# National-Level Energy Impacts of Cooperative Adaptive Cruise Control (CACC) Systems

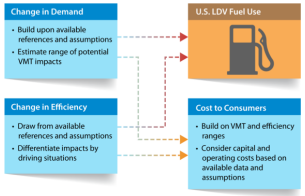
Eleftheria (Ria) Kontou Ph.D., Jacob Holden, Matteo Muratori Ph.D., Jeffrey Gonder
Transportation and Hydrogen Systems Center, **N**ational **R**enewable **E**nergy **L**aboratory (NREL)
Contact: ria.kontou@nrel.gov

External collaborators: Tom Stephens (ANL), Hao Liu, Xiao-Yun Lu, Steven Shladover (LBNL), Paul Leiby, Zhenhong Lin (ORNL), Ramin Shabanpour, Abolfazl (Kouros) Mohammadian (UIC).

## Research Objectives

### Research Questions

- What is the national-level energy impact of adopting connected and automated vehicles and technologies (e.g., Cooperative Adaptive Cruise Control examined here, eco-signal implementation, automated mobility districts applications)?
- How do different levels of CACC adoption affect on-road fuel economy for different vehicle powertrains?
- What changes in vehicle miles traveled distribution are induced by CACC adoption and what is the potentially induced change in demand, primarily on US freeways and highways?



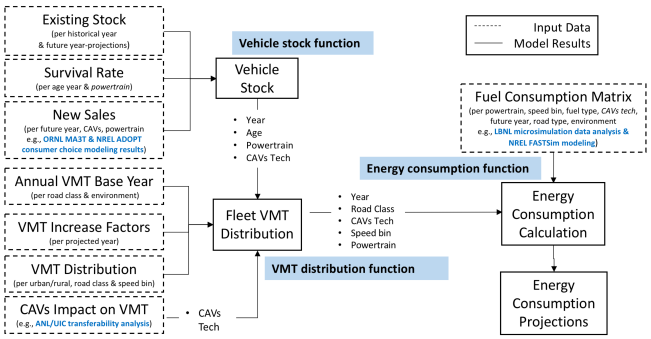

Source: Stephens et al. (2016). Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, http://www.nrel.gov/docs/fy17osti/67216.pdf

### Modeling Assumptions & Data Insights

- Insights and data from micro-simulation modeling of CACC vehicle use in a freeway stretch in Sacramento CA, conducted by Lawrence Berkeley National Lab (LBNL)
- Induced demand assumptions, using preliminary results of agent-based modeling simulations conducted by Argonne National Lab (ANL)

## Methodology

The methodology proposed accounts for vehicle stock evolution, fuel consumption changes due to CACC adoption for different vehicle powertrains, and vehicle miles traveled (VMT) distribution changes as well as impacts of induced demand




Methodology described in detail in : Chen et al. (2018). Quantifying autonomous vehicles national fuel consumption impacts: A data-rich approach. Transportation Research Part A: Policy and Practice

Important modeling inputs:

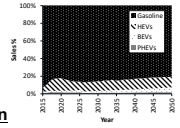
- Modeling period: 2018-2050
- Existing vehicle stock & new sales of different powertrains, including CACC capabilities (e.g., AEO projections, ADOPT Scenarios, Shladover & Greenblatt white paper scenarios)
- CACC impacts on vehicles' fuel economy across speed bins (e.g., based on LBNL Aimsun micro-simulation analysis)
- National-level impacts of CACC on VMT across speed bins (e.g., LBNL micro-simulation) and due to perceived changes in vehicle travel time and induced travel demand (e.g., ANL/UIC agent based simulations)

## Data Inputs

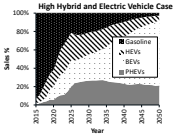
### Powertrain Adoption Scenarios

Vehicle sales projected using NREL's ADOPT model, based on AEO 2017 fuel prices and different technology improvement trends over time:

