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Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy – 2025-2035

Gary Marchant (Chair), Therese Langer (Member),

Carla Bailo, Nady Boules, Ulrich Kranz, Anna Stefanopoulou (Members)

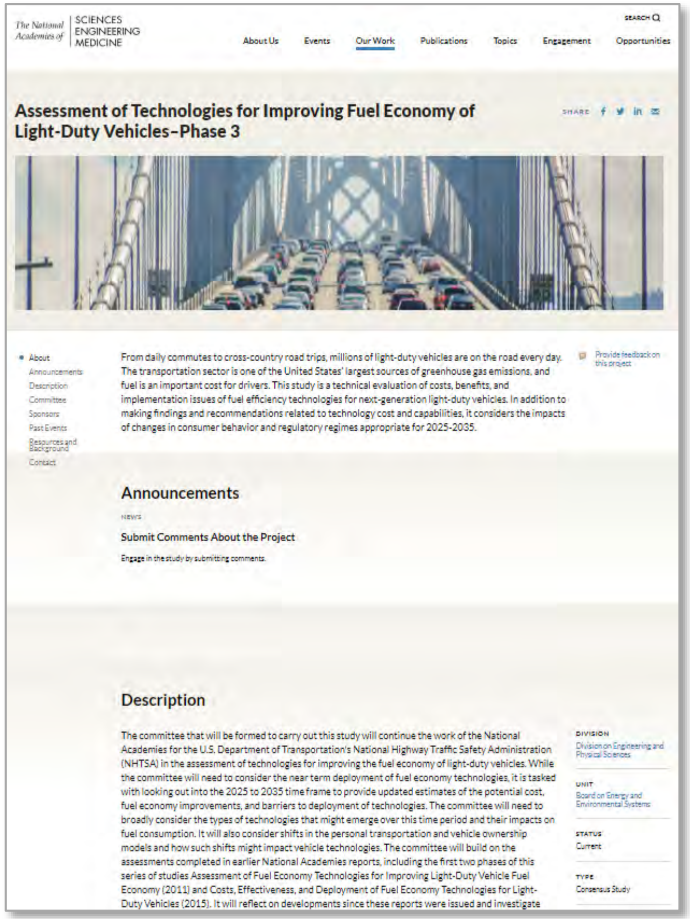
Beth Zeitler (Study Director)

TRB Automated Vehicles and Shared Mobility Forum

Light Duty Vehicle Efficiency: The Big Picture

- Despite 40 years of the CAFE program, the transportation sector remains the largest contributor of GHG emissions and second largest energy consuming sector in the U.S. economy.
- The good news is that new vehicle technologies are finally becoming feasible and cost-effective to make major changes in fuel economy and GHG emissions from LDVs.
- We found a broad convergence on the goal and ability to move LDVs toward zero emissions in the coming two decades.
- The vehicle industry will undergo unprecedented technological change in the 2025-2035 period, affecting every sector in the vehicle and transportation industries as well as consumers.

About the Study



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The committee was asked to examine the **costs, fuel economy benefits, and implementation timing** of light-duty vehicle efficiency technologies likely to be available in 2025-2035.

The committee focused on **electric, hybrid, internal combustion engine, fuel cell, non-powertrain and connected and automated vehicle technologies.**

The committee was also asked to examine **consumer responses** to vehicle technologies, **regulatory considerations**, and the impact of **shifting transportation choices and business models** on technologies and vehicle use.

The study was sponsored by **U.S. DOT's NHTSA**, and was mandated by Congress in **EISA 2007**.

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Committee Roster

Gary Marchant, Arizona State University, *Committee Chair*

Carla Bailo, Center for Automotive Research

Nady Boules, NB Motor, LLC

David Greene, Univ. of Tennessee (resigned March, 2021)

Daniel Kapp, D.R. Kapp Consulting, LLC

Ulrich Kranz, Independent Consultant

Therese Langer, American Council for an Energy-Efficient Economy

Zhenhong Lin, Oak Ridge National Laboratory

Joshua Linn, University of Maryland

Nic Lutsey, International Council on Clean Transportation

JoAnn Milliken, Independent Energy Consultant

Randa Radwan, Univ. of North Carolina, Chapel Hill

Anna Stefanopoulou, Univ. of Michigan, Automotive Research Center

Deidre Strand, Wildcat Discovery Technologies

Kate Whitefoot, Carnegie Mellon University

The committee learned from automakers, suppliers, academics, government and others over 2.5 years

