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Energy Impacts of Connected and Automated Vehicles (CAVs)

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NREL Transportation Center

ARPA-E NEXTCAR Program Kickoff, April 2017

DOE SMART MOBILITY LABORATORY CONSORTIUM

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Multi-Year, Multi-Lab Effort (3 years, 5 labs)

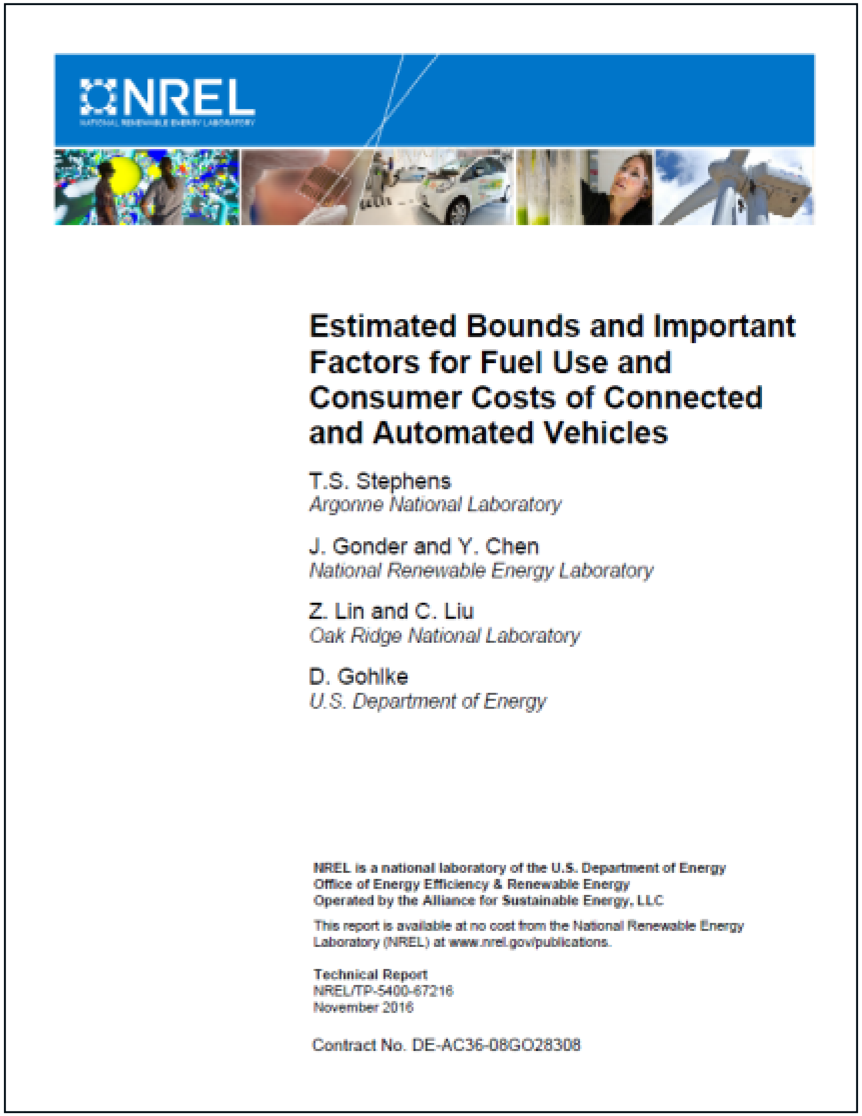
- Energy implications of connectivity & automation
- Multi-modal transport of people and goods
- City-scale urban mobility models for planning
- Informed fueling infrastructure investments
- Understanding consumer mobility decisions

Recent Multi-Lab Technical Report on CAVs Energy Impacts

Objectives:

- Review relevant studies and assess what is known about potential energy and market implications of CAVs for passenger travel and energy use
- Estimate bounds on the impacts of CAVs on energy use (<u>focus on U.S. light-duty passenger vehicles</u>)
- Identify key knowledge gaps/uncertainties

Report available on-line:
www.nrel.gov/docs/fy17osti/67216.pdf



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Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles

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Technical Report
NREL/TP-5400-67216
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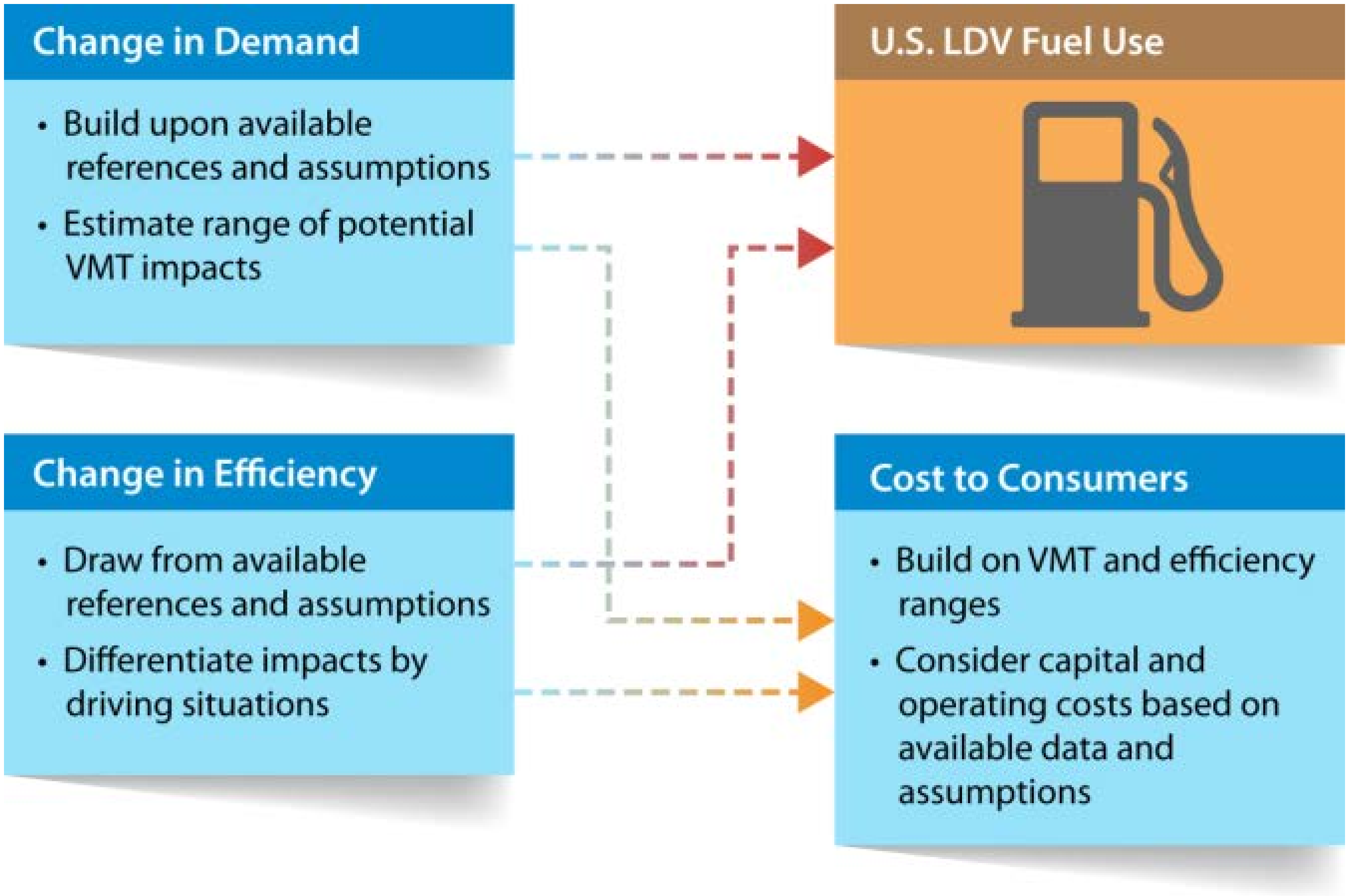
Methodology

