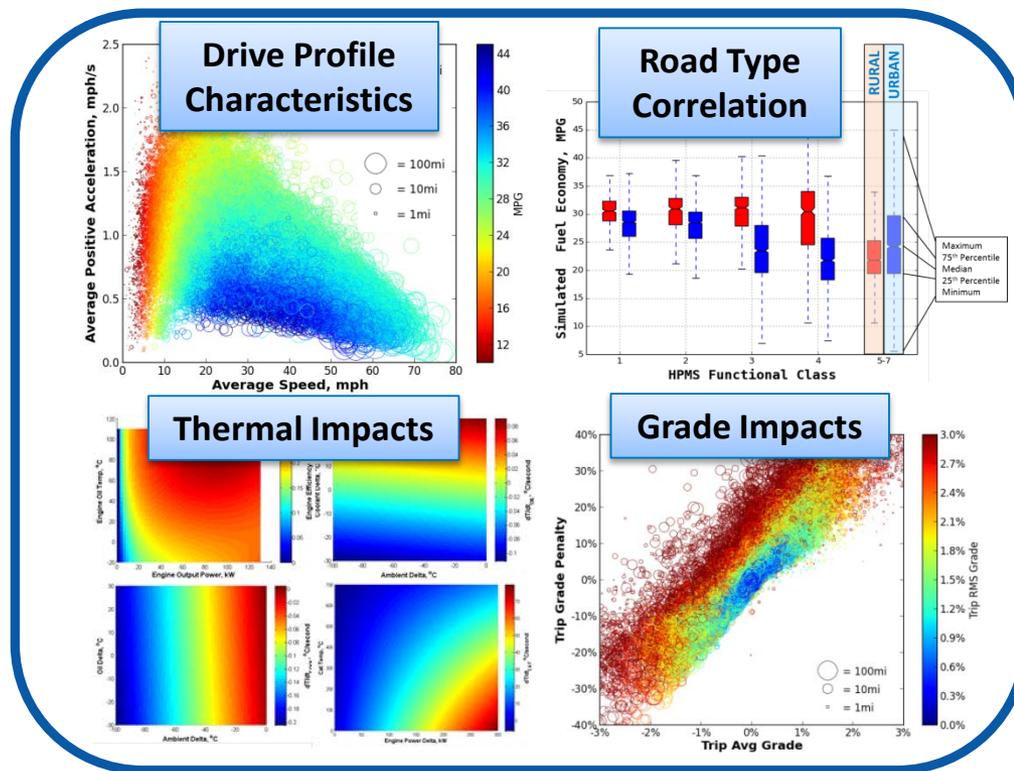
Lammert and Gonder poster: www.nrel.gov/docs/fy14osti/62494.pdf

Lammert, et al. *SAE Int. J. Commer. Veh.*: www.nrel.gov/docs/fy15osti/62348.pdf

Photo from Mike Lammert, NREL

Prototyped Process for National-Level Aggregation of “Off-Cycle” Technology Impacts - 1