Conventional powertrain dominant

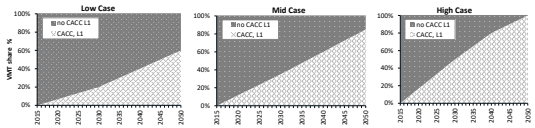



Plug-in electric vehicle powertrain dominant




### CACC Adoption

CACC VMT share on highways and freeways, 3 scenarios of CACC adoption:




Source: Shladover and Greenblatt. (forthcoming). Connected and Automated Vehicle Concept Dimensions and Examples. LBNL Report

### National-Level VMT

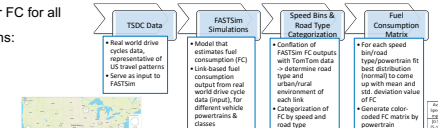
Based on conflation of typical daily VMT from the Highway Performance Monitoring System (HPMS) with typical daily speed profiles from TomTom data:

Total VMT (in millions) distributed by road category, environment, and average driving speeds at the time of travel (considered indicative of congestion level)

| Avg Speed Bins (mph) | Freeways & Highways | | Connectors & Arterials | | Local Roads | |
|---|---|---|---|---|---|---|
| | Rural | Urban | Rural | Urban | Rural | Urban |
| [0-5] | 0.000 | 0.000 | 0.004 | 0.010 | 0.013 | 0.123 |
| [5-10] | 0.006 | 0.046 | 0.148 | 1.123 | 0.350 | 3.147 |
| [10-15] | 0.019 | 0.172 | 1.267 | 8.469 | 3.290 | 17.752 |
| [15-20] | 0.040 | 0.375 | 3.553 | 22.210 | 5.324 | 34.868 |
| [20-25] | 0.092 | 0.679 | 7.287 | 43.720 | 5.992 | 33.297 |
| [25-30] | 0.183 | 1.466 | 13.926 | 74.978 | 9.742 | 38.947 |
| [30-35] | 0.339 | 3.160 | 23.217 | 114.512 | 13.668 | 48.795 |
| [35-40] | 0.466 | 5.173 | 30.301 | 129.852 | 14.877 | 47.928 |
| [40-45] | 0.668 | 11.947 | 36.814 | 116.873 | 15.693 | 30.652 |
| [45-50] | 0.951 | 24.784 | 45.680 | 84.444 | 12.975 | 12.415 |
| [50-55] | 1.863 | 52.048 | 58.591 | 54.800 | 12.835 | 4.803 |
| [55-60] | 4.956 | 114.023 | 99.089 | 50.712 | 12.506 | 1.868 |
| [60-65] | 16.907 | 267.692 | 67.158 | 55.630 | 2.516 | 0.332 |
| [65-70] | 62.286 | 186.095 | 62.429 | 34.555 | 0.080 | 0.001 |
| [70-75] | 95.927 | 42.591 | 8.523 | 2.249 | 0.000 | 0.000 |
| [75-80] | 4.802 | 0.328 | 0.002 | 0.000 | 0.000 | 0.000 |
| >80 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| Total Number (from HPMS) | 189.50 | 650.58 | 453.99 | 794.15 | 109.87 | 274.93 |

### Vehicle Fuel Consumption

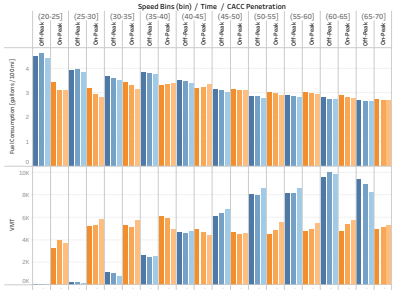
Base year FC for all powertrains:




FASTSim described in: Brooker, A., Gonder, J., Wang, L., Wood, E., Lopp, S., & Ramroth, L. (2015). FASTSim: A model to estimate vehicle efficiency, cost and performance (No. 2015-01-0973). SAE Technical Paper.