- Estimate demand and efficiency impacts from 12 factors
- Calculate upper and lower bounds for fuel consumption and consumer cost



Factors Studied

- Demand
  (Changes in VMT)
  (Changes in 'mobility')
  - ↑ Easier Travel
  - ↑ Underserved
  - ↑ Empty Miles
  - ↑ Mode Shift
  - ↓ Hunting for Parking
  - ↓ Ridesharing

- Efficiency
  (Changes in MPG)
  (Changes in 'operation')
  - ↑ Vehicle/Powertrain Resizing
  - ↑ Drive Smoothing
  - ↑ Platooning
  - ↑ Collision Avoidance
  - ↑ Intersection V2I
  - ↓ Fast Travel

VMT = vehicle miles travelled; MPG = miles per gallon;
V2I = vehicle to infrastructure (communication)

Study Scenarios and Caveats

Four "scenarios" synthesized from literature findings:

- Conventional (negligible levels of automation and ridesharing)
- Partial Automation (with limited connectivity)
- Full Automation (and connectivity)
- Full Automation (and connectivity), with Ridesharing

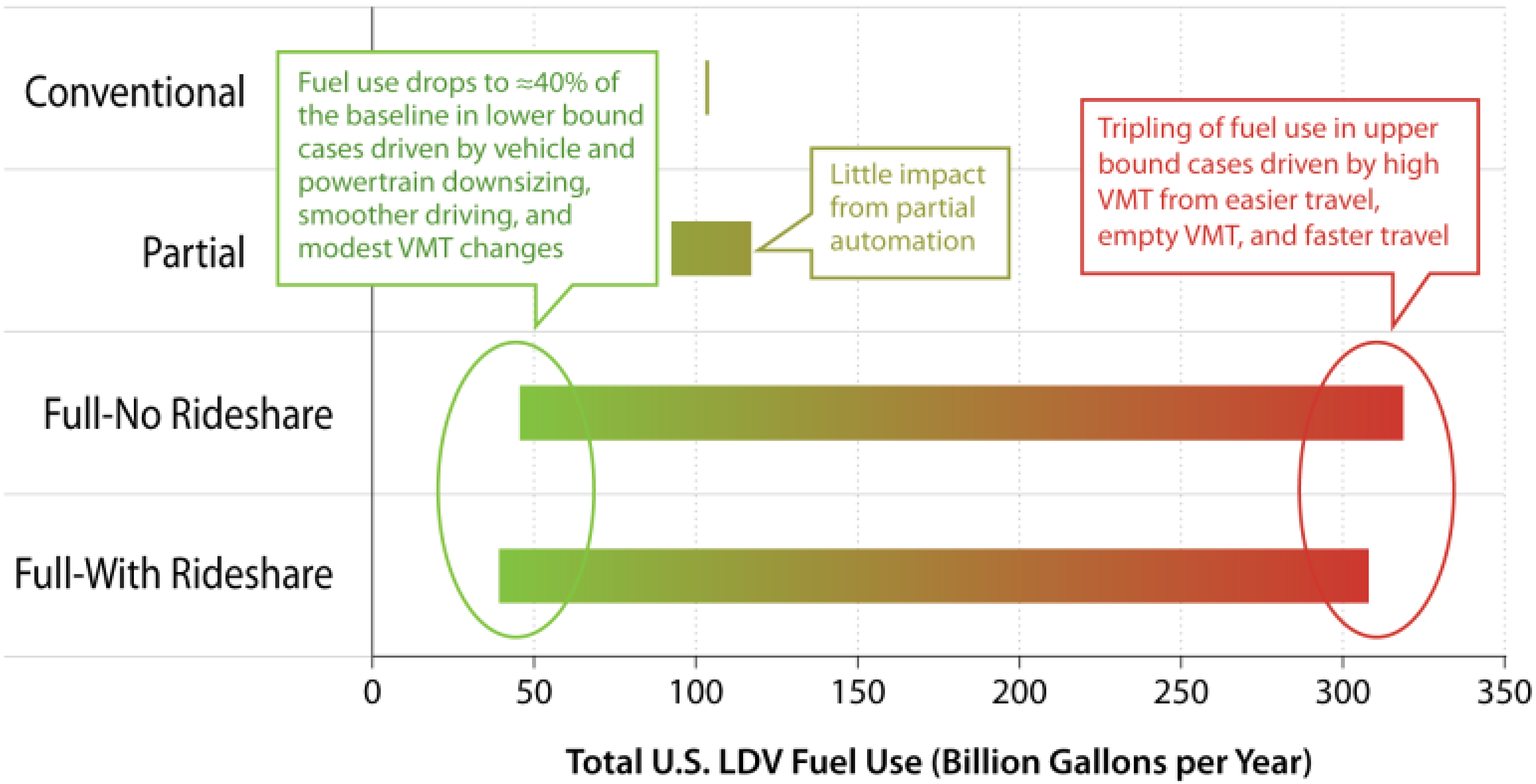
Caveats/limitations:

- Only light-duty vehicles
- No fuel switching/alternative powertrains
- Assumed full penetration by CAVs
- Roadway capacity constraints not explicitly considered
- Road conditions and driving cycle considered only approximately at an aggregate level

Results: Wide Range of National-Level Energy Impacts

- Partial automation: +/- 10%-15%
- Full automation: -60% / +200%
- Ride-sharing: Reduction of up to 12%

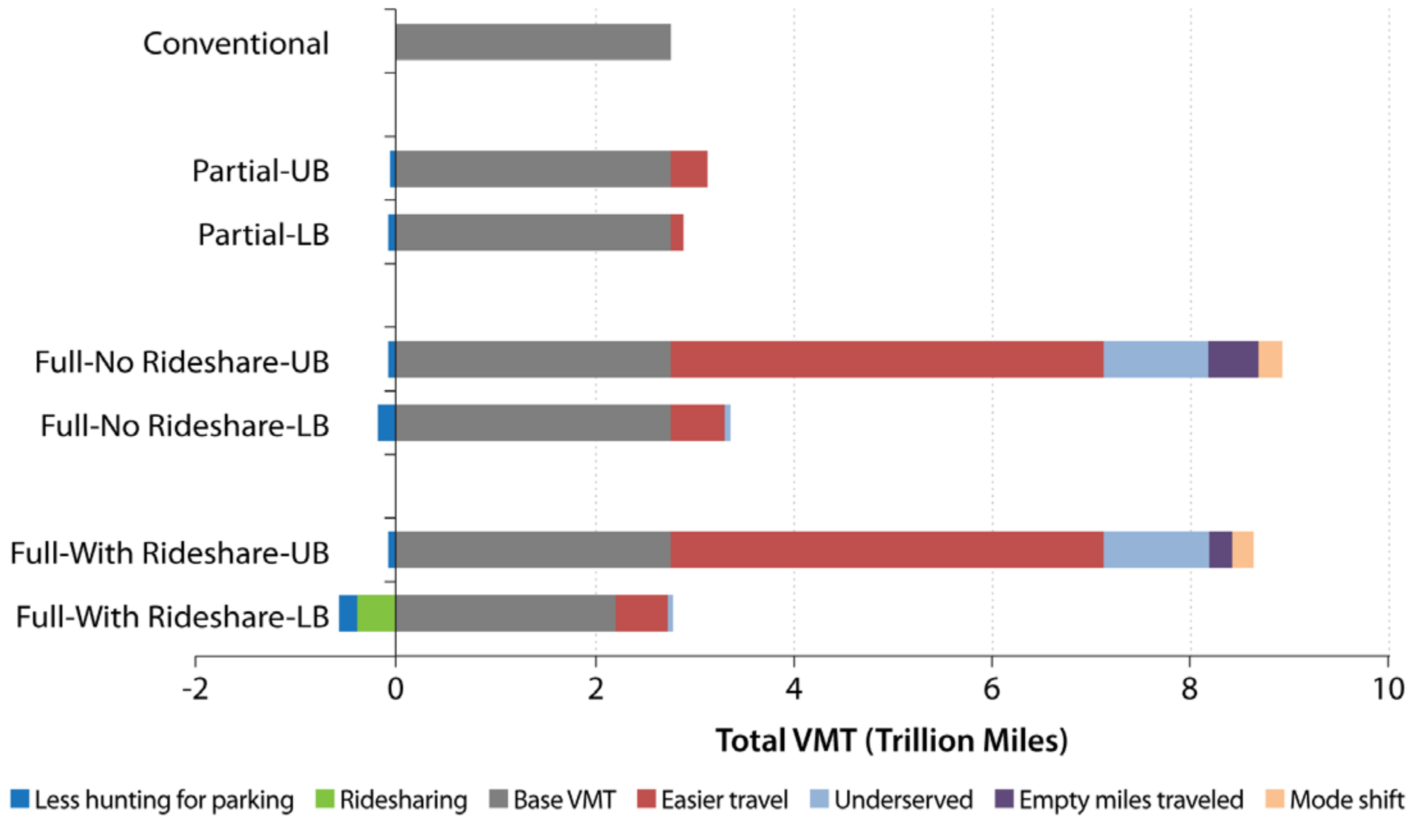
(No fuel switching or electrification included)



What Drives the Range of Results?

Travel Demand (VMT)