Fuel Consumption Rates

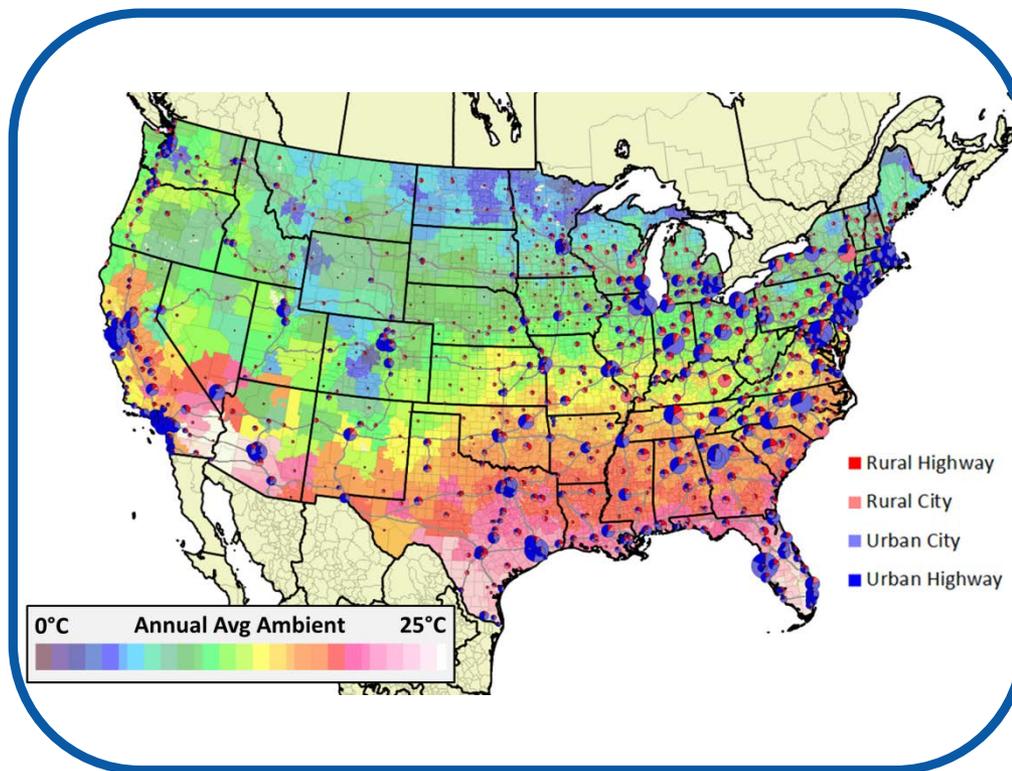


Use test data plus modeling to determine a given vehicle’s fuel consumption rate over a range of driving situations

- Consider drive profile characteristics, road grade, temperature, solar load, etc.
- Use large real-world driving database to correlate drive profile characteristics with road type/traffic conditions

Prototyped Process for National-Level Aggregation of “Off-Cycle” Technology Impacts - 2

Vehicle Miles Traveled (VMT) Volumes

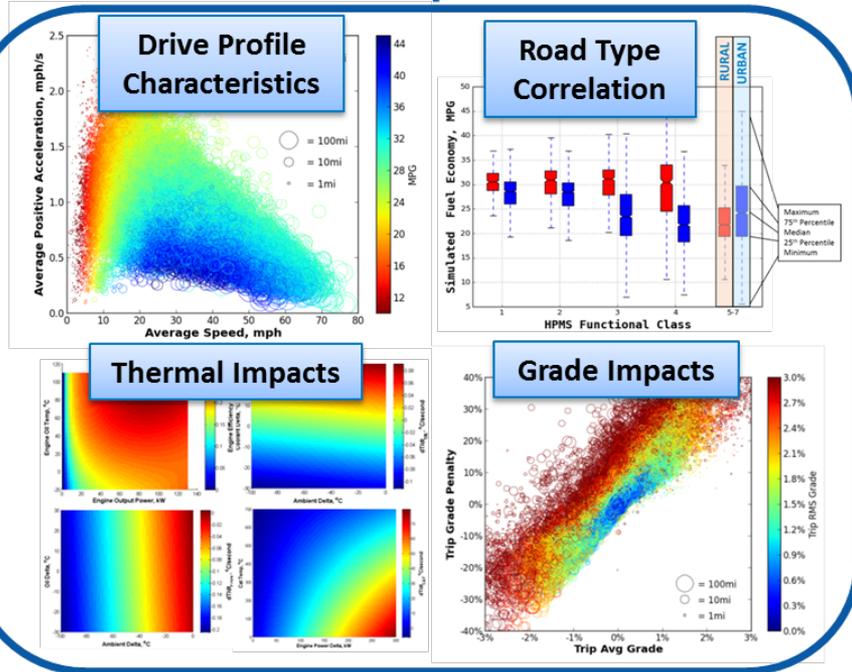


Combine national datasets on driving volumes by road type, climate conditions, road grades, etc.

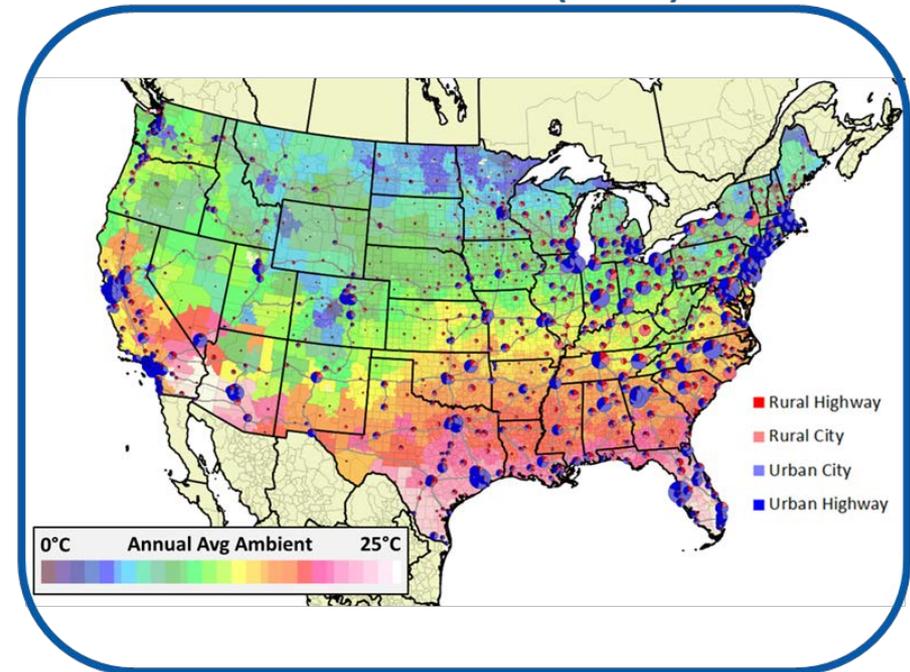
- Proportionally weight consumption rates from different situations by the amount of driving each represents across the country and a typical meteorological year
- Calculate aggregated national-level fuel economy