Public session information gathering

- **Industry, DOE, EPA, NGO** July 16, 2018
- **Academic, Industry** October 15-16, 2018
- **State Government, Industry, Academic** January 24, 2018
- **Electric Charging Infrastructure** May 2, 2019
- **Materials** May 17, 2019
- **Hydrogen Infrastructure** June 26, 2019
- **Safety** September 25, 2019
- **Design Optimization** January 6, 2020
- **EPA Discussion** June 16, 2020

Not-open-to-the-public information gathering

- **FCA / Delphi** June 5-6, 2019
- **Munro / Bosch** September 24-25, 2019
- **BMW / Daimler / VW** October 14-18, 2019
- **Ford** December 9, 2019
- **Tesla** January 16, 2020
- **GM** January 30, 2020
- **Nissan / Toyota / Hyundai Panasonic / LG Chem** February 3-13, 2020
- **Toyota Follow-up** June 18, 2020
- **Honda** September 10, 2020

Key Findings: CAFE in 2025-2035

Growing Role of ZEVs

- ZEVs represent the long-term future of energy efficiency and petroleum reduction.
- Vehicle efficiency standards for 2035 should be set consistent with market dominance of ZEVs, with consumer acceptance a key barrier to overcome.

CAFE Continuation and Statutory Authorization

- The CAFE program serves an important role in ensuring energy conservation, energy security, and vehicle safety, and should be continued.
- Explicit authorization for maximum feasible fuel economy expires in 2030.
- Congress should define long-term goals for the CAFE program to include reduction in GHG emissions.

NHTSA ZEV Authority

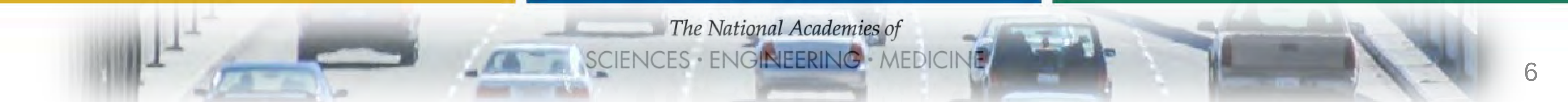
- Through statutory change or interpretation of existing statute, NHTSA should be allowed to consider AFVs (in particular ZEVs) in stringency setting.

Agency Coordination

- Agencies should continue to coordinate standards.
- Standards should diverge unless NHTSA can consider AFVs/ZEVs in stringency.

Net-zero Emissions LDV System

- Congress should set an explicit goal of net-zero LDV GHG emissions by a specified date.
- The goal should be technology neutral.
- Will require consideration of full-fuel-cycle emissions and lifecycle emissions, via CAFE or other means.



Key Findings: Technology Advances in 2025-2035

Internal Combustion Vehicles

- Increased peak engine efficiency
- Engines optimized for efficient operating modes, especially with hybrid synergies
- Transmission efficiencies

Battery Electric Vehicles

- Improved energy storage capabilities and machine energy efficiency
- Reduced cost, particularly of batteries

Fuel Cell Vehicles

- Reduced cost of components with scaling
- Improved fueling infrastructure is needed

Nonpowertrain Tech

- Reduced road load via mass reduction, aerodynamics, and tire improvements

Connected and Automated Tech

- Automation and connectivity technologies are capable of fuel savings
- To ensure savings, automakers need to be encouraged to design for efficiency of CAV technologies

Low-carbon, Nonpetroleum Fuels

- Electricity needs scale-up of low-carbon generation
- Hydrogen technology needs low-carbon RD&D
- Low-carbon, liquid fuels need RD&D to contribute beyond biofuel blends

Key Findings: Consumers, Markets, and Policy

Consumers Face Barriers to Novel Technology

- PEV and FCEV purchase subsidies should be continued to overcome financial and psychological consumer barriers, and changed to a point-of-sale rebates, with income eligibility considered.
- Policy interventions beyond purchase subsidies may be needed to address additional barriers.