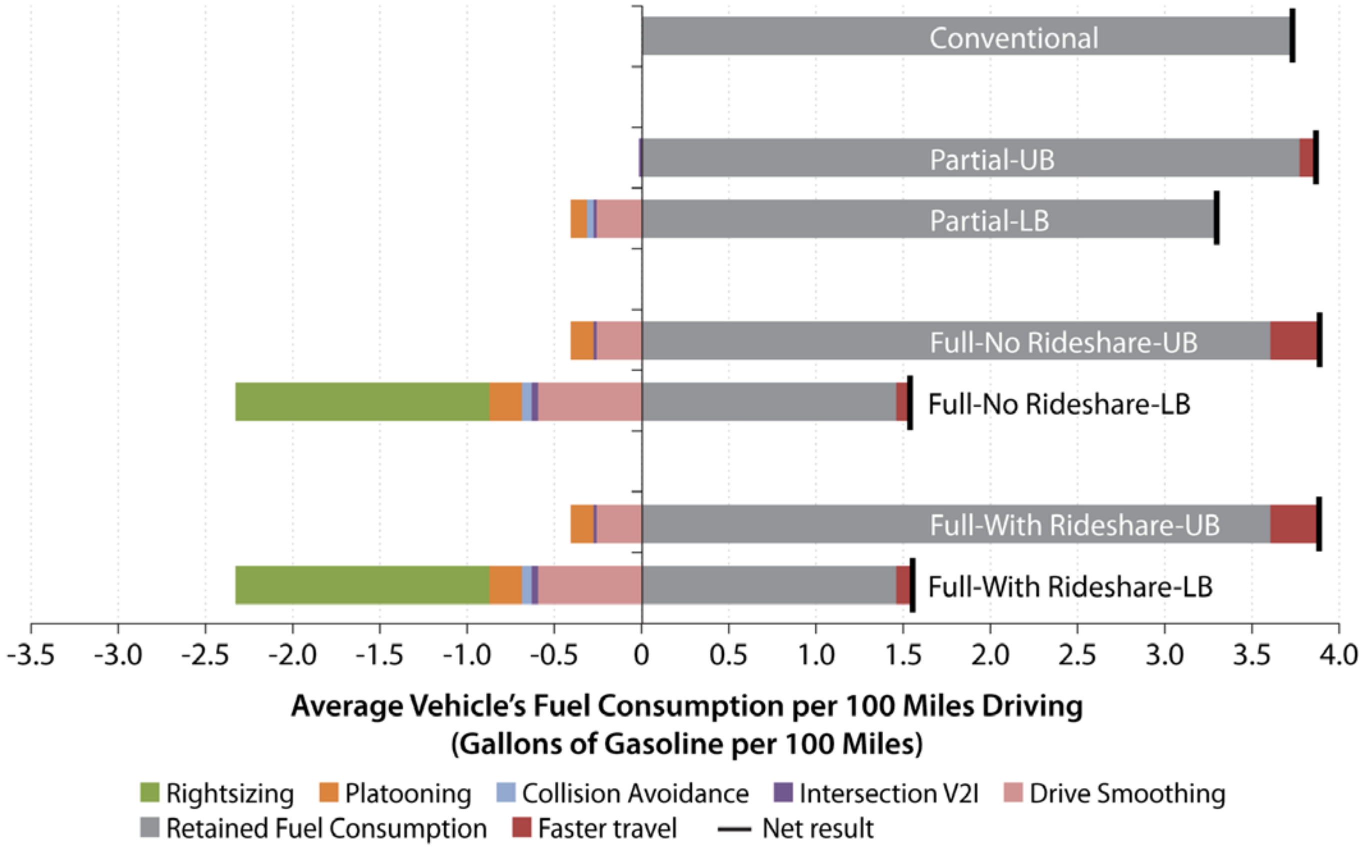
- **Easier travel** is a major demand driver
- **Underserved** (+access), **empty miles** (repositioning), **mode shift**, and **ridesharing** are other important factors



What Drives the Range of Results?

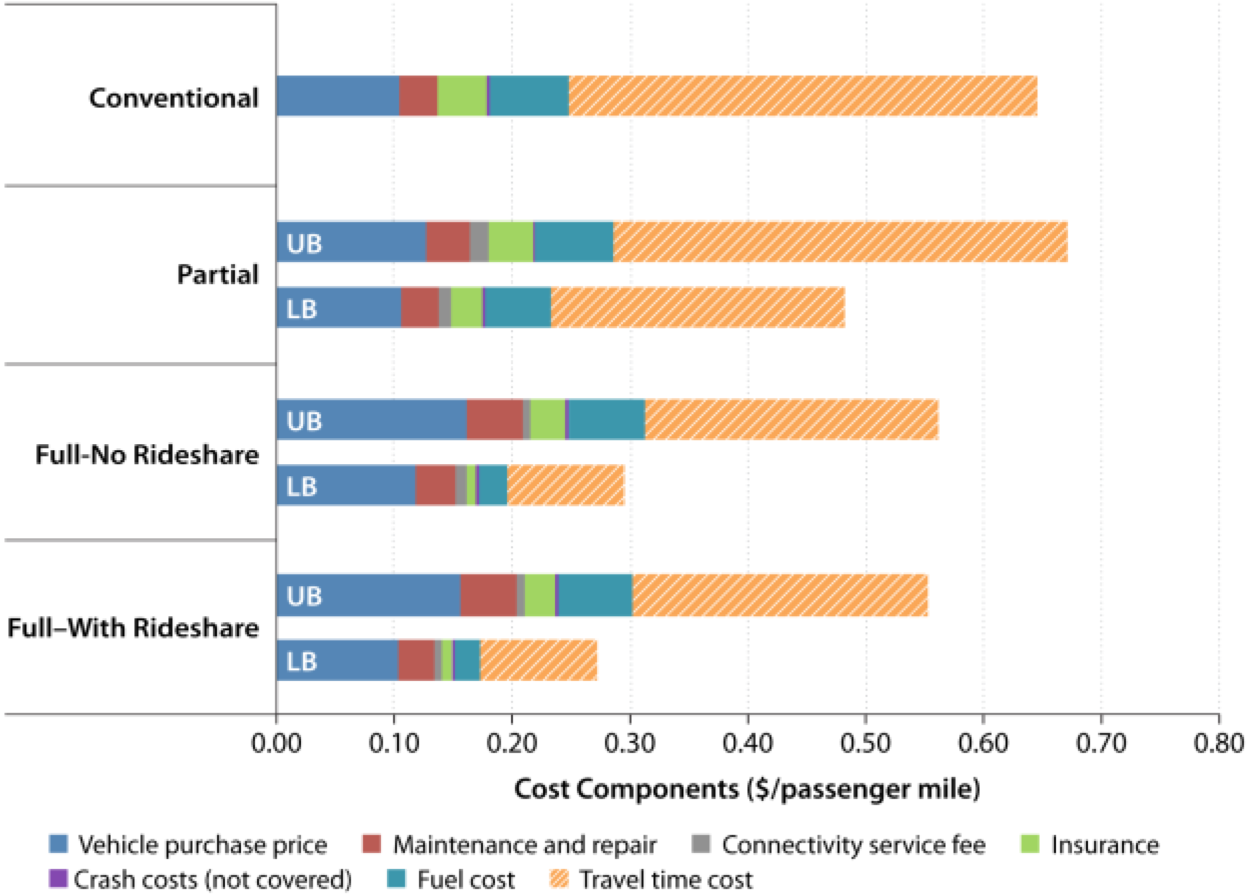
Vehicle Efficiency

- **Right-sizing** potentially gives the largest efficiency gains
- Efficiency improvements from **smoother driving**, **platooning** and **connectivity** also contribute
- **Faster (safe) travel** can potentially offset some efficiency gains



What is the Value to the Consumer?

