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<td>Transportation</td>
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<td>Raquel Kravitz</td>
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Zero Emission Vehicles and Automated Vehicles: Uncertainty and Energy Implications

For
California Energy Commission
May 2, 2019 | Sacramento, CA

By
Nicholas Chase, Lead Economist
Overview

• Zero emission vehicles

• Vehicle automation

• Ongoing vehicle automation updates (time permitting)
Zero emission vehicles
Transportation energy consumption declines between 2019 and 2037 in the Reference case as increases in fuel economy more than offset growth in vehicle miles traveled.
Alternative and electric vehicles gain market share in the Reference case but gasoline vehicles remain the dominant vehicle type through 2050.
Modeling vehicle choice in the NEMS—involves manufacturers (building) and consumers (buying)

- Manufacturers Technology Choice Component (MTCC)
  - Adopt vehicle subsystem technologies (86) based on value of fuel economy and/or performance improvement
  - Alternative fuel vehicles (15)

- Consumer Vehicle Choice Component (CVCC)
  - Determines consumer acceptance by vehicle fuel type (conventional gasoline, hybrid, diesel, etc.) by size class utilizing 9 attributes

- Meeting CAFE through the MTCC and CVCC
  - CAFE credits and banking
Policies promoting battery electric vehicle sales

- California Zero-Emission Vehicle Mandate, adopted by nine other states
- California SB-32 for GHG Reduction
  - Further increases electric vehicle share
  - Decreases VMT
- State and federal tax credits
  - Federal credit up to a maximum of $7,500
    - Full amount limited to 200,000 vehicles per manufacturer then begins to phase out
  - State tax credits and incentives not modeled in NEMS
AEO2019 battery cost, projections from 2018

Lithium-ion retail battery costs
2018$ / kW-hr

Source: EIA, AEO2019 Reference case

EV200 and EV300 assume same cost

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Modeling the Zero Emission Vehicle Mandate in NEMS

- Regions which contain ZEV states must sell a minimum amount of ZEVs (BEVs and hydrogen fuel cells) and optional PHEVs
  - Required “credit” percentage based on a manufacturer’s conventional vehicle sales
  - Credits earned per vehicle vary by ZEV capability - longer range BEVs and PHEVs produce more credits
  - Credits may be banked, spent, and can travel

- Assumed to follow an optional compliance pathway
  - Lower initial requirements in exchange for higher midterm credits
  - Allowed Mfrs to bank a high number of credits before 2018 (more favorable credit terms)

- Vehicles are sold according to least cost optimization by Mfr
Uncertainties

• Policies
  – Future light-duty vehicle CAFE/GHG standards
  – Change in State Policies, including authority to issue own standards or mandates

• Battery technology breakthrough
  – Solid state batteries
  – Ultra-fast charging capability and infrastructure

• Autonomous vehicles and change in mobility
  – Change in sales patterns, travel, powertrain choice, and regulatory compliance pathways
Vehicle automation
Definition of vehicle automation

- Operational and safety-critical control functions occur without driver input
- Connected and automated vehicles

Source: U.S. Department of Transportation, Automated Driving Systems 2.0, A Vision for Safety
Potential benefits underlie interest but there are also key uncertainties and obstacles

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Obstacles</th>
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<tr>
<td>• Road safety</td>
<td>• Consumer acceptance</td>
</tr>
<tr>
<td>• Increased system efficiency</td>
<td>• Technology cost and function</td>
</tr>
<tr>
<td>– Route harmonization</td>
<td>• Cybersecurity</td>
</tr>
<tr>
<td>– Reduced congestion</td>
<td>• Legal framework</td>
</tr>
<tr>
<td>• Increased mobility for</td>
<td>• Infrastructure</td>
</tr>
<tr>
<td>underserved population</td>
<td>• Policy</td>
</tr>
<tr>
<td>• Less time driving</td>
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Range of potential effects of autonomous vehicles on light-duty vehicle energy consumption

2017 U.S. delivered energy consumption

- 6.1 quadrillion Btu (3.3 million b/d oil equivalent)
- 15.3 quadrillion Btu (8.3 million b/d oil equivalent)
- 45.9 quadrillion Btu (24.9 million b/d oil equivalent)

There is uncertainty about how highly automated vehicles could affect future transportation energy demand.