In-Use Performance and Drive Cycles

- The agencies should measure in-use fuel consumption and GHG emissions of the LDV fleet, to evaluate and improve the CAFE and GHG programs, not for year-by-year enforcement of individual manufacturers.
- Driving patterns should be studied to propose new LDV test cycles.

Off-cycle technologies

- The agencies should consider off-cycle technologies, including for CAVs, in setting standard stringency.
- Off-cycle credit approval should follow an annual cycle, and should require greater automaker transparency.

Car and Truck Standards

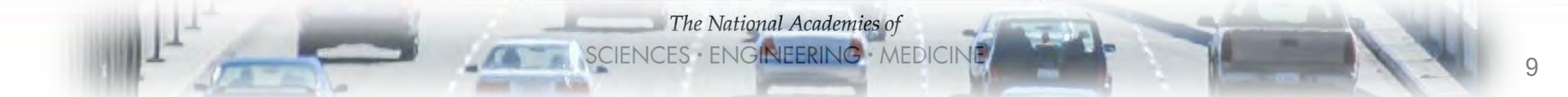
- The agencies should commission a study of the effectiveness and appropriateness of separate car and truck standards.

Autonomous Vehicle Policy

- The agencies should consider actions to guide system effects of autonomous driving, including policies to promote vehicle sharing and complementarity to less energy-intensive modes.

Key energy issues for CAVs and fully autonomous vehicles (L4/5) are fundamentally different

	CAVs (Chapter 8)	Autonomous vehicles (Chapter 9)
Energy impacts	Effects on fuel efficiency of individual vehicle	Effects on vehicle ownership and miles traveled
Policy challenge	How to integrate technologies into fuel economy program to promote energy savings	How to gain AV benefits without undermining transportation sustainability



CAV Effectiveness

Automation Can Enable Efficiency

- Through optimizing velocity and minimizing acceleration events, automation technologies can provide fuel savings of up to 8 percent, depending on driving conditions and powertrain type

Connected and Automated Together Offer Greater Fuel Savings

- Connected and automated driving can allow some engine and powertrain efficiency technologies to achieve their full savings potential
- With reliable V2I, connected and automated vehicle technologies together could increase fuel efficiency by as much as 20 percent for some powertrain types in some driving conditions.

Power Draw

- Power draw for a given function will decline rapidly over time as electronic systems evolve and refine, but total electrical load of these systems may remain significant as their functionality increases, due especially to growing computing requirements.

CAV Cost and Effectiveness (Table 8.6)

Technology Package **Fuel savings principles**	**Technologies in package and technology assumptions**	**2020 Package Cost**	**2035 Package Cost**	**Package Effectiveness (Fuel Consumption Reduction)**			
				ICE	**HEV**	**PHEV**	**BEV**
Level 2 automation: Optimized velocity, minimized acceleration events	•Sensors •Data and mapping technology •Onboard computing and vehicle controls •Wiring	$1,520	$1307	5% urban/ 5% hwy	4% urban/ 3% hwy	8% in combined hwy and urban driving (longer than battery range)	4% urban/ 4% hwy
Level 2 automation w/ PT controls + connectivity: Above plus: •V2X to extend prediction horizon •Optimization of engine and transmission controls + power management (HEV, PHEV)	Previous package plus: •Communications technology (DSRC or C-V2X transceiver) •Additional computer	$2,410	$2,073	9% urban/ 5% hwy	6% urban/ 3% hwy	20% in combined hwy and urban driving (longer than battery range)	5% urban/ 4% hwy Additional 5% with optimum thermal and state-of-charge management
Level 4/5 + connectivity: Above plus: Fully autonomous driving, permitting low-cost ride hailing, lower car ownership, and more high-efficiency vehicles	Same as above, plus: •Sensor (LiDAR) •Additional computer	$7,210-$17,210	$2,545-$4,683	Wide range of energy outcomes including savings from increased BEV adoption, vehicle "rightsizing", and ridesharing, as well as higher consumption from autonomous driving system power draw and more vehicle miles traveled			

Caveats—CAV Cost and Effectiveness

- CAV technologies are added primarily for safety and other non-energy related purposes, so costs should not be entirely attributed to fuel economy.
- Package effectiveness estimates do not reflect operation over the standardized test cycles, but rather are mostly based on testing or simulation reflecting driving patterns closer to actual conditions and optimization for individual vehicles.
- The technology effectiveness represents an upper bound with respect to a baseline without the CAV technology packages.