- **Cost of the vehicle** and **maintenance** would be higher with additional technology
- Per mile costs expected to decrease for **fuel** (improved efficiency) and **insurance** (lower accident rates)
- The **value of travel time** is a large uncertainty, but the gain in opportunity cost is potentially larger than any other economic factors



Important Data/Knowledge Gaps

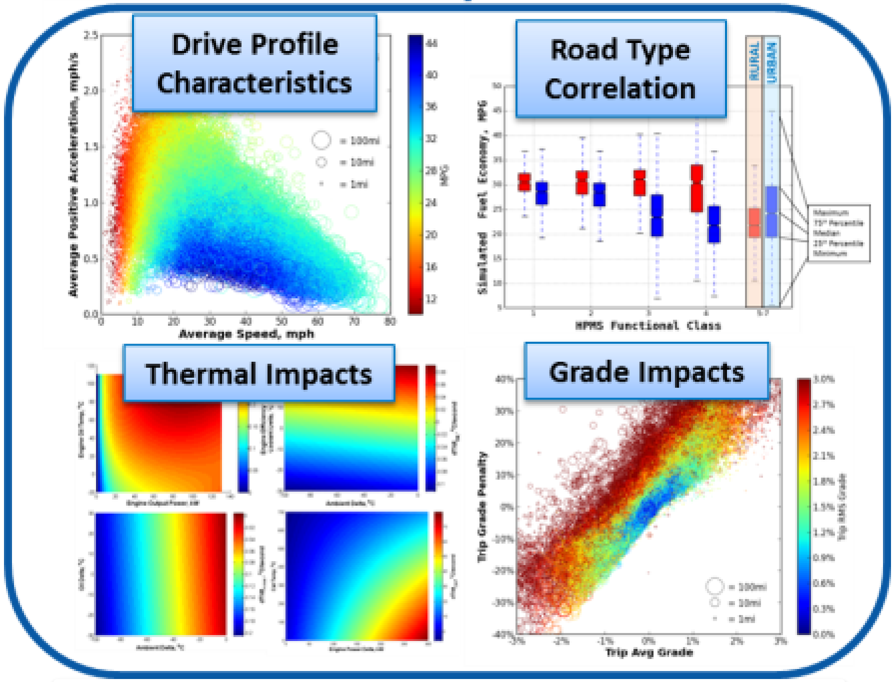
- How will travel demand (VMT) change?
- Which CAVs capabilities will be adopted and at what rates by various population segments?
- How will CAVs change vehicle efficiency?
  - Light-duty
  - Heavy-duty
- How do CAVs' impacts scale with penetration?

Next steps

- Calculation framework to scale up from micro-analysis/road-link-level to national level
- Establish intermediate/nuanced scenarios
- Explore impacts and sensitivities with the framework
  - Informed by technology-specific evaluations within SMART Mobility CAVs pillar

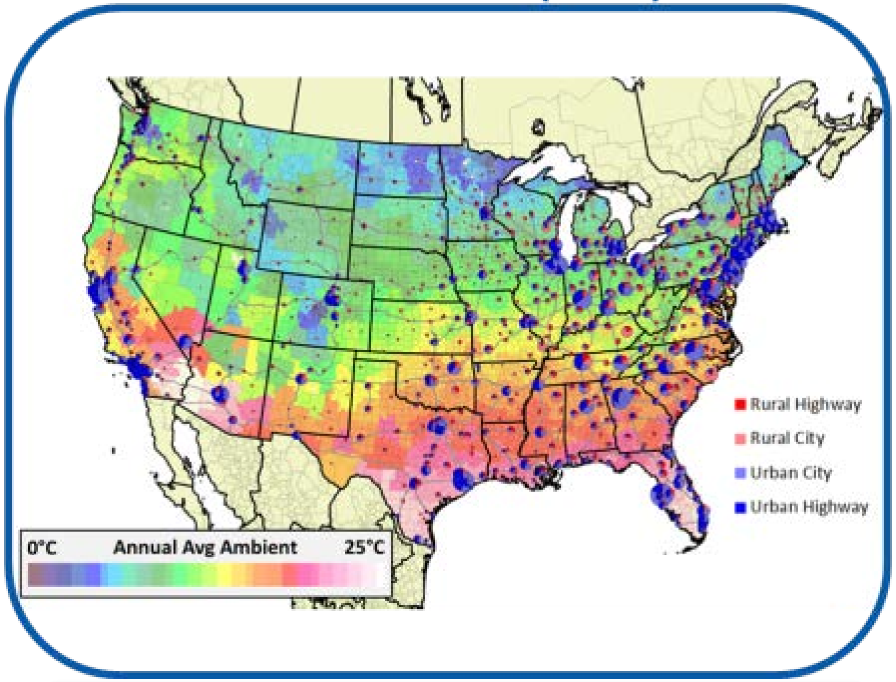
Rigorous National-Level Aggregation Approach

Fuel Consumption *Rates*



Quantify different CAV feature fuel economy impacts in different driving situations

Vehicle Miles Traveled (VMT) *Volumes*



Consider the relative proportion of national VMT represented by each driving situation

- Aggregate weighted results for national-level impact, making A/B comparisons for fuel use with or without a given technology active

NREL prototyped this process with “off-cycle” thermal technologies; CAV technologies require same assessment approach

- E.g., efficient routing, cycle smoothing, and adaptive control technologies
- Assess energy benefit from potential real-world change, and frequency of occurrence
- Existing pathway offered for demonstrating off-cycle credit beyond pre-defined table of technologies

Demonstrations not Based on 5-Cycle Testing

In cases where the benefit of a technological approach to reducing CO_2 emissions cannot be adequately represented using 5-cycle testing, manufacturers will need to develop test procedures and analytical approaches to estimate the effectiveness of the technology for the purpose of generating credits. These provisions were

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Book 2 of 2 Books
Pages 62623–63200

Part II

Environmental Protection Agency
40 CFR Parts 85, 86, and 600

Department of Transportation
National Highway Traffic Safety Administration
49 CFR Parts 523, 531, 533, *et al.* and *600*
2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule

TABLE II–22—OFF-CYCLE TECHNOLOGIES AND CREDITS AND EQUIVALENT FUEL CONSUMPTION IMPROVEMENT VALUES FOR CARS AND LIGHT TRUCKS

Technology	Adjustments for cars		Adjustments for trucks	
	g/mi	gallons/mi	g/mi	gallons/mi
+High Efficiency Exterior Lights* (at 100 watt savings)	1.0	0.000113	1.0	0.000113
+Waste Heat Recovery (at 100W)	0.7	0.000079	0.7	0.000079
+Solar Panels (based on a 75 watt solar panel)**;				
Battery Charging Only	3.3	0.000372	3.3	0.000372
Active Cabin Ventilation and Battery Charging	2.5	0.000282	2.5	0.000282
+Active Aerodynamic Improvements (for a 3% aerodynamic drag or Cd reduction)	0.6	0.000068	1.0	0.000113
Engine Idle Start-Stop;				
w/ heater circulation system#	2.5	0.000282	4.4	0.000496
w/o heater circulation system	1.5	0.000169	2.9	0.000327
Active Transmission Warm-Up	1.5	0.000169	3.2	0.000361
Active Engine Warm-up	1.5	0.000169	3.2	0.000361
Solar/Thermal Control	Up to 3.0	0.000338	Up to 4.3	0.000484

*High efficiency exterior lighting credit is scalable based on lighting components selected from high efficiency exterior lighting list (see Joint TSD Section 5.2.3, Table 5–21).
**Solar Panel credit is scalable based on solar panel rated power, (see Joint TSD Section 5.2.4). This credit can be combined with active cabin ventilation credits.
#In order to receive the maximum engine idle start stop, the heater circulation system must be calibrated to keep the engine off for 1 minute or more when the external ambient temperature is 30 deg F and when cabin heat is demanded (see Joint TSD Section 5.2.8.1).
+This credit is scalable; however, only a minimum credit of 0.05 g/mi CO_2 can be granted.

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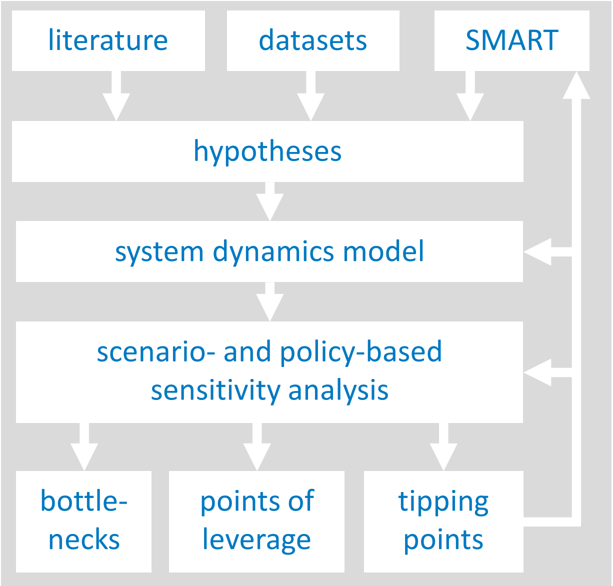
Other Synergistic Projects…

Other SMART Mobility Modeling/Simulation Projects

- Modeling CAVs Transition Dynamics and Identifying Tipping Points
  - Identify and quantify circumstances/dynamics of potential transitions
  - System dynamics model-based examination of barriers, points of leverage, “tipping points” and “lock-in” for large-scale deployment of CAV technologies and Mobility as a Service



- Enabling Electrification of Connected and Automated Vehicles
  - Data-driven charging decision modeling
  - Leverage analysis relevant to non-CAVs
  - Apply analysis to CAV-specific scenarios (e.g., low-speed automated repositioning and recharging)

Other SMART Mobility Testing/Data Analysis Projects

- Truck Platooning
  - Testing to measure interaction with aero changes and control enhancements
  - Truck activity data analysis to evaluate platooning opportunity space

- Green routing evaluation
  - On-road validation of green routing algorithms for different vehicles
  - Large-scale green routing opportunity assessment relative to actual routes taken

- CAV deployment evaluation
  - Work with Volvo Car Corp. to quantify efficiency impacts—initially of low-level ACC and later of full 100 vehicle Drive Me pilot deployment

ACC = adaptive cruise control

NREL's TRANSNET Connected Traveler Project

- Multi-disciplinary undertaking that will seek to validate potential for transformative transportation system energy savings by incentivizing efficient traveler behavior
- Control architecture will be developed that incorporates adaptive learning, refined incentives, and control strategies to provide high certainty of adoption
- Metropia platform will allow for real-world validation of traveler behavior and assist in refining incentives and control strategies
- NREL Transportation Secure Data Center and related tools will be used to determine individual energy consumption
- Individual energy impacts will be extrapolated to estimate transportation system energy consumption

Control Strategies

- Change in Departure Time
- Mode Choice
- Carpooling
- Alternate Routing
- Alternate Destinations
- Elimination of Need for Trips

