

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

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Public Report Release Briefing

Today's Presenters



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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

The screenshot shows the website for the study. At the top, it says 'The National Academies of SCIENCES ENGINEERING MEDICINE'. Below that are navigation links: 'About Us', 'Events', 'Our Work', 'Publications', 'Topics', 'Engagement', and 'Opportunities'. The main heading is 'Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles - Phase 3'. There is a large image of a highway with cars. Below the image, there is a 'Description' section with text: 'From daily commutes to cross-country road trips, millions of light-duty vehicles are on the road every day. The transportation sector is one of the United States' largest sources of greenhouse gas emissions, and fuel is an important cost for drivers. This study is a technical evaluation of costs, benefits, and implementation issues of fuel efficiency technologies for next-generation light-duty vehicles. In addition to making findings and recommendations related to technology cost and availability, it considers the impacts of changes in consumer behavior and regulatory regimes appropriate for 2025-2035.' There are also 'Announcements' and 'Description' sections with more details.

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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**.

Committee Roster



Gary Marchant, Arizona State University, *Committee Chair*



Carla Bailo, Center for Automotive Research



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



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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
- 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.

Tech Advances: Internal Combustion Engines

Downsize/Boosted Engine Technology

- Mass-market but advanced TCDS technologies in 2020 are likely to be standard in 2025, similar to technology listed in columns in the figure to the right.
- Technologies which allow for application of Miller Cycle are expected to improve thermal efficiency.

Naturally Aspirated Engine Technology

- Cylinder deactivation is well suited to NA engines.
- Atkinson cycle will be increasingly implemented for peak efficiency.

	Intro Year	Variable Valve Timing (VVT)	Integrated Exhaust Manifold	High Geometric CR	Friction Reduction	Higher Stroke/Bore Ratio	Boosting Technology	cooled EGR	Variable Valve Lift (VVL)	Miller Cycle	VNT/VGT Turbo	Partial Discret Cylinder Deac.	Full Authority Cylinder Deac.	Variable Compression Ratio	Gasoline SPCCI / Lean Modes
Boosted Engines															
Ford EcoBoost 1.6L	2010														
Ford EcoBoost 2.7L	2015														
Honda L15B7 1.5L	2016														
Mazda SKYACTIV-G 2.5L	2016						4				4				
VW EA888-3B 2.0L	2018														
VW EA211 EVO 1.5L	2019							?							
VW/Audi EA839 3.0L V6	2018				?										
Nissan MR20 DDT VCR 2.1L	2018			+	?		?	?							?
Mazda SKYACTIV-X SPCCI 2.0L SC ¹	2019			+	?						NA				
EPA/Ricardo EGRB24 1.2L ²	N/A														

yellow = early implementation *light & dark green* = nearing maturity *red* = technology not present

1- Supercharged 2- EPA Draft TAR 3- Not known at time of writing

4- Mazda accomplishes equivalent of VNT/VGT using novel valving system

FIGURE 4.2 Example production boosted engines (except the EPA/Ricardo engine), with implemented efficiency technology solutions in green and yellow. Unimplemented efficiency technologies are shown in red. SOURCE: Stuhldreher et al. (2018).

Tech Advances: ICEV Transmissions, Diesels, Advanced Combustion

Transmission

- Planetary automatic 8, 9 and 10 speed transmissions will replace advanced 6 speed transmissions. Some manufacturers will continue to develop and use advanced CVTs.
- Future development of transmissions may focus on integration with electrification.

Diesel Technology

- Light-duty diesel vehicles will not play a meaningful role in the U.S. market, due to cost of criteria emissions compliance.

Other Advanced Combustion

- Combustion systems utilizing lean air to fuel mixtures, such as HCCI, will not likely see widespread implementation due largely to criteria emission constraints.

Tech Advances: ICEs for Hybrid Applications

Engines will be designed for efficient hybrid applications

- TCDS engines can implement less expensive Miller Cycle operation, and possibly further downsize.
- Series hybrid engines will operate only in their most efficient modes, acting as a generator for motor-driven vehicle propulsion.

NHTSA should improve its cost estimates for hybrid technologies

- Strong hybrids represent the maximum fuel efficiency possible in vehicles powered only by gasoline, both in the current fleet and into the future.

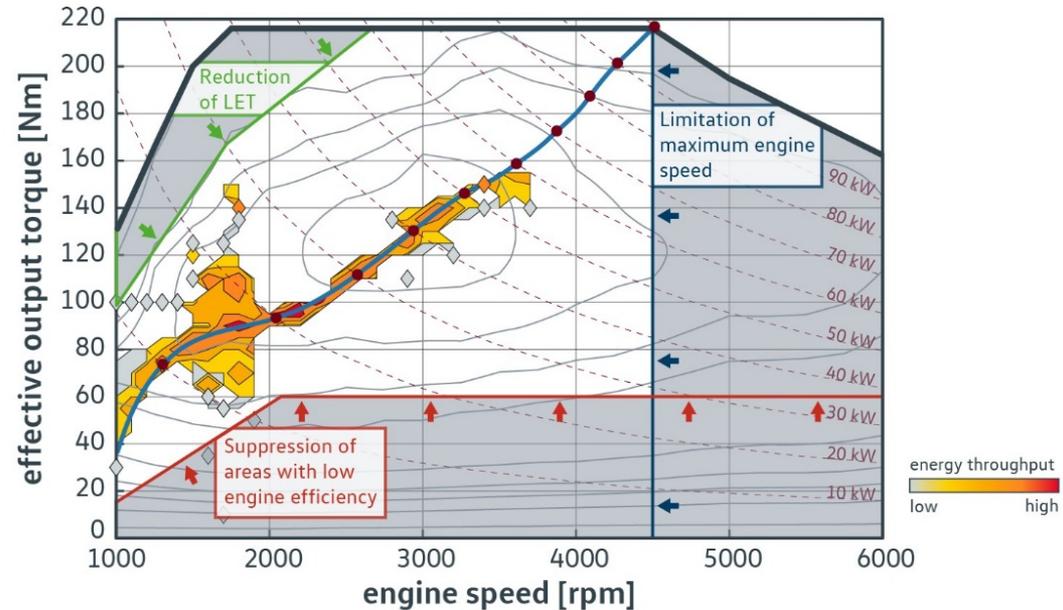


FIGURE 4.8 Example engine map of the Volkswagen 1.5L TSI evo engine. Grey boxes illustrate some areas of torque vs speed that no longer have to be provided by the engine alone. For example, motor-driven propulsion can replace low load operation at the lower engine torques, and the motor can supplement higher load operation at high speed and/or low speed high torque. SOURCE: Brannys (2019).

Technology Advances: Electric vehicles

Battery Technology

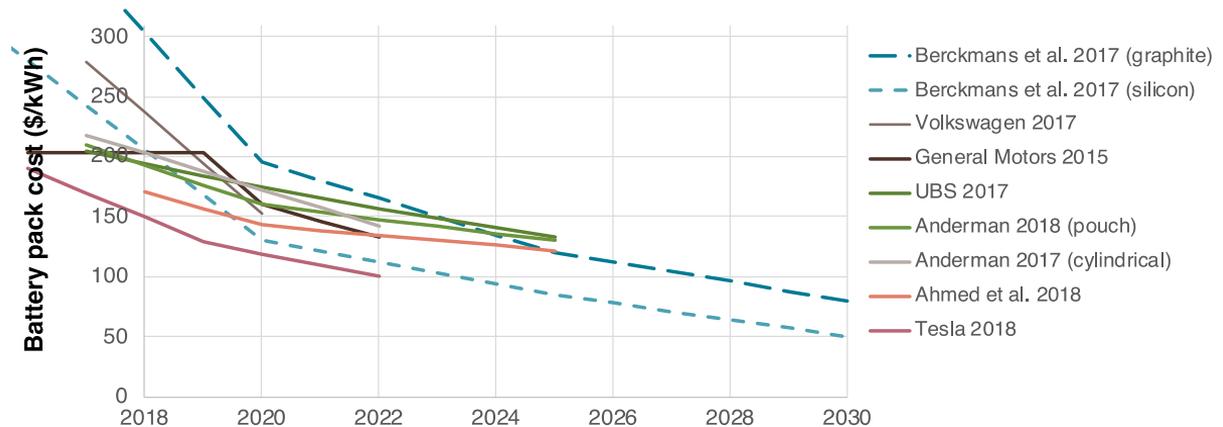
- Lithium-ion batteries will be the dominant battery technology.
- Chemistries will have incremental improvements in performance and cost.
- Widespread “beyond lithium ion” breakthroughs are more uncertain.

Other Technologies

- Motors, inverters, power electronics technologies are improving with supplier and automaker innovation.
- Advances are to lower cost, increase performance, and increase range.

BEV Cost

- Longer range BEVs (e.g., 300 mile) may reach first-cost parity with comparable internal combustion vehicles by 2030.
- Shorter-range BEVs may be favored by some and reach cost parity even sooner.
- For high-volume battery production, BEV battery cost is expected to decrease to \$90-115/kWh by 2025 and \$65-80/kWh at the pack level by 2030.

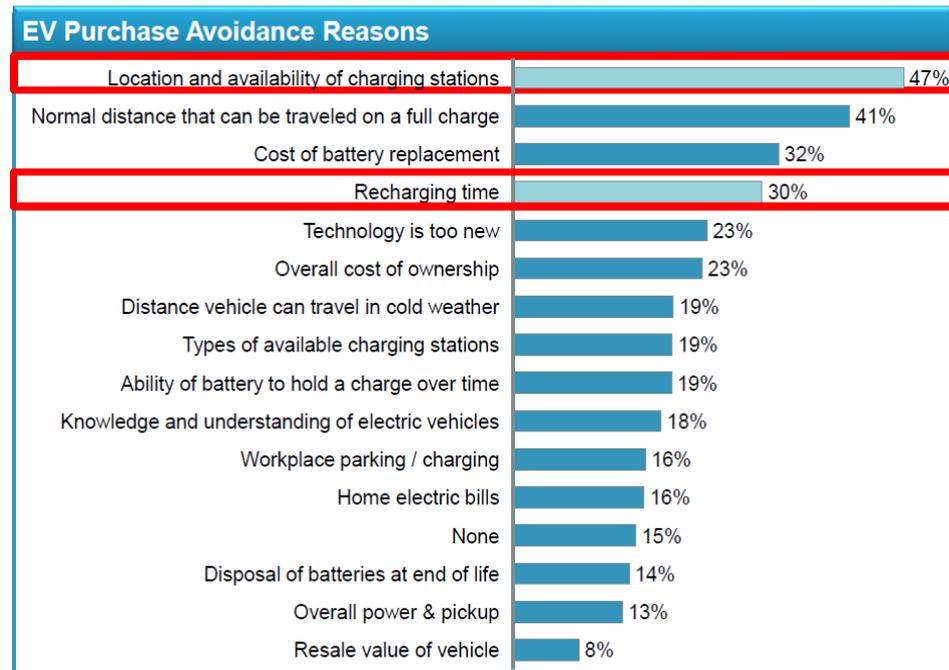


SOURCE: Lutsey and Nicholas, 2019

Technology Advances: Electric Charging

Charging Infrastructure

- Charging infrastructure can increase electric miles and overall fleet fuel economy, but the extent is unclear.
- DOE should study consumer value, expected utilization and business models of public charging, including DCFC to guide further deployment decisions.
- DOT, EPA and DOE should coordinate to facilitate electric charging infrastructure deployment with a national public-private partnership to identify and address infrastructure and policy gaps (e.g., corridor, public parking spaces, home and workplace).



SOURCE: Strategic Vision, 2017

Tech Advances: Fuel Cell Electric Vehicles

Materials, Design and Engineering

- Materials and design and engineering improvements continue to lower cost and improve performance of fuel cell systems, hydrogen storage tanks.
- Research focused on developing:
 - lower platinum content fuel cells
 - non-precious metal catalysts
 - higher temperature membranes
 - higher efficiency, lower cost electrolyzers for renewable H₂
 - lower cost carbon fiber storage tanks
 - lower cost hydrogen compression technologies

FCEV Deployment

- A few major automakers are planning a strategy of high FCEV deployment to take advantage of long ranges and short refueling times.
- FCEVs could reach parity with internal combustion engine vehicles in total cost of ownership in 2025-2035 if aggressive efficiency and cost targets are met.

H₂ Fueling Infrastructure

- Hydrogen infrastructure build-out is the most significant challenge for FCEV deployment.
- H₂ infrastructure for other applications could accelerate LDV refueling network build-out.

Tech Advances: Connected and Automated Vehicles

CAV Technology Can Enable Efficiency

- Connected and automated driving can allow some engine and powertrain efficiency technologies to achieve their full savings potential, offering more than 10% savings in some conditions.

Connected and Automated Together Offer Greater Fuel Savings

- With reliable V2I, connected and automated vehicle technologies together could increase fuel efficiency by as much as 20 percent in some driving conditions.

Research is Needed to Quantify Energy Impacts

- 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.

Off-cycle credits could promote CAV technology for efficiency

- But credits should be available only to the extent technologies demonstrably improve fuel efficiency.

Tech Advances: Fully-Autonomous Vehicles

Fully Autonomous Vehicle Deployment

- 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.

AV Energy Impacts

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

AV Efficiency Regulation

- NHTSA should now consider how to regulate AVs in fuel economy standards, including fleet vs personally owned vehicles.

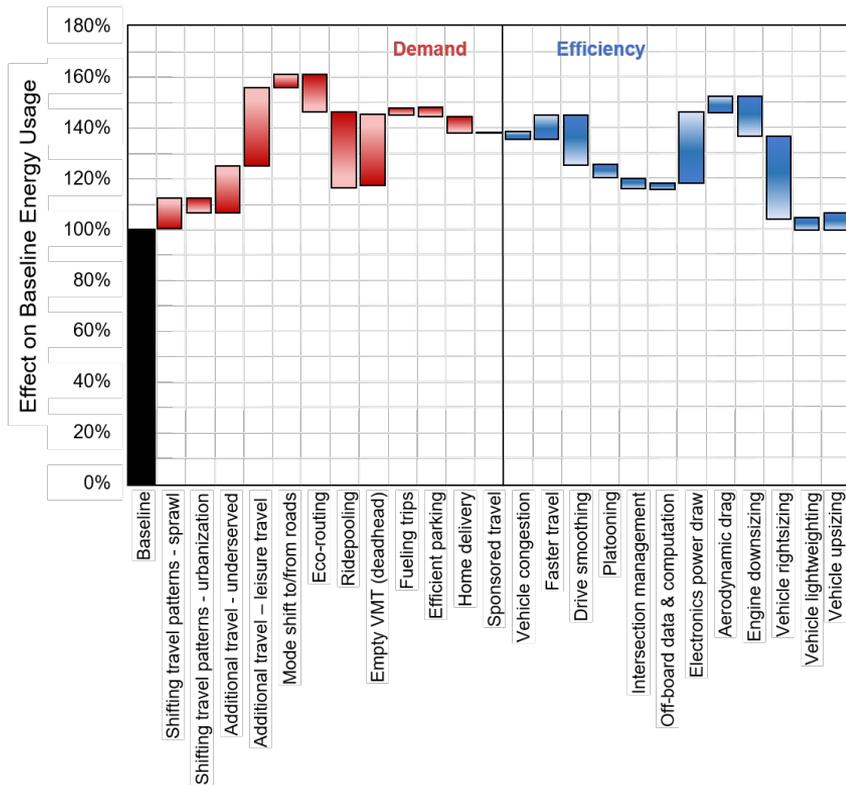


FIGURE 9.2 Energy changes from each factor. SOURCE: Gohlke (2020).

Tech Advances: Nonpowertrain Technologies

Aerodynamic Technologies

- Improved aerodynamics will be challenged by shift to taller vehicles with larger frontal area, and may be positively or negatively impacted by electrification.
- Elimination of outside mirrors has the potential to reduce aerodynamic drag.

Tires

- Incremental improvements in rolling resistance will be available.

Mass Reduction

- Will be implemented for fuel consumption reduction and driveability for all vehicles, and also for increased driving range for BEVs and FCEVs.

Mass and Safety

- NHTSA should study potential changes in mass disparity in the fleet and societal safety risk.
- NHTSA should study how crash type and severity change in an ADAS-enabled fleet.

Tech Advances: Low-Carbon Nonpetroleum Fuels

Low-Carbon Electricity

- Electricity generation technologies are mature, and increased deployment will help reduce EV well-to-wheels GHG emissions.

Low-Carbon Hydrogen

- Hydrogen generation technologies currently suffer from high costs and low production volumes, and are an area of active R&D.

Low-Carbon Liquid Fuels

- Low-carbon liquid fuels can serve as drop-ins for conventional gasoline and diesel, presenting an opportunity to decarbonize both existing and future LDV fleets, but require significant R&D.
- As low-carbon fuels become more prevalent in the light-duty fleet, NHTSA and EPA should consider a full-fuel-cycle approach to setting regulatory standards

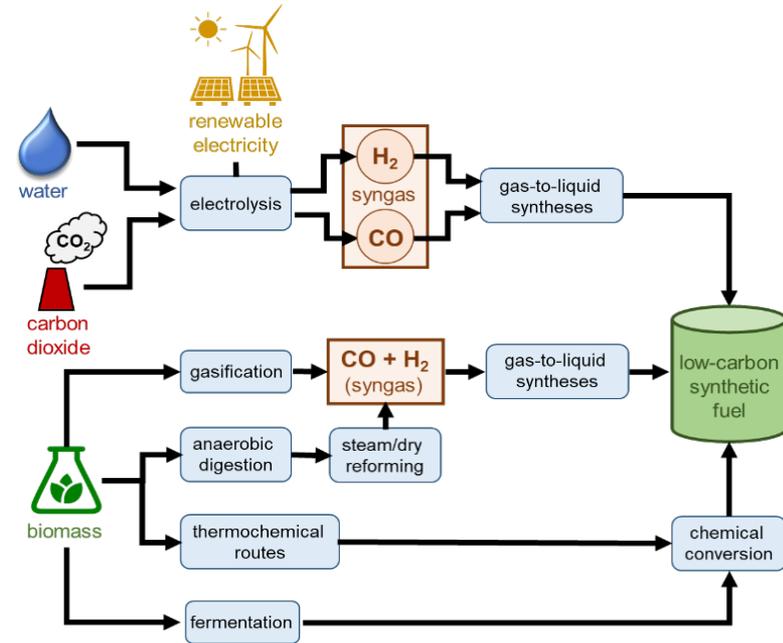


FIGURE 10.3 Pathways for the production of low-carbon synthetic fuel. SOURCE: Adapted from The Royal Society (2019).

Consumer and Market Responses

Consumers Value of Efficiency Technologies is Uncertain

- Consumer unfamiliarity and misperceptions about BEVs are a significant impediment to consumer demand. Improved performance of BEVs, particularly longer range, will help overcome such impediments.
- The agencies should use all their delegated authority to drive the development and deployment of ZEVs, because they represent the long-term future of energy efficiency, petroleum reduction, and GHG emissions reduction in the light-duty vehicle fleet.
- The agencies should collect further evidence on the influence of vehicle performance trade-offs on automaker compliance strategies and consumers, and reassess whether forgone performance improvements should be included in standard benefit-cost analysis.

Safety and Policies to Accelerate Turnover Should be Studied

- EPA, in conjunction with DOE and DOT, should study the cost and effectiveness of accelerated turnover programs at emissions reduction, increasing ZEV sales, and addressing equity considerations.
- NHTSA should ensure that its standards do not incentivize increases in the mass of heavier vehicles, exacerbating mass disparity.

Policy and Regulation

Credit Trading and Transparency

- NHTSA should undertake a large-scale data collection process to measure the real-world fuel economy benefits of off-cycle technologies.
- NHTSA should publically report credit trade quantities and prices between manufacturers. This reporting would increase transparency and provide useful information for economic analysis of the regulations.

Consideration of ZEVs in CAFE Standard Setting

- NHTSA should reinterpret the statute to consider the market share of ZEVs in setting the standard.
- Congress should amend NHTSA's statute to clarify that the fuel economy of ZEVs can be included in standard setting.

Thank you!

Questions?

- Please add your questions to the Q&A

Share the report!

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

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

The screenshot shows the top navigation bar with links for About Us, Events, Our Work, Publications, Topics, Engagement, and Opportunities. The main heading is "Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles - Phase 3". Below the heading is a large image of a highway with many cars. To the right of the image are social media share icons. Below the image is a "Description" section with a "Final Report" link. To the right of the description is a "Description" section with a "Final Report" link. Below the description is an "Announcements" section with a "Submit Comments About the Project" link. Below the announcements is a "Description" section with a "Final Report" link.

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