Other CAV findings

- Consumer acceptance of higher level automation is uncertain at present, but with continued declines in cost, increases in capabilities, and increases in consumer familiarity with automated features, it may be common by 2035.
- Connectivity is unlikely to be widely deployed in 2025 but could reach high adoption levels by 2035 if public infrastructure is updated to collect, process, and distribute data and if useful, affordable, connectivity services are available.
- Off-cycle credits could promote CAV technology for efficiency
  - But credits should be available only to the extent technologies demonstrably improve fuel efficiency.
  - EPA, DOT and DOE should research current driving patterns to support sound estimates of the energy impacts of off-cycle fuel efficiency technologies including CAV technologies.

Autonomous Vehicle Energy Impacts

- Energy implications of AVs will be largely determined by their effects on mode choices, VMT, and other travel behaviors.
- Energy impact of AVs also influenced by expectations of vehicle performance and features
- Research indicates that at full penetration autonomous vehicles could plausibly impact energy consumption by –40% to +70%.

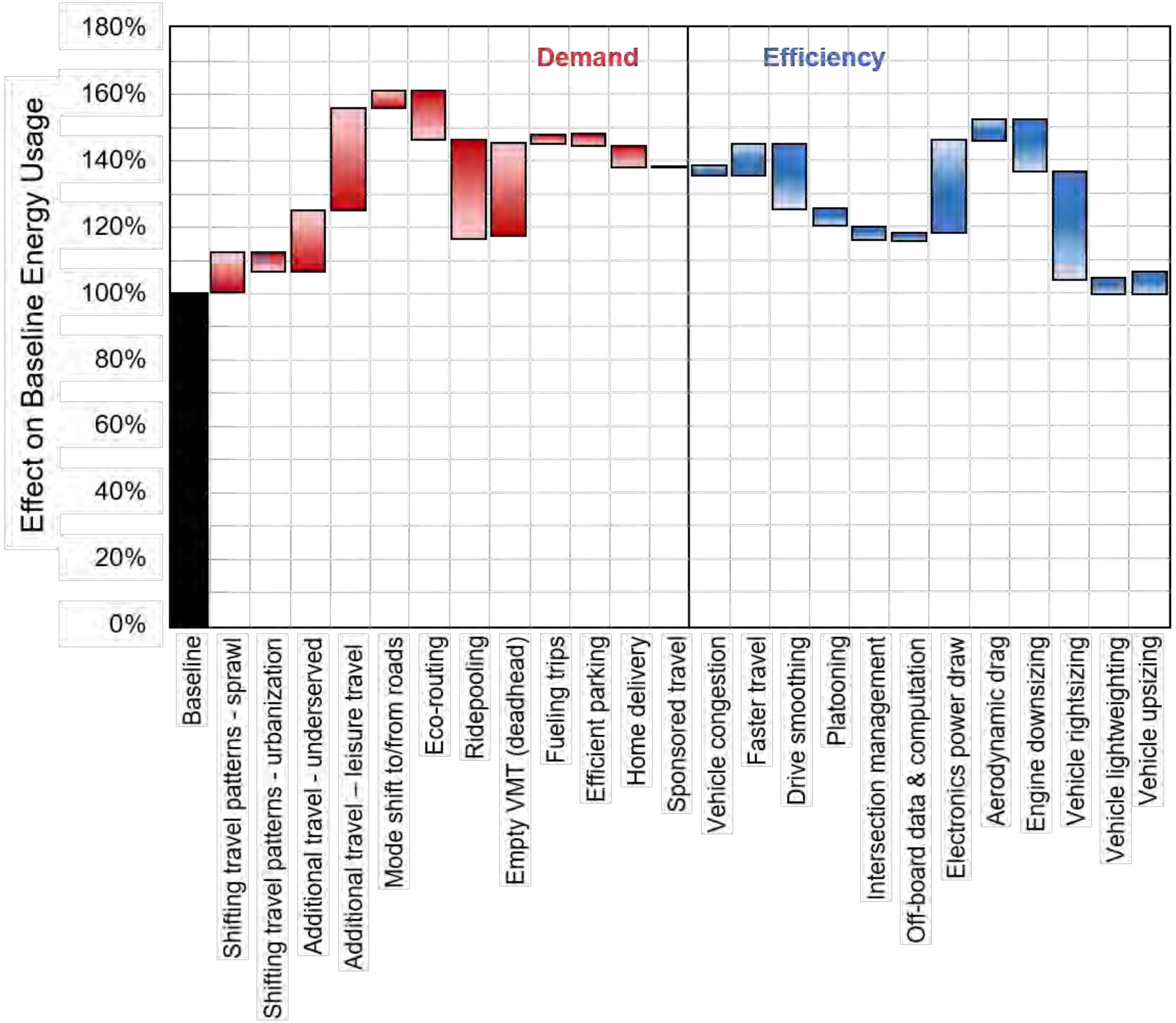
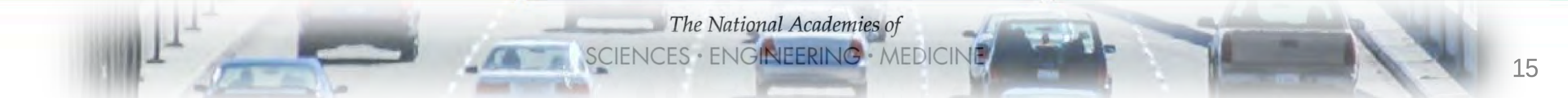