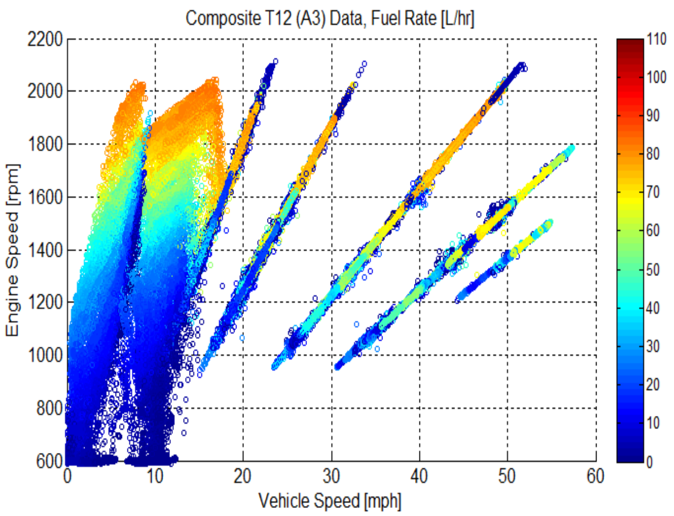
Incentive Spectrum

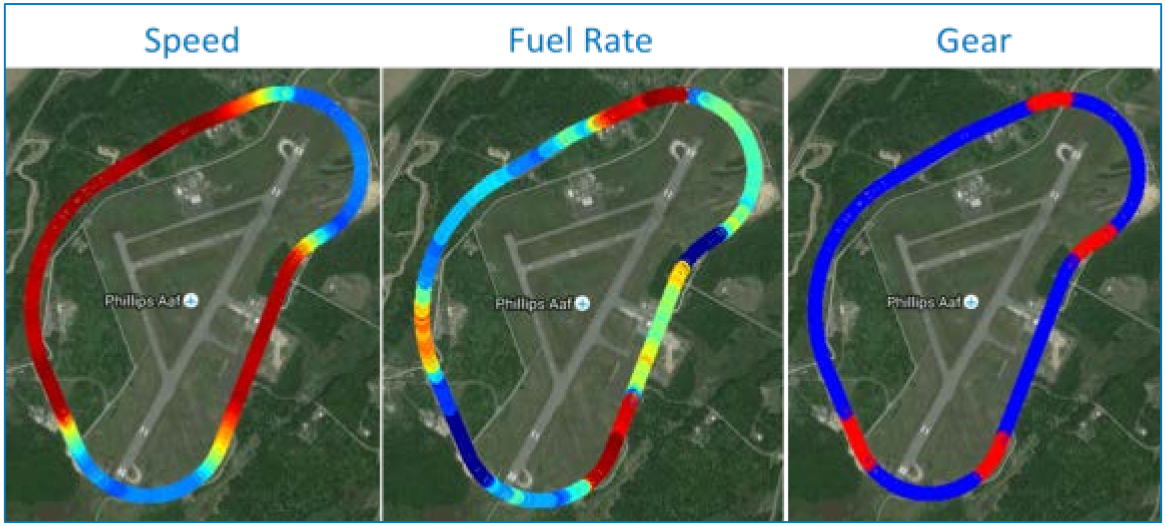
- Navigation Service
- Travel Time Minimization
- Predictive Analytics
- **Points, Points, Points**
- Products – ex., Starbucks coupon
- Services – ex., transit pass or discount
- Charity – ex., plant a tree

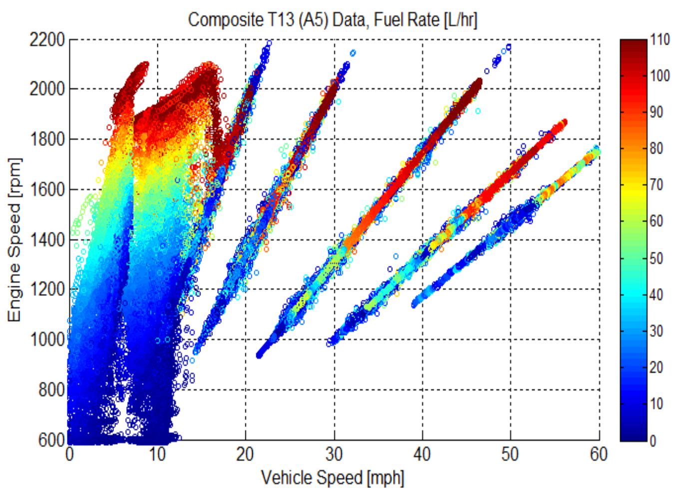
Supported by DOE, ARPA-E

Automation-Enabled Fuel Savings for Military Vehicles

- Collaborators include NREL, TARDEC, U.S. Army Aberdeen Test Center, Argonne National Lab, Lockheed Martin, and Primus Solutions
- SAE "Type II" testing on two M915 variants





