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

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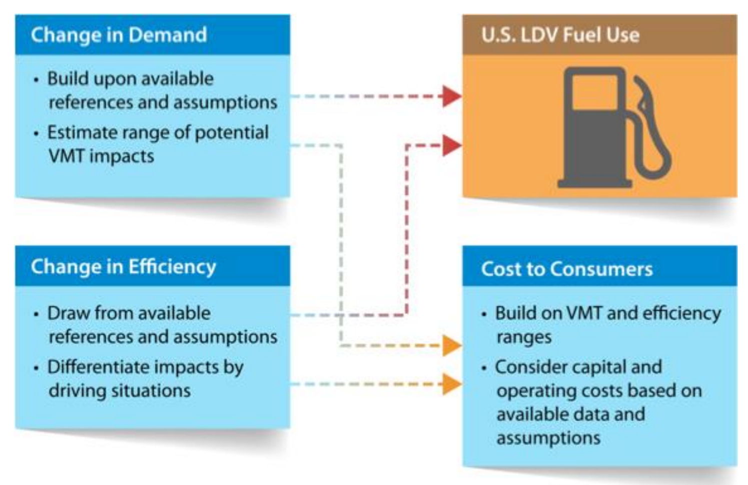
Research Objectives

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?



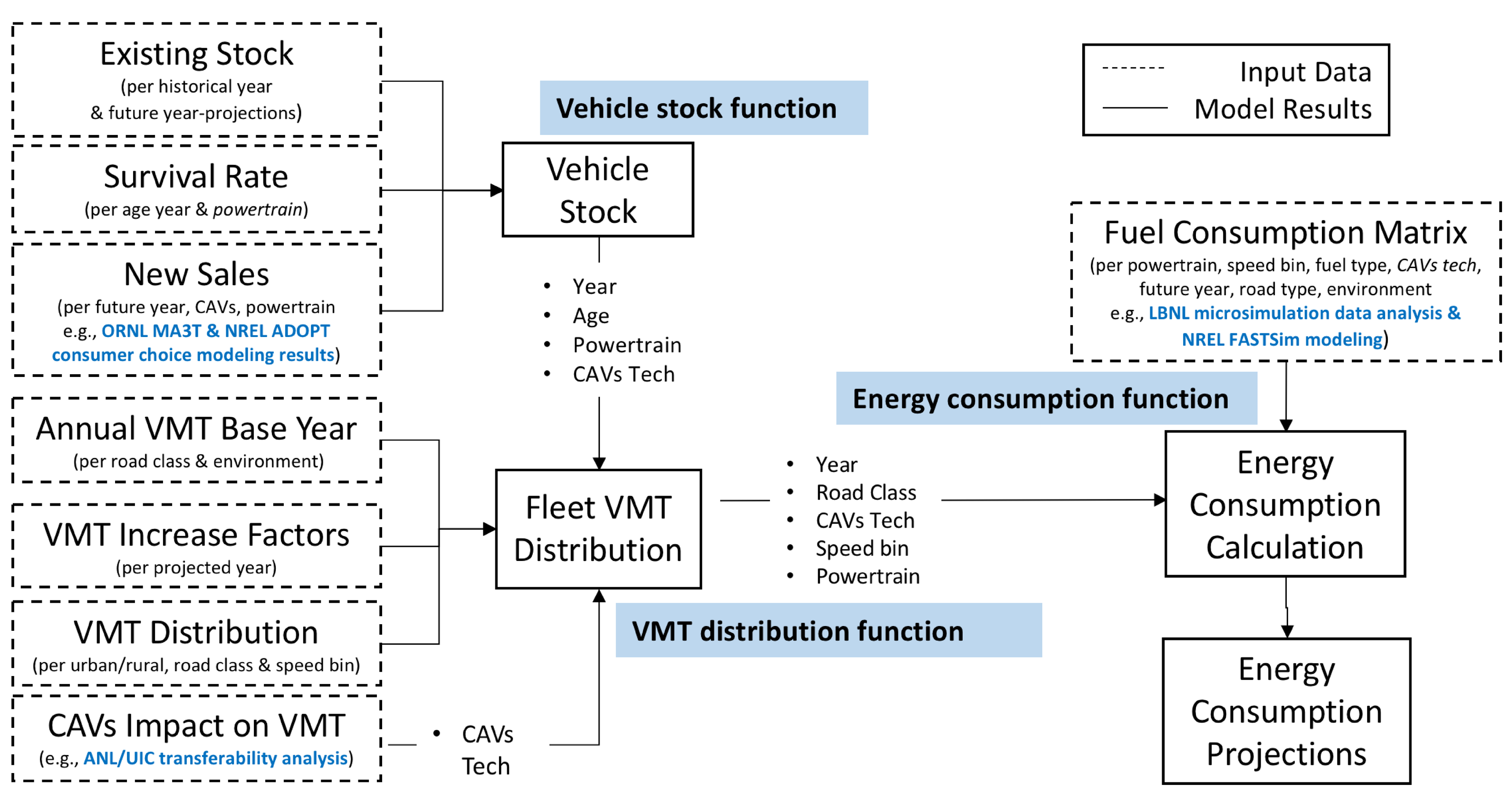
Source: Stephens et al. (2016). Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, http://www.nrel.gov/docs/fy17osti/67216.pdf