Prototyped Process for National-Level Aggregation of “Off-Cycle” Technology Impacts - 3

Fuel Consumption Rates



Vehicle Miles Traveled (VMT) Volumes



Repeat process with and without a given off-cycle technology enabled to calculate its national-level benefit

- Methodology captures varying impacts a technology can have across a broad range of driving conditions
- Aggregation process permits the national-level A/B comparison

Multi-Lab SMART Consortium

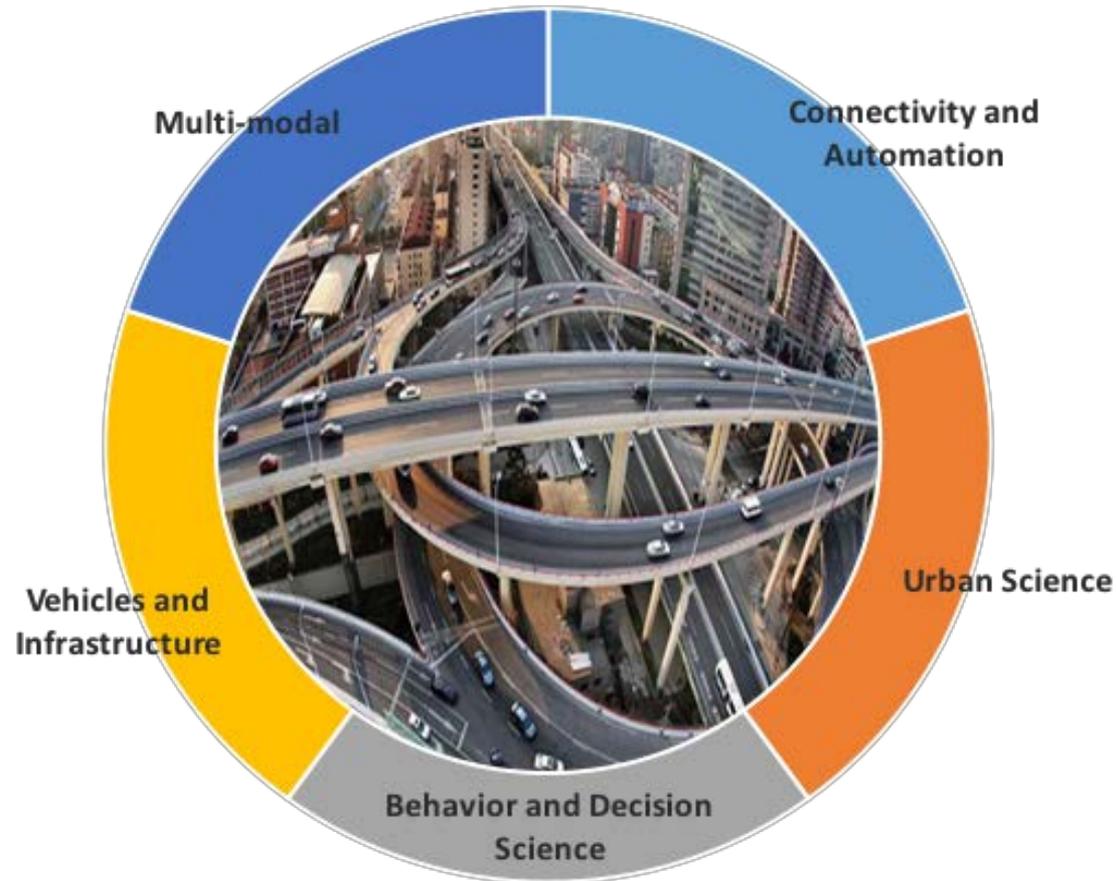
Investigating Energy and GHG Impacts of Connected and Automated Vehicles

Today:

- Vehicle-level focus
- Independent
- Unconnected
- Subject to behaviors & decisions

Tomorrow:

- System-level focus
- Connected
- Automated
- In concert
- Across modes
- Managed behaviors & decisions



Exploring untapped transportation system-level efficiencies

www.nrel.gov