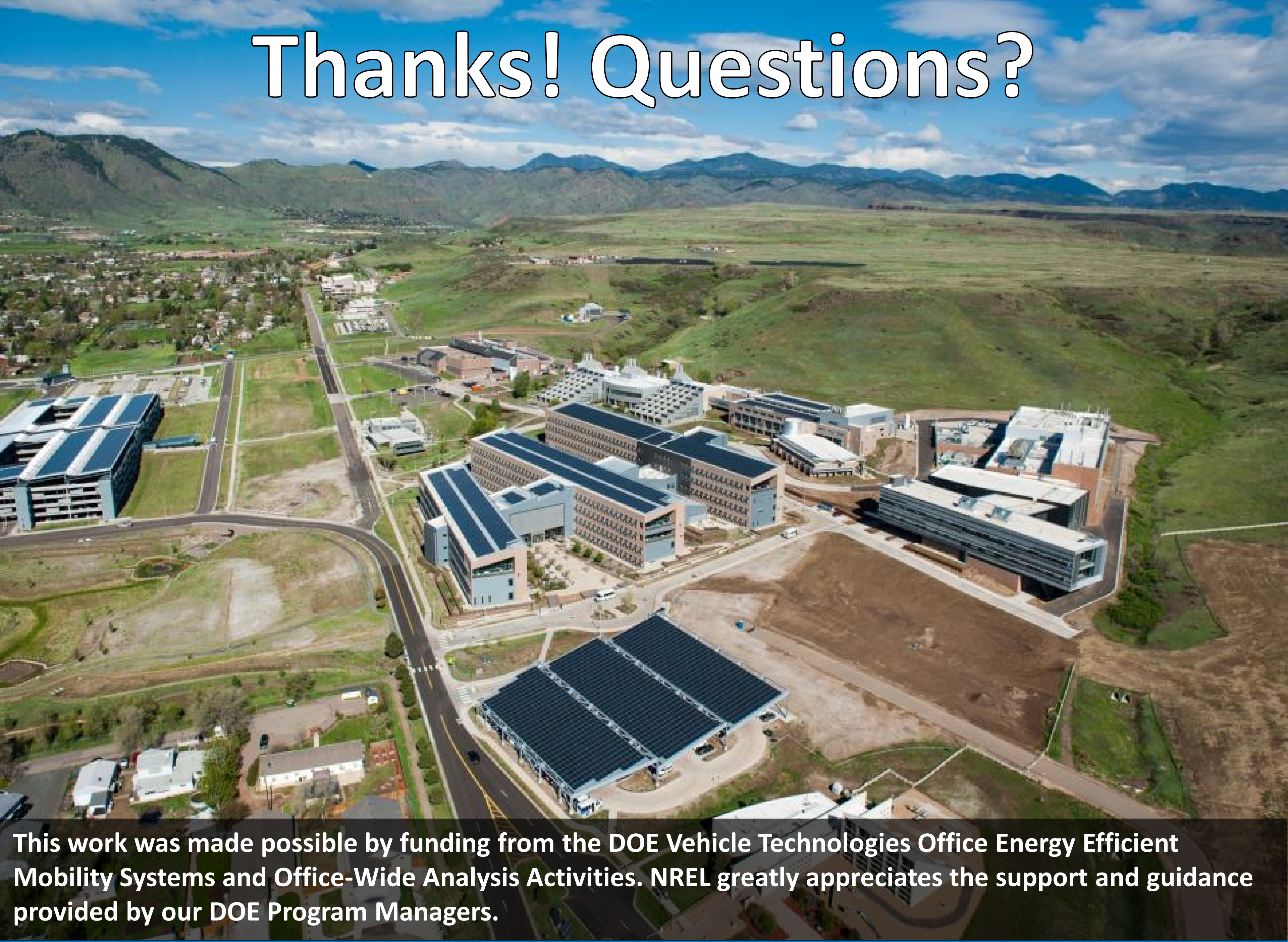


TARDEC = Tank Automotive Research, Development and Engineering Center
Supported by DOD, Office of the Deputy Assistant Secretary of Defense for Operational Energy

Summary

- Potential energy impacts from CAVs are highly uncertain
  - Near-term impacts will be modest
  - Longer-term, vehicle efficiency may improve, but travel demand may increase
- Further research needed and on-going
  - Both within and beyond DOE's SMART Mobility Laboratory Consortium
  - Modeling/simulation and testing/data analysis
  - Exploring multiple dimensions:
    - Automation levels
    - Penetration rates
    - Vehicle classes
    - Powertrain types

Thanks! Questions?



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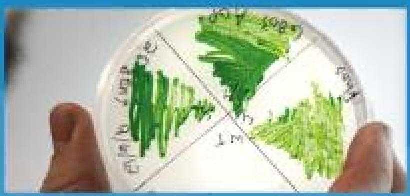
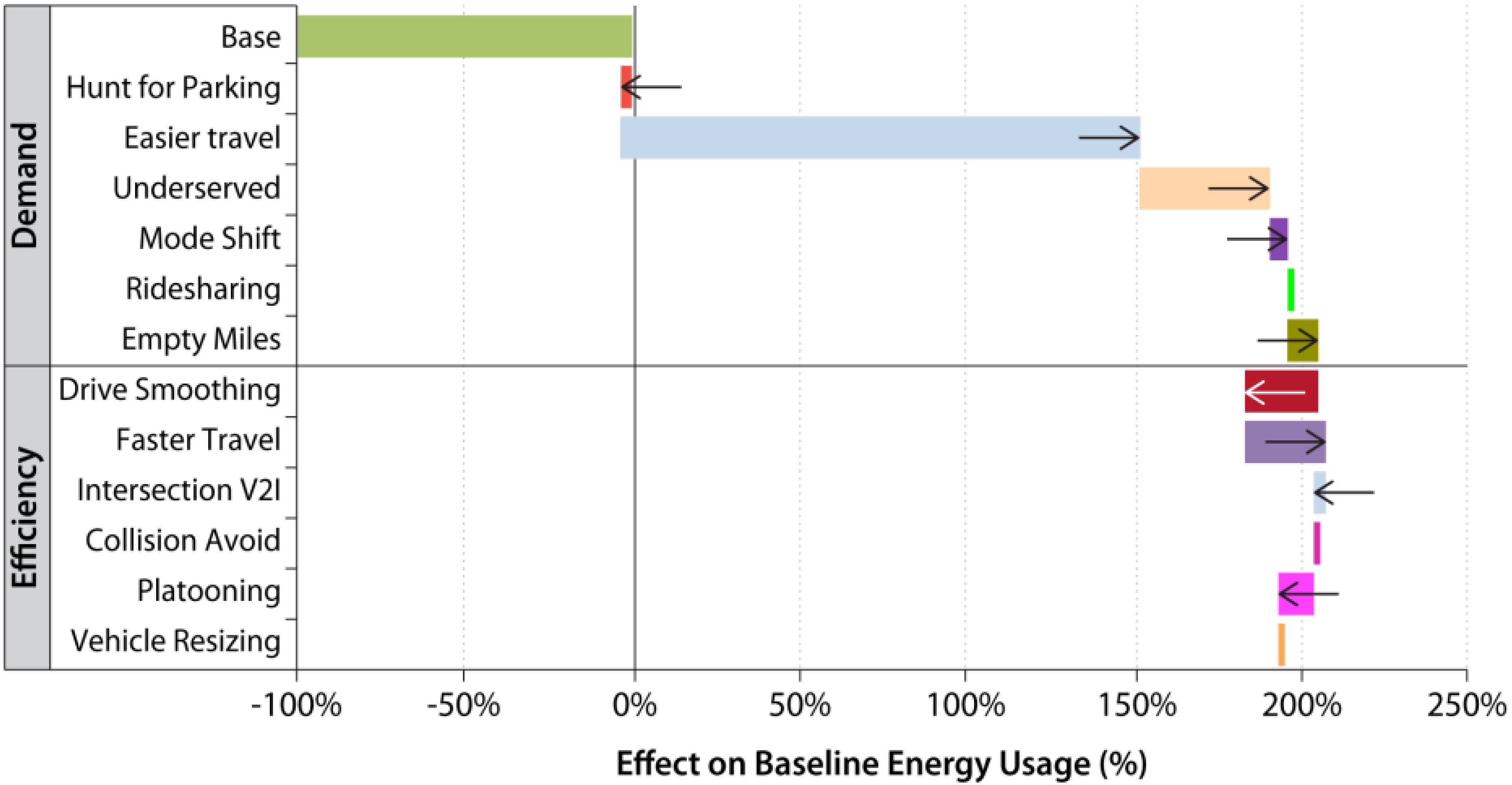




Appendix

Influence of Each Factor on the Total Fuel Use, Upper Bound



Influence of Each Factor on the Total Fuel Use, Lower Bound