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:

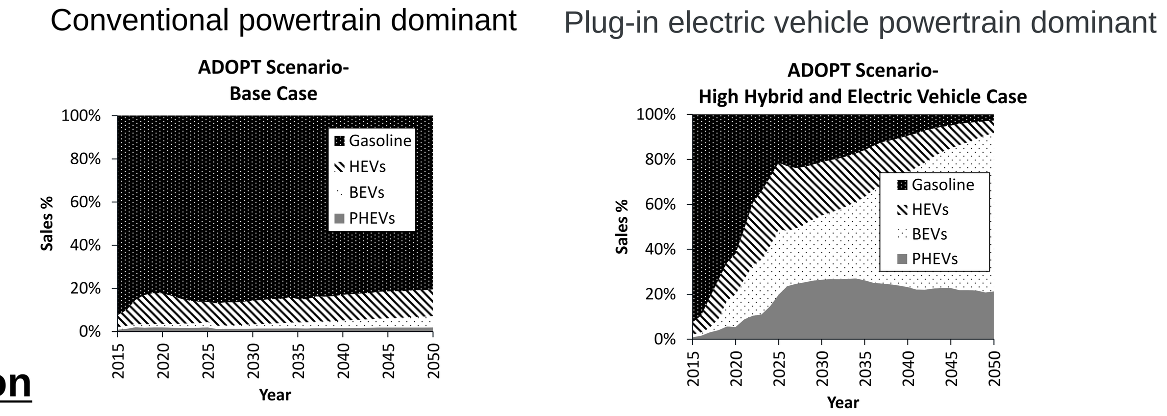
- Modeling period: 2018-2050
- Existing vehicle stock & new sales of different powertrains, including CACC capabilities (e.g., AEO projections, ADOPT Scenarios, Shladover & Greenblatt white paper scenarios)
- CACC impacts on vehicles' fuel economy across speed bins (e.g., based on LBNL Aimsun micro-simulation 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

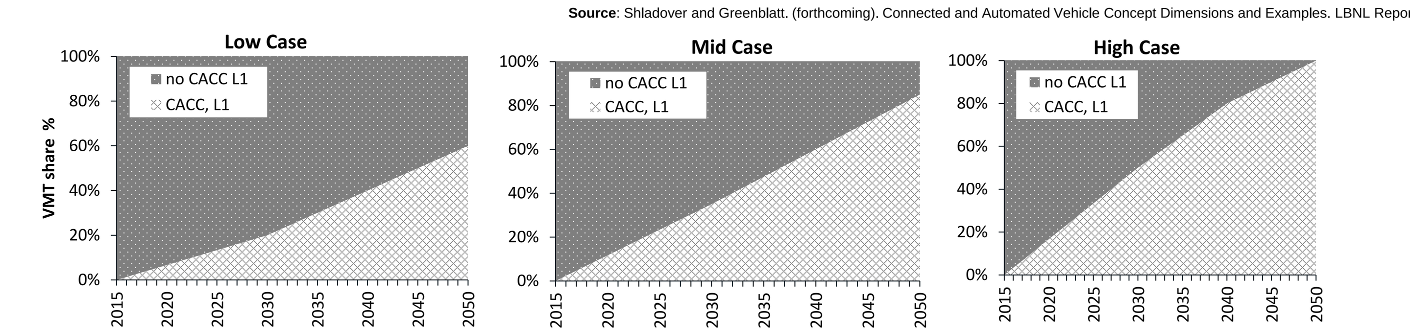
Vehicle sales projected using NREL's ADOPT model, based on AEO 2017 fuel prices and different technology improvement trends over time:

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

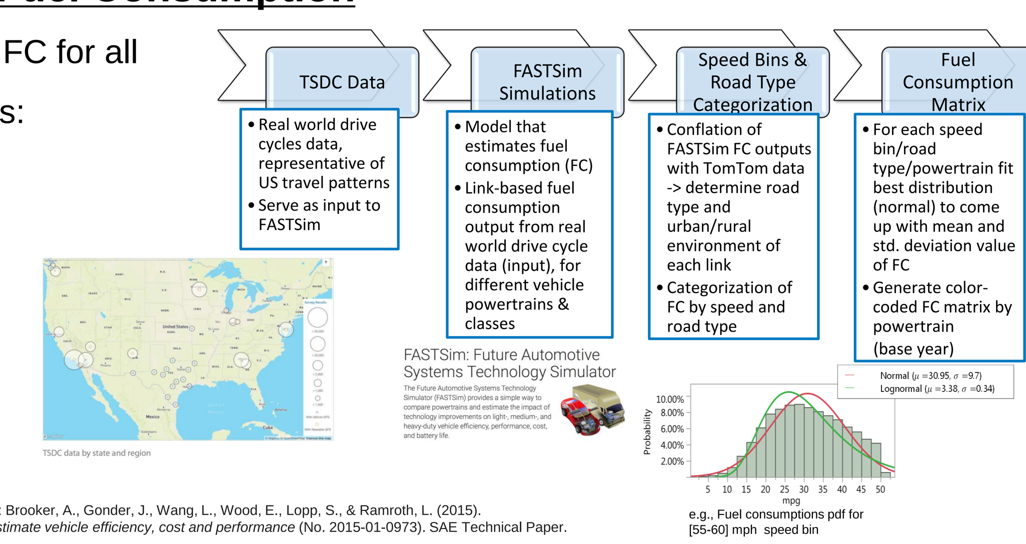
Based on conflation of typical daily VMT from the Highway Performance Monitoring System (HPMS) with typical daily speed profiles from TomTom data:

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	0.020	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	15.699	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	95.089	50.712	12.506	1.868
(60-65]	16.907	207.692	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:



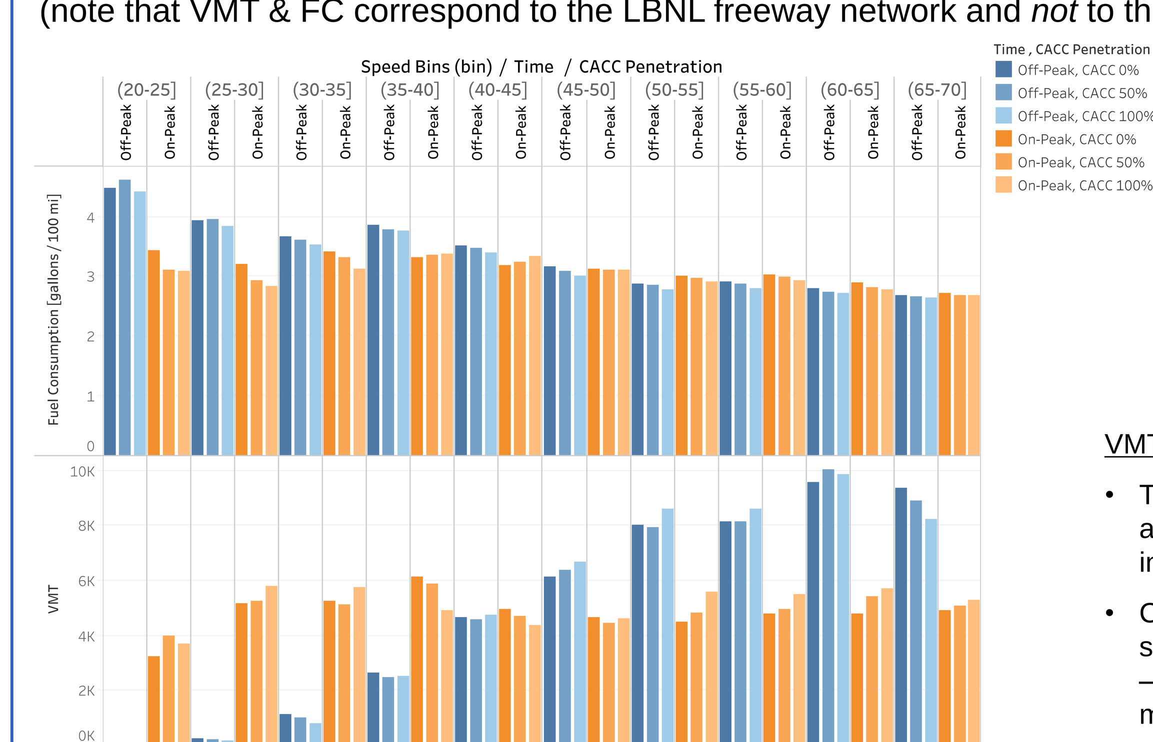
e.g., Fuel consumptions for conventional vehicle (Toyota Camry) – analysis base year

Avg Speed mph	freeways & highways		connectors & arterials		local roads	
	Rural	Urban	Rural	Urban	Rural	Urban
[0-5]						10.97
(5-10]				10.37	8.95	10.67
(10-15]			7.63	8.21	6.87	7.55
(15-20]			7.34	7.64	6.39	6.95
(20-25]			6.55	6.71	5.85	6.25
(25-30]		4.74	5.77	5.86	5.22	5.39
(30-35]		4.4	4.98	4.99	4.67	4.55
(35-40]		4.26	4.42	4.35	4.15	4.04
(40-45]	4.27	4.16	4.06	3.98	3.71	3.79
(45-50]	3.86	3.91	3.61	3.81	3.58	3.68
(50-55]	3.34	3.69	3.66	3.69	3.44	3.67
(55-60]	3.08	3.5	3.49	3.51	3.26	3.59
(60-65]	3.16	3.44	3.44	3.41	3.32	
(65-70]	3.33	3.52	3.49	3.53		
(70-75]	3.49	3.65	3.53	3.6		
(75-80]	3.76					
>80						

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

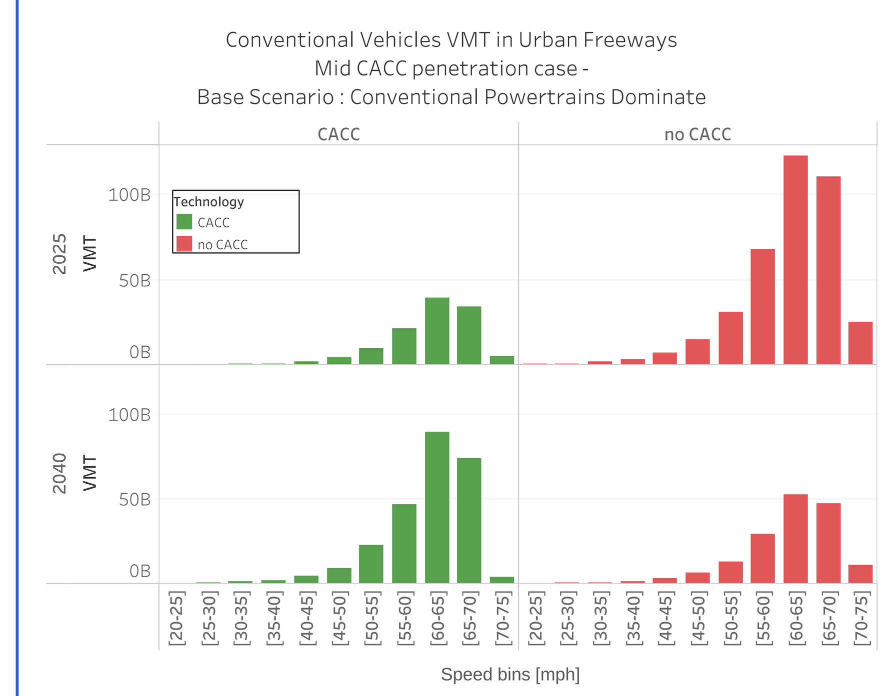
VMT impacts

- 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)



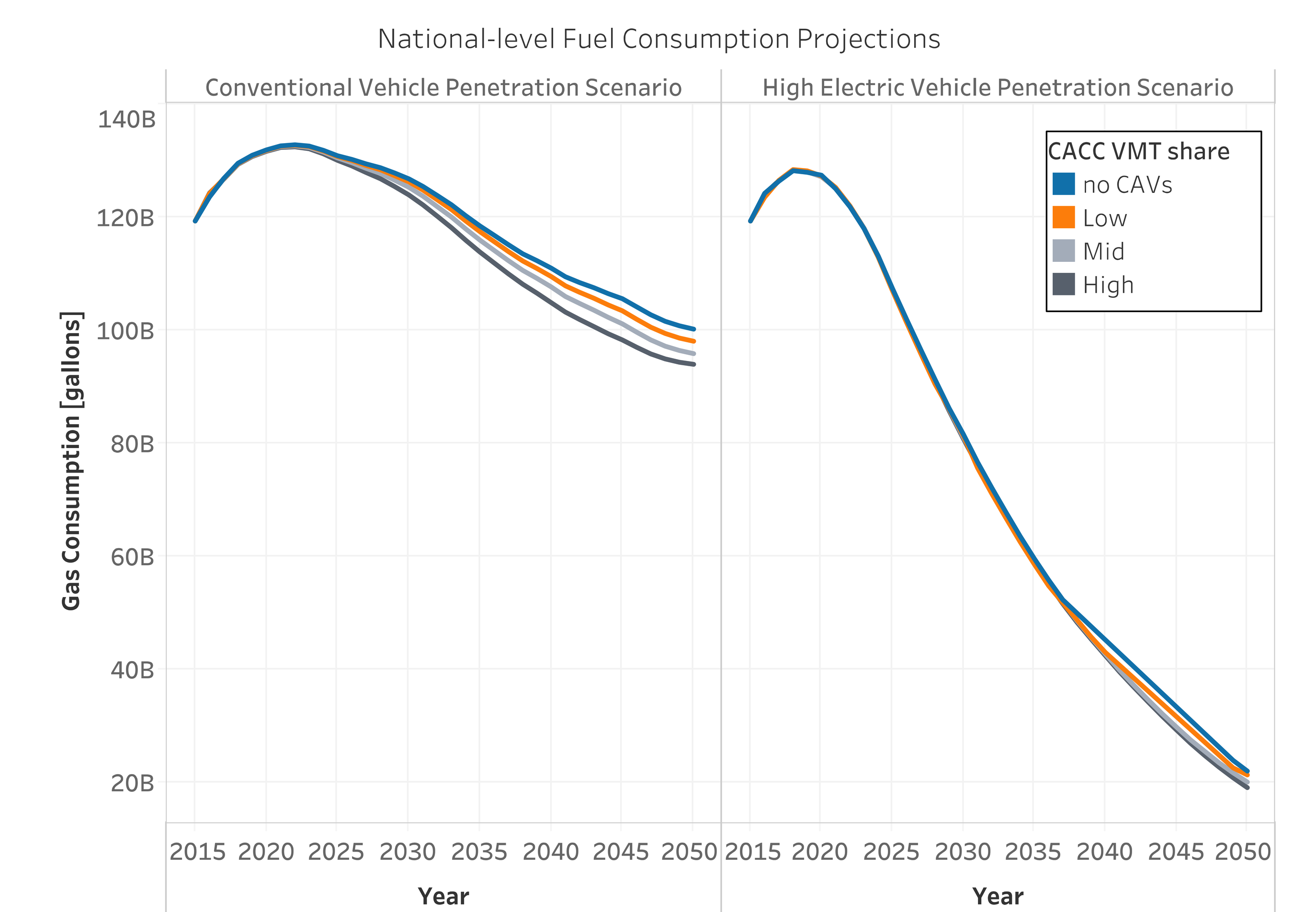
Conventional Vehicle FC Changes
Urban Highway

Gallons per 100 mi (2.64 – 3.97)

Speed Bins (mph)	2025	2035	2045
[20-25]	3.97	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	2.93	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

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.

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