Sources: Help or Hindrance? The Travel, Energy, and Carbon Impacts of Highly Automated Vehicles (Wadud et al); Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles (Stephens et al)
Additional ways vehicle automation technology could affect transportation energy consumption

• Alternative fuels and energy efficient powertrains
• Commercial trucks
• Mass transit
Description of scenarios

• Reference case
  – Autonomous vehicles enter fleet light-duty vehicles
    • 1% of new sales by 2050
  – Autonomous vehicles used more intensively
    • 65,000 miles/year and scrapped more quickly
  – Autonomous vehicle fuel type
    • 100% conventional gasoline internal combustion engine
  – Autonomous vehicles affect mass transit
    • Increases use of commuter rail
    • Decreases use of transit bus and transit rail
Description of scenarios–two scenarios examine energy implications from more widespread use of autonomous vehicles

• Identical assumptions
  – Autonomous vehicles enter household and fleet light-duty vehicles
    • 31% of new sales by 2050
  – Autonomous vehicles used more intensively
    • 65,000 miles/year (fleet) ; +10% miles/year (household) on average
  – Autonomous vehicles affect mass transit modes
    • Increases use of commuter rail
    • Decreases use of transit rail
    • Decreases use of transit bus until mid-2030s, thereafter, increases transit bus use from automation technology
  – Automation technology included on long-haul fleet commercial trucks enables platooning
Description of scenarios—two scenarios examine energy implications from more widespread use of autonomous vehicles

• **Autonomous Battery Electric Vehicle case**
  - Increasing share of autonomous vehicles are battery electric through 2050
    - 96% of fleet and 82% of household autonomous vehicles by 2050

• **Autonomous Hybrid Electric Vehicle case**
  - Increasing share of autonomous vehicles are hybrid electric through 2050
    - 96% of fleet and 71% of household autonomous vehicles by 2050
Light-duty vehicle sales by fuel type across scenarios

U.S. light-duty vehicle sales

Transportation fuel consumption differs between cases because of changes in light-duty vehicle fuel type.

Transportation energy consumption by fuel quadrillion Btu

- **motor gasoline**
- **diesel**
- **electricity**

Ongoing vehicle automation updates
(time permitting)
Recent modeling

- ROI
- Availability of ride hailing
- Cost ride hailing
- Cost transit
- Cost & utility of vehicle ownership
- Tech cost curve
- Fuel economy
- Scrappage rates
- PMT
- The BRAIN
- VMT
- Deliveries
- Empty miles
- Traditional
- Urban v. suburban v. rural
- Population density
- Underserved population
- Nicholas Chase, Sacramento, CA, May 2, 2019
Recent modeling focus: adding levels of highly automated vehicles—

- Levels of vehicle automation (introduction year, cost, weight, fuel economy, etc.):

<table>
<thead>
<tr>
<th>automation level</th>
<th>description</th>
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<tbody>
<tr>
<td>Level 1</td>
<td>driver assistance technology</td>
</tr>
<tr>
<td>Level 2</td>
<td>partial automation technology</td>
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<tr>
<td>Level 3</td>
<td>conditional automation technology</td>
</tr>
<tr>
<td>Level 4a</td>
<td>low speed (&lt;35 mpg) operation in limited geofenced areas such as urban centers</td>
</tr>
<tr>
<td>Level 4b</td>
<td>full speed operation in limited geofenced areas such as limited access highways</td>
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<tr>
<td>Level 5</td>
<td>fully autonomous vehicle that can operate on all roads and all speeds</td>
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Recent modeling focus—and the economics of ride-hailing fleet adoption

- Separates taxi fleet (taxi and future Transport Network Companies) with unique VMT and scrappage curves

- Economics of adoption:
  - **Return on Investment (ROI)** as net present value (NPV) of fare revenue minus operating cost (driver, revenue miles, data costs, etc.)
  - **Logit function** adoption with (dis)utilities related to new technology and operational domain parameters
  - **Technology cost:**
    - LiDAR system (low-resolution and high-resolution) as experience function with time-based R&D
    - HAV system as time-based R&D function
Example of highly automated vehicle cost and sales into ride-hailing fleet

vehicle cost

share of ride-hail fleet sales

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Recent modeling
Current research

ROI
Availability of ride hailing
Availability of transit
Population density
Urban v. suburban v. rural

Tech cost curve
Fuel economy
Scrappage rates

Cost ride hailing
Cost transit
Cost & utility of vehicle ownership

PMT
The BRAIN
VMT

Underserved population

Deliveries
Empty miles
Traditional

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U.S. population by geographic density and Census Division

Share of U.S. population by geographic density

Source: U.S. Census Bureau, American Community Survey (ACS) 2015

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U.S. population living in Core Based Statistical Areas (CBSAs) by geographic density

Share of U.S. population within CBSAs by geographic density

%

100%

90%

80%

70%

60%

50%

40%

30%

20%

10%

0%

over 900 CBSAs (largest → smallest)

Source: U.S. Census Bureau, American Community Survey (ACS) 2015

Nicholas Chase, Sacramento, CA,
May 2, 2019