### Impact of CACC Penetration Levels on VMT and Fuel Consumption

LBNL microsimulation data outputs inform fuel consumption & VMT matrices under CACC adoption (note that VMT & FC correspond to the LBNL freeway network and *not* to the national level analysis)




**Fuel consumption impacts**

- CACC reduces FC rates in most but not all speed bins
- Relative impact greater at low speeds, though the smaller impacts at high speeds apply to more VMT

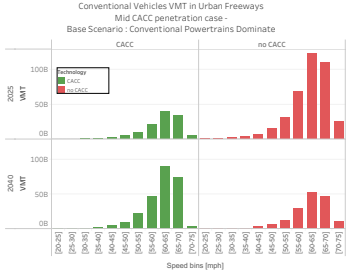
**VMT impacts**

- Total VMT kept constant across CACC scenarios (no induced demand effect)
- CACC increases VMT in speed bins between 50 mph – 70 mph for on-peak and 45 mph – 65 mph for off-peak conditions

## Preliminary Findings

### CACC Penetration Impacts on Conventional Vehicles

- VMT attributed to CACC increase over the years (urban highways example)
- Conventional fuel consumption decreases as CACC % increases (e.g., urban highways)



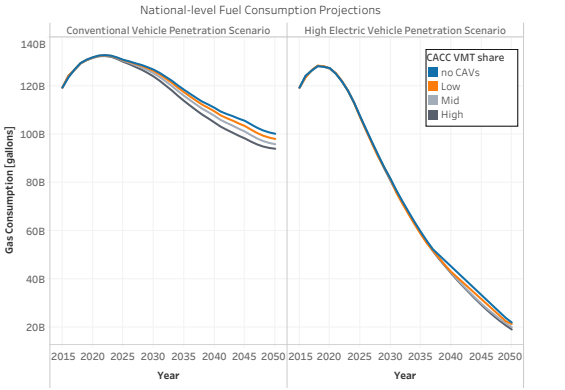

Conventional Vehicle FC Changes Urban Highway

| Speed Bins (mph) | 2025 | 2035 | 2045 |
|---|---|---|---|
| [20-25] | 3.57 | 3.81 | 3.65 |
| [25-30] | 3.74 | 3.57 | 3.40 |
| [30-35] | 3.55 | 3.42 | 3.29 |
| [35-40] | 3.52 | 3.47 | 3.43 |
| [40-45] | 3.44 | 3.42 | 3.40 |
| [45-50] | 3.20 | 3.14 | 3.08 |
| [50-55] | 3.00 | 2.92 | 2.85 |
| [55-60] | 2.85 | 2.78 | 2.71 |
| [60-65] | 2.79 | 2.71 | 2.64 |
| [65-70] | 2.87 | 2.81 | 2.75 |

Gallons per 100 mi: 2.64 – 3.97

### National-Level Fuel Consumption Results

- Potential for gasoline fuel savings from CACC adoption, particularly when conventional powertrains dominate




## Future Work

- Refine inputs and interactions with other tools
  - VMT transferability from ANL/UIC (Chicago → nation)
  - Microsimulation data outputs (trajectory data from local CACC implementation, automated mobility districts microsimulation, etc.)
- Sensitivity analysis to explore impact of several input parameters on the national-level fuel consumption results
- Add additional vehicle and CAV technology scenarios:
  - Explore national-level fuel consumption impacts of eco-signal implementation
  - Explore national-level fuel consumption impacts of automated mobility districts and innovative mobility solutions
- Collaboration with other SMART Mobility pillars
  - e.g., Urban Science, Advanced Fueling Infrastructure, etc.

*This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.*

*This poster and the work described were sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Laboratory Consortium, an initiative of the Energy Efficient Mobility Systems (EEMS) Program. The authors acknowledge Eric Rask of Argonne National Laboratory for leading the Connected and Automated Vehicles Pillar of the SMART Mobility Laboratory Consortium. The authors would particularly like to thank David Anderson and Michael Berube with DOE's Office of Energy Efficiency and Renewable Energy (EERE) for helping to establish the project concept and advance its implementation, and for providing ongoing guidance and support.*



*Automated Vehicles Symposium*
*San Francisco, California*
*July 9-12, 2018*