FIGURE 9.2 Energy changes from each factor. SOURCE: Gohlke (2020).

Autonomous Vehicle Adoption and Policy

- AVs' share of the market in 2035 is highly uncertain but likely to fall in the 0-40% range, with ride hailing and delivery fleets accounting for 40-60% of those sales.
- Agencies should consider regulating fleet AVs differently from personally owned vehicles; consider an EV mandate
- Agencies should support research and policies that advance the simultaneous achievement of the safety, economic, environmental, and equity benefits that autonomous vehicles can provide.



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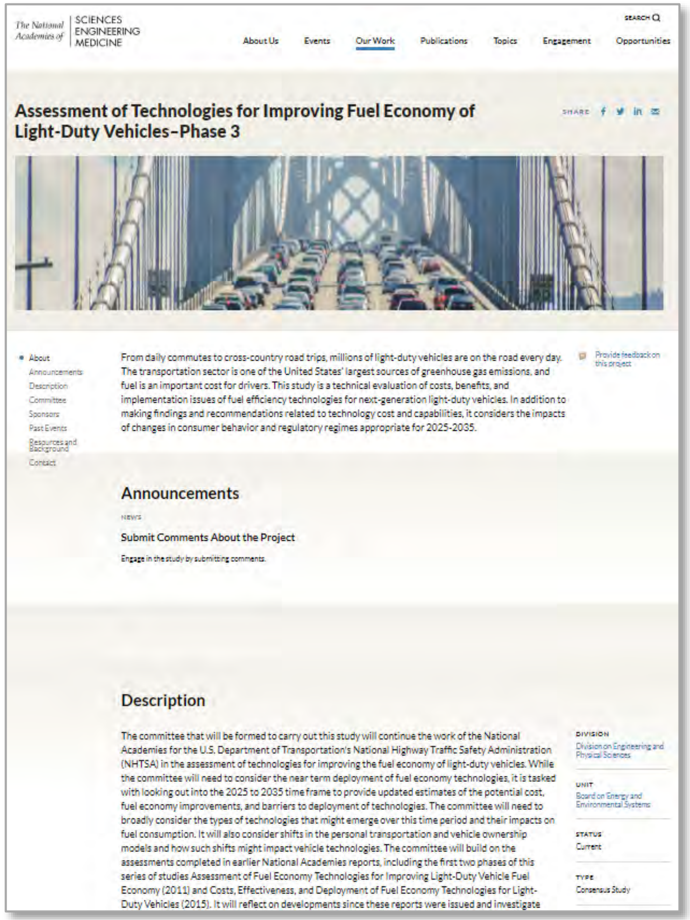

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Questions?

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- Available at https://www.nap.edu/catalog/26092

See BEES reports on fuel economy, energy systems, and emissions: