International Council on Clean Transportation comments on Revised Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks

Public submission to

National Highway Traffic Safety Administration

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THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

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Public Comments Summary

The International Council on Clean Transportation (ICCT) welcomes the opportunity to provide comments on the *Revised Corporate Average Fuel Economy Standards for Model Years 2024–2026 Passenger Cars and Light Trucks.* The ICCT is an independent nonprofit organization founded to provide unbiased research and technical analysis to governments in major vehicle markets around the world. Our mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation in order to benefit public health and mitigate climate change.

A. Overview

The proposed standards seek to correct for a rollback that, as we noted at the time, was fundamentally flawed, and put the United States out of step with every other major auto market and manufacturing center.

While ICCT supports increasing the CAFE standards, the cost of compliance is overstated due to the use of outdated technology data and information. Vehicle efficiency technology has been consistently improving for decades. This technology trend shows no signs of slowing down, as supported by a variety of recent comments and publications. For example:

- The EPA Fuel Economy Trends report[1] documents rapid development and deployment of many technologies that are now commonplace in the market.[2]
- ICCT commented extensively on recent technology improvements in its 2018 comments on the SAFE NPRM for 2021-26 cars and light trucks (ICCT 2018 comments)[3], its study of LPM and OMEGA modeling of the 2018 Camry (ICCT 2018 Camry)[4], and its supplemental comments responding to Toyota comments on ICCT's study of LPM and OMEGA modeling of the 2018 Camry (ICCT 2019 comments)[5].

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[1] 2020 EPA Automotive Trends Report, https://www.epa.gov/automotive-trends/download-automotive-trends-report#Full%20Report

[2] Specific technologies reported in the 2020 EPA Trends Report are port fuel injection, gasoline direct injection, multi-valve, variable valve timing, cylinder deactivation, turbocharging, stop/start, hybridization, and electric vehicles

[3] ICCT Comments on the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks, submitted October 26, 2018: https://theicct.org/news/comments-safe-regulation-2021-2026 (ICCT 2018 comments)

[4] German J. (2018). *How things work: OMEGA modeling case study based on the 2018 Toyota Camry.* https://theicct.org/publications/how-things-work-omega-modeling-case-study-based-2018-toyota-camry (ICCT 2018 Camry)

[5] Supplemental Comment from the International Council on Clean Transportation, dated April 2019, Docket #NHTSA-2018-0067-12387 https://www.regulations.gov/comment/NHTSA-2018-0067-12387 , #NHTSA-2018-0067-12388 https://www.regulations.gov/comment/NHTSA-2018-0067-12388 (ICCT 2019 comments)

- The Union of Concerned Scientists' SAFE2 reconsideration petition to NHTSA[6] and the Joint NGO SAFE2 reconsideration petition to EPA[7] also provided updated assessments of vehicle technology.
- Section 1.2.1 (pages 1-6 through 1-9) of EPA's draft RIA for its proposed rule summarizes updated technology analyses and data from EPA's TSD for EPA's 2018 MTE Analysis.

Further, two recent reports[8] [9] demonstrate that further technology improvements are coming that can boost ICE efficiency well beyond even HCR2 efficiency levels, and a third shows the declining costs of a 48-volt mild hybrid and BEVs[10].

In addition, the EPA draft RIA (DRIA) acknowledges that technologies have improved since the publication of the TSD in 2016 for the November 2016 Proposed Determination. EPA also acknowledges that the engine maps in the proposed rule are outdated and that it has more up-to-date baseline and future engine maps within its OMEGA model. For example, EPA's DRIA states:

> "EPA has continued its independent evaluation of advanced engine and transmission technologies and update and improve our assessment of light-duty vehicle GHG emissions over the intervening 4 years since publication of the TSD. The results of these analyses have been published in over a dozen peer-reviewed technical and journal papers." (*see* DRIA 2021 page 2-10)

However, NHTSA proposal doesn't incorporate these updated engine maps from EPA, or even discuss them. Indeed, it appears that no technology improvements or cost reductions from EPA's independent evaluations or from any comments submitted to NHTSA or new studies over the last 5 years were included in the proposed rule, beyond the additional of DEAC to HCR1. This basis for NHTSA's analysis is an overly conservative assessment of the costs of the standards. As documented in the following sections, technology effectiveness and cost have continued to improve. Thus, **if technology costs and benefits were updated with the latest information, it would show that the proposed standards are much more feasible and lower-cost than NHTSA's analysis indicates – indeed, that Alternative 3 standards are easily achievable**.

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[6] Union of Concerned Scientists' Petition for Reconsideration of NHTSA's Final Rule—The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, submitted June 12, 2020 (UCS 2020 reconsideration petition)

[7] *Center for Biological Diversity et al. Petition for Reconsideration of EPA's Final Rule—The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, submitted June 29, 2020 (Joint NGO 2020 reconsideration petition) https://ago.vermont.gov/wp-content/uploads/2020/08/20200629-UCS-et-al-SAFE-Part-II-Petition-for-Reconsideration_Print_Copy.pdf*

[8] AVL Webinar on Passenger Car powertrain 4.x – Fuel Consumption, Emissions, and Cost on June 2, 2020 https://www.avl.com/-/passenger-car-powertrain-4.x-fuel-consumption-emissions-and-cost plus slides are attached to these comments (AVL 2020)

[9] Roush report on Gasoline Engine Technologies for Improved Efficiency (Roush 2021 LDV) https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0208-0210

[10] Roush report on 48V and BEV costs (Roush 2021 48V) https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0208-0210

Even if NHTSA chooses to not incorporate the full extent of new data and information into the final rule for MY2024-2026, NHTSA should at least acknowledge the improvements that have been made, both to effectiveness and costs of compliance technologies, in the intervening years and that the technology assessments in the proposed rule are out of date, explain that this causes the costs of more stringent standards to be overstated, briefly summarize new technology developments, and commit to incorporating the latest data and information into future rulemaking.

Finally, NHTSA is undercounting the benefits of the proposed standards in a variety of ways. NHTSA's assumptions about vehicle price elasticity in modeling sales, modeling of sales shares between cars and light-trucks, assumption of rebound effect, and assumption of post-Covid VMT all have a systematic impact of undercounting potential fuel savings benefits of the potential standards, and thus NHTSA is consistently overestimating the increases in vehicle costs necessary to meet the maximum feasible reduction in fuel consumption from new motor vehicles.

Not only is the transportation sector the largest contributor to the greenhouse gas emissions in the United States, it continues to be heavily dependent on petroleum globally. While other major economies (e.g., Europe, China) have been acting on that crucial realization by taking steps to strengthen fuel economy and CO_2 standards and to reduce the transportation sector's dependence on petroleum, the United States has lagged. That represents not only a setback for energy conservation and the climate but also a looming crisis for the American manufacturing economy. Since 2010 the U.S. share of global EV production has fallen, from 20% to 18%, and without intervention that trend will continue: a mere 15% of the $340 billion total investment global automakers have planned in EV manufacturing is presently destined for the United States. Strengthening the 2026 standards beyond Alternative 2 would allow the United States to close some of this gap, help the US compete globally on both conventional vehicle technology and electric vehicles, and set the stage for more ambitious post-2026 standards.

Due to all of the above reasons, **ICCT strongly supports adoption of Alternative 3 CAFE standards in the final rule.**

B. Summary of Previously Submitted Technology Assessments

Technologies discussed in previous comments – as well as in reports issued by EPA since the 2016 RIA – but not incorporated in the proposed NHTSA rule are summarized in this section.

Outdated engine maps: The engine maps that are included in the agency modeling are severely outdated. For example, all base naturally aspirated engine maps are based on an unidentified 2013 or older vehicle, all turbo (non-Miller cycle) maps are based on a vehicle whose specifications match that of the 2011 MINI R56 N18 / BMW N13 engine, the hybrid Atkinson cycle map (for PS and PHEV) is based on the 2010 Toyota Prius, and the HCR1 map is based on the 2014 Mazda

SkyActiv 2.0L engine. Essentially, NHTSA is assuming there will be no efficiency improvements in any of these technologies through at least 2026, or for 12 to 16 years from the model year of the vehicle used to generate the maps. As just two examples of how absurd it is to assume no improvements in any of these engine technologies for at least 12 years, the turbocharged engine introduced by Honda in 2016 was significantly more efficient than the engine used to generate all the turbocharged maps in the proposed rule and the 2018 Camry hybrid improved fuel economy by 15% (XLE/SE) to 25% (LE) compared to the 2017 Camry hybrid.[11] And these (unincorporated) improvements were already in the market by 2016 and 2018 – still 8 to 10 years before 2026. For additional information see UCS Reconsideration Petition pages 68-72.

Miller Cycle effectiveness: VW is already using Miller Cycle engines as the base engine in the Passat, Arteon, Atlas, and Tiguan and a hybrid-specific version of this engine with CEGR and VGT is under development by VW that demonstrates a peak BTE of 41.5%.[12] The fact that Miller cycle is already included on the standard engine for many of VW's most popular vehicles supports that Miller cycle is a cost-effective addition to turbocharged engines. Yet there are no Miller cycle applications in 2026 beyond the specific Mazda and Volvo models that already had Miller cycle in 2017. For additional information, see ICCT 2018 comments page I-71 and EPA DRIA page 2-13.

Turbocharging effectiveness: EPA added a 2nd generation turbocharged downsized engine package based on EPA benchmark testing of the Honda L15B7 1.5L turbocharged, direct-injection engine to its 2018 MTE, which was not used in NHTSA's proposed rule.[13] For additional information see EPA DRIA page 1-8.

HCR engine effectiveness: EPA added an engine map in its 2018 MTE for Atkinson (ATK2+CEGR) technology based on EPA benchmark testing of the MY2018 Camry 2.5L A25A FKS engine. However, NHTSA's proposed rule continued to use developmental engine test data and GT-POWER engine modeling within the 2016 TSD.[14] For additional information see EPA DRIA page 1-8, ICCT 2018 Camry, ICCT 2018 comments, ICCT 2019 supplemental comments, and UCS Reconsideration Petition pages 60-63.

Cylinder Deactivation on Turbocharged Vehicles and HCR1 engines: The modeled benefit of adding cylinder deactivation to turbocharged and HCR1 vehicles is only about 25% of the benefit

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[11] Up to 10% of the fuel economy gain might be explained by modest roadload and mass reductions, but a large amount is clearly due to improvements in engine and powertrain efficiency.

[12] EPA DRIA page 2-13

[13] Stuhldreher, M., Kargul, J., Barba, D., McDonald, J., Bohac, S., Dekraker, P., & Moskalik, A. (2018). Benchmarking a 2016 Honda Civic 1.5-liter L15B7 turbocharged engine and evaluating the future efficiency potential of turbocharged engines. SAE International journal of engines, 11(6), 1273.

[14] Kargul, J., Stuhldreher, M., Barba, D., Schenk, C., Bohac, S., McDonald, J., & Dekraker, P. (2019). Benchmarking a 2018 Toyota Camry 2.5-liter Atkinson Cycle Engine with Cooled-EGR. SAE International Journal of Advances and Current Practices in Mobility, 1(2), 601.

from adding DEAC or ADEAC to a basic engine.[15] While adding DEAC to a turbocharged or HCR1 engine has smaller pumping loss reductions than for base naturally aspirated engines, DEAC still has significant pumping loss reductions and has the additional benefit of enabling the engine to operate in a more thermal efficient region of the engine fuel map. The agencies also failed to provide even the most basic information supporting their effectiveness estimates for TURBOD. Further compounding the problem, NHTSA based the effectiveness of adding DEAC to HCR engines on the TURBOD estimate, without any further justification. For additional information see Joint NGO 2020 Reconsideration Petition, pages 62-64,

Engine downsizing and secondary mass reduction restrictions: Consistent with NHTSA's earlier position that it is "impractical" to always resize the engine in response to tractive load changes,[16] in NHTSA's proposed rule the engine is "only resized when mass reduction of 10% or greater was applied to the glider mass".[17] This implicitly assumes that existing engines are all perfectly sized. In practice, engines are commonly shared across a variety of models and trim levels, with a wide variety of weight and roadload, as well as different target performance levels. This means the engine is sized to ensure that the worst case application still meets its performance target. Which in turn means that a modest amount of load reduction can justify the use of a smaller engine on many vehicle variants. In fact, only downsizing engines for large changes in tractive load artificially increases the overall performance of the fleet, the consumer benefits of which the proposed rule does not address. Due to the large uncertainties in when and how to downsize engines for the variety of vehicles, the only acceptable solution is to always model the appropriate amount of engine downsizing to maintain performance. For additional information see Joint NGO 2020 Reconsideration Petition, pages 124-125, and 2019 Supplemental Comment of H-D Systems.[18]

Strong hybrid effectiveness: As a specific example of the outdated engine maps used in NHTSA's modeling, real-world fuel economy and GHG improvements in the MY 2018 Toyota Camry hybrid and the MY 2019 Toyota RAV4 Hybrid are well beyond the maximum theoretically possible in the agencies' modeling. Toyota made improvements to the 2018 Camry and 2019 RAV4 hybrids, which after the redesigns reduced CO2 emissions by 19% relative to 2017 on the Camry Hybrid LE, 11% on Camry Hybrid XLE/SE, and 19% on the RAV4 Hybrid. In contrast, the CAFE model projects only a 7 to 8% reduction in the Camry Hybrid CO2 emissions from its 2018 redesign and only a 12% reduction for the RAV4 Hybrid from its 2019 redesign. The difference is because NHTSA's modeling does not allow *any* hybrid powertrain improvements (on any hybrid vehicles in the fleet) through 2026 beyond those that were already incorporated into the MY 2017 Camry and RAV4 Hybrids. Indeed Engine map 26 used for all strong hybrids through 2026 is based on the 2010 Toyota Prius. NHTSA should update their modeling of emissions-improving

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[15] NHTSA proposed 2024-26 rule, TSD Figure 3-5 page 192

[16] 85 Fed. Reg. at 24,561; see also id. at 24,336, 24,463.

[17] NHTSA Proposed 2024-26 rule, page 49692

[18] Supplemental Comment of H-D Systems, dated May 23, 2019 (Docket # NHTSA-2018-0067-12395; #EPA-HQ-OAR-2018-0283-7575)

technologies to reflect the feasible, real-world improvements in production today and the achievable future improvements, rather than premising their analysis upon technologies pulled from eleven years ago. For additional information see Joint NGO 2020 Reconsideration Petition, pages 64-68

Direct Injection (GDI) cost: ICCT submitted direct injection cost data in our 2018 comments based on a 2015 FEV teardown cost study (FEV 2015)[19], which found costs to be about 26% lower than the agencies assessment. The FEV teardown study costs were ignored and have not been incorporated into NHTSA's proposed rule. For additional information see ICCT 2018 comments pages I-69 to I-70 and FEV 2015.

Cooled Exhaust gas recirculation (CEGR) cost: ICCT submitted CEGR cost data in our 2018 comments based on a 2015 FEV teardown cost study, which found CEGR costs (DMC) in to be roughly $100 less than the agencies assessment after applying learning to 2025. The FEV teardown study costs have not been incorporated into NHTSA's proposed rule. Supporting FEV's teardown cost analysis, CEGR costs in EPA's 2018 MTE were changed to a single EGR loop from a higher cost low-pressure/higher pressure dual loop system, but its updated CEGR costs were not used in NHTSA's proposed rule. For additional information see ICCT 2018 comments page I-70, FEV 2015, and EPA DRIA page 1-9.

HCR cost: DMC costs for HCR in the SAFE rule, which are unchanged in NHTSA's proposed rule, were about $200 more than in EPA's 2016 TAR. This is a clear case where the agencies appear to have not used the best available data from EPA, which extensively analyzed this technology and its associated cost, nor has NHTSA justified how it increased the associated costs in this proposal. For additional information see ICCT 2018 comments pages I-70 to I-71.

Advanced cylinder deactivation cost: FEV's 2015 teardown analysis for ICCT found advanced cylinder deactivation cost to be based on variable valve lift (VVL) technology ($121 for a 4-cylinder engine) plus NVH improvements ($32). NHTSA's cost estimate of $565[20] is over 3 times higher than FEV's calculated costs. The rationale for NHTSA's cost is unclear, but appear to account for finger-follower de-lashing on a fixed block of cylinders (half the cylinders of a V6 or V8), which is not needed for dynamic cylinder deactivation. These findings are corroborated by EPA's communications with NHTSA and other officials, as shared in interagency emails and posted in the rulemaking docket. EPA indicates that the agencies' assumed cost for ADEAC is 2 to 4 times the cost of industry-quoted costs for the version of the technology in production in MY2019. [21] This is

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[19] FEV 2015 – David Blanco-Rodriguez, 2025 Passenger car and light commercial vehicle powertrain technology analysis. FEV GmbH. September 2015. https://www.theicct.org/publications/2025-passenger-car-and-light-commercial-vehicle-powertrain-technology-analysis

[20] NHTSA proposed 2024-26 rule, TSD Table 3-25, page 208

[21] "Email 5": Email_5_-_Email_from_William_Charmley_to_Chandana_Achanta_-_June_18,_2018. https://www.regulations.gov/document?D=EPA-HQ-OAR-2018-0283-0453. Page 48. "The cost of ADEAC is 2-4 times higher than industry quoted costs for the version of the technology which is going into production in MY2019"

troubling that the assumed agency cost would so wildly diverge from important information, and that NHTSA would choose not to share this clearly applicable information other than buried in interagency dialogue. For additional information see ICCT 2018 comments pages I-71 to I-72 and FEV 2015.

Turbocharging cost: The agencies have overestimated turbocharging costs by hundreds of dollars per application of the turbocharging package. Much of this may be due to the agencies not appropriately downsized engines to maintain constant vehicle utility and performance. Compared to FEV's 2015 engineering teardown analyses, as well as EPA's detailed technology benchmarking analysis for the 2016 TSD, the agencies greatly increased turbocharging costs in the SAFE rule and, hence, in the proposed rule. Based on the FEV teardown and EPA analysis, turbo-downsizing costs for 18-bar turbocharging range from a -$391 (i.e., a benefit due to moving from 6 to 4 cylinders) to a cost increase of $315 (for shift from I4 to I3) and $376 (for shift from V8 to V6).[22] The agencies current cost assessments for 18-bar systems range from $638 to $1,052 for the same configurations (Table 1). For additional information see ICCT 2018 comments pages I-72 to I-74, FEV 2015, and EPA 2016 TAR.

Table 1. Technology cost on turbocharging and downsizing

	Cost		
	I4 to I3	V6 to I4	V8 to V6
Agency 18bar turbo (over VVT)	$638	$642	$1,052
Agency 24bar turbo (over 18bar)	$204	$204	$343
Agency CEGR (over 24bar)	$244	$244	$244
Updated, appropriate (ICCT, EPA) 18bar (over VVT)	$315	($391)	$376
Updated, appropriate (ICCT, EPA) 24bar (over 18 bar)	$223	$223	$387
Updated, appropriate (ICCT, EPA) CEGR (over 24 bar)	$116	$116	$149

Non-battery BEV and PHEV cost: For 2018 Mid Term Evaluation, non-battery BEV and PHEV costs were updated based on more recent teardown data from California Air Resources Board,

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[22] Draft TAR Tables 5.68 through 5.72 and Aaron Isenstadt and John German (ICCT); Mihai Dorobantu (Eaton); David Boggs (Ricardo); Tom Watson (JCI). Downsized boosted gasoline engines, October 28, 2016. http://www.theicct.org/downsized-boosted-gasoline-engines

UBS, and other references,[23] [24] [25] but these updated costs were not used in the proposed NHTSA rule. For additional information see EPA DRIA page 1-8.

Off-Cycle credit cost: The agencies use an arbitrarily and unrealistically high estimate of off-cycle credit costs in their compliance modeling*.* In the 2016 TSD, EPA did not assess "particular off-cycle technologies or their costs and credits," but used an OMEGA sensitivity run for two-cycle technologies as a proxy to find the cost per g/mi reduction was $34. [26] EPA then made a second increment of off-cycle credits available in the model and increased the price premium from 30 percent to 60 percent. EPA did not offer any justification for using projections of the cost to comply with the "Perfect Trading" sensitivity run or for the 60% cost premium and the rapidly increasing use of off-cycle credits for compliance demonstrates that off-cycle credits are more cost-effective than test cycle technologies, not less. For additional information see Joint NGO 2020 Reconsideration Petition, pages 50-56, and UCS 2020 Reconsideration Petition pages 47-54.

Battery cost: Unlike for the other technologies in the agencies' analysis, the vast majority of costs related to the RPE markup are already included in the base costs that the agencies used from ANL lookup tables. In other words, those lookup tables do not provide "direct manufacturing costs," they provide total costs, including indirect costs. Thus, NHTSA erroneously inflated battery costs by applying the retail price equivalent (RPE) markup to base costs that already include indirect costs. For additional information see UCS Reconsideration Petition, pages 88-90.

C. New technology studies

Roush has released two reports commissioned by CAELP to assess the current state-of-the-art in light-duty engines and powertrains (Roush 2021 LDV)[27] and to assess the cost and effectiveness of 48-volt mild-hybrid systems and Battery electric vehicles (Roush 2021 48v).[28] Roush based their

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[23] California Air Resources Board. Advanced Strong Hybrid and Plug-In Hybrid Engineering Evaluation and Cost Analysis, CARB Agreement 15CAR018, prepared for CARB and California EPA by Munro & Associates, Inc. and Ricardo Strategic Consulting, April 25, 2017.

[24] Hummel, P., Lesne, D., Radlinger, J., Golbaz, C., Langan, C., Takahashi, K., ... & Shaw, L. (2017). UBS Evidence Lab Electric Car Teardown—Disruption Ahead. UBS report, Basel. 10/26/21 7:33:00 PM

[25] Safoutin, M.J. (2018) Predicting Powertrain Costs for Battery Electric Vehicles Based on Industry Trends and Component Teardowns. Proceedings of the 31st International Electric Vehicle Symposium & Exhibition and International Electric Vehicle Technology Conference. Society of Automotive Engineers of Japan, 2018. ISBN: 9781510891579.

[26] EPA used the OMEGA model to estimate the average cost to comply with the previous standards (with a then-projected CO_2 target of 199 grams CO_2 per mile in 2025) under the "Perfect Trading" run (which treats the entire U.S. Fleet as one manufacturer).

[27] Roush report on Gasoline Engine Technologies for Improved Efficiency (Roush 2021 LDV) https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0208-0210

[28] Roush report on 48V and BEV costs (Roush 2021 48V) https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0208-0210

findings on a review of published data, information from major automotive suppliers, and proprietary knowledge of potential product plans. In addition, ANL made a presentation at a 2020 webinar in Europe that supports many of the Roush comments and recommendations (AVL 2020).[29] The following summarizes the new data and findings.

Naturally Aspirated Engine: Roush recommends focusing on Atkinson cycle engines with higher geometric compression ratio, lower bore-to-stroke ratios, and increased cooled EGR dilution, including design improvements for high in-cylinder turbulence, high energy ignition systems, and In-cylinder fuel reforming technologies.

Turbocharged Engines: Future turbocharged engines should increase use of the Miller cycle with a smaller bore to stroke ratio, higher geometric compression ratio, and higher EGR dilution rates, facilitated by combinations of variable geometry turbochargers, electrically assisted turbochargers, design elements for high in-cylinder turbulence, high energy ignition systems, and in-cylinder fuel reforming technologies.

Mild Hybrid: Suppliers are developing 48-volt systems with higher power outputs (20 - 30kW) and more efficient P2, P3, and P4 hybrid architecture, as opposed to the current P0 geometries. Synergies provided by these systems include potential advancements in launch assist, low-speed electric driving, aggressive fuel cutoff, start-stop, torque assist during driver tip-in, and synergistic technologies such as advanced electric boosting solutions, high energy ignition systems, advanced cylinder deactivation, and electric accessories. A 30kW 48V P2 system mated to a low bore-to-stroke ratio miller cycle engine with electrified boost, advanced cylinder deactivation, and cooled EGR can reduce GHG emissions by more than 30% compared to a Turbo1 engine.

Full Hybrid Powertrains: The hybrid system is an energy management tool that can maximize the time spent in the high-efficiency parts of the engine operating map, minimze low load engine operation using the electric drive, minimize operation under the low-speed high torque areas of the engine which are prone to knocking, and effectively support transient torque demand. This will allow optimization of both naturally aspirated and turbocharged engines for a narrow operating range, enabling higher compression ratios and increased EGR dilution while maintaining good drivability. AVL estimates dedicated hybrid engines can achieve 45% efficiency at Lambda = 1.

Negative Valve Overlap (NVO) fuel reforming: In-cylinder fuel reforming by using pilot fuel injection during NVO has shown to significantly improve cooled EGR (cEGR) tolerance, combustion stability, and engine efficiency. Such a system can have wide application in turbocharged and NA engines with minimal hardware requirements. Roush estimates an efficiency improvement in the range of 5 to 10% is possible and low cost.

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[29] AVL Webinar on Passenger Car powertrain 4.x – Fuel Consumption, Emissions, and Cost on June 2, 2020 https://www.avl.com/-/passenger-car-powertrain-4.x-fuel-consumption-emissions-and-cost plus slides are attached to these comments (AVL 2020)

Passive prechamber engine: Prechamber combustion systems are one of the most promising technologies for improving the dilution limit of engines, thereby improving system efficiency. It can also enable extremely fast burn rates increasing the knock tolerance of turbocharged engines, allowing higher compression ratios and the associated efficiency improvements.

high energy ignition systems: High energy volume ignition systems can enable combustion of dilute (cEGR or air diluted) in-cylinder mixtures resulting in a step-change in engine efficiency compared to conventional spark plugs. Such systems can be a drop-in replacement for a spark plug, thereby representing a cost-effective GHG improvement option. Systems such as plasma ignition can support good combustion stability with high amounts of cooled EGR, thereby achieving engine efficiency improvements in the range of 5-10%.

These data and findings are analyzed in detail in Section 1 of the Appendix.

D. Strong hybrid cost and availability

In response to NHTSA's request for comments on its cost estimates for the power-split hybrid (page 316 of the TSD), ICCT is providing cost estimates from FEV's 2010 and 2015 tear-down cost assessments. NHTSA has substantially overestimated the costs of full hybrid vehicles, as:

- eCVT costs are far lower than the CVTL2 costs assumed by NHTSA;
- NHTSA's high-voltage cable cost is more than twice that of both NAS and FEV;
- NHTSA's battery size and cost are overstated, as they do not take into account power density improvements that cut the size and cost of strong hybrid battery packs in half; and
- NHTSA's analysis has $432 for power electronics and thermal management that appear to be already be included in motor/inverter/ generator/regen brake costs for NAS and FEV.

There is no engineering or technical reason to limit application of strong hybrids in the fleet. Powersplit hybrids may have torque limits, but there is no limitation for parallel hybrid systems, whether P0, P1, P2, P3, or P4 architecture, as the engine output is routed separately from the motor output. This is demonstrated by the 2021 Ford F150 pickup truck with a P2 strong hybrid and the upcoming 2022 Toyota Tundra full-size pickup truck with a strong hybrid and a conventional 10-speed automatic.

These findings are analyzed in detail in Section 2 of the Appendix.

E. Atkinson Cycle engine restrictions (HCR0, HCR1, HCR2)

We suppport NHTSA's expansion of the availability of HCR1 engines and for allowing cylinder deactivation to be added to HCR1 (although the efficiency benefit is too low as discussed in

Section B, above). However, the exclusion of HCR2 engines from NHTSA's modeling through 2026 and the remaining restrictions on HCR1/HCR1D engines are not supportable.

HCR2 exclusion: Not only does EPA's proposed rule allow HCR2 technology to be used in their modeling, but comments previously submitted and previous EPA documentation provide extensive justification for HCR technology benefits beyond just HCR1D.[30] Also, both cooled EGR and cylinder deactivation have been in production since 2018.[31] Thus, it is not credible to assume no further advances in HCR technology prior to 2027. Further, the manufacturer claim of "diminishing returns to additional conventional engine technology improvements" is also not credible, given the discussion in the Appendix Section 1 of extensive engine technologies under development that can reduce GHG emissions by over 30%. ICCT certainly supports developing an updated family of HCR engine map models that incorporate many of the technologies discussed in Section 1for future rulemakings. But in the intertim, HCR2 should be allowed in the Final Rule using EPA's engine map for HCR2 developed in the Technical Support Documents for EPA's Proposed and 2017 Final Determination.

HCR application restrictions: NHTSA argued Atkinson Cycle engines (HCR0, HCR1, HCR2) cannot be used on engines with more than 405 horsepower, pickup trucks and vehicles that share engines with pickup trucks, or performance-focused manufacturers "due to their prescribed duty cycle being more demanding and likely not supported by the lower power density found in HCR-based engines."[32] These arguments are backwards and wrong. Engines in pickup trucks and high-performance vehicles are sized and powered to handle higher peak loads and, thus, operate at lower loads relative to their maximum capacity. According to supplemental tables for the 2020 EPA FE Trends report found online, pickups have 18% to 19% higher power to weight than both cars and truck SUVs, which means that pickup trucks and high-performance vehicles will spend more time in Atkinson Cycle operation than lower performance vehicles on both the test cycles and in the real world, not less. Any need for "additional torque reserve" is met by switching to Otto cycle. The one exception is towing, which does impose constant high loads on the engine. However, Strategic Vision data finds that "75 percent of [pickup] truck owners use their truck for towing one time a year or less".[33] The large majority of pickup trucks spend the vast majority of driving at low loads relative to the engine's capability, where Atkinson Cycle engines are very effective. Thus, all restrictions on HCR engines should be removed.

These findings are analyzed in detail in Section 3 of the Appendix.

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[30] For example, Technical Support Documents for EPA's Proposed and 2017 Final Determination, ICCT 2018 Camry study, ICCT 2018 comments pages I-2 to I-12, and ICCT 2019 supplementation comments responding to Toyota comments on ICCT's study of LPM and OMEGA modeling of the 2018 Camry, dated April 2019, Docket #NHTSA-2018-0067-12387

[31] EPA DRIA page 2-12

[32] NHTSA proposed rule, Chapter III.D.1, pages 49661-49662

[33] Berk, B., You Don't Need a Full-Size Pickup Truck, You Need a Cowboy Costume. Thedrive.com, March 13, 2019. https://www.thedrive.com/news/26907/you-dont-need-a-full-size-pickup-truck-you-need-a-cowboy-costume

F. Off-Cycle credit cap revision

NHTSA revised the off-cycle credit caps from 10 g/mi in the SAFE rule to 15 g/mi in the proposed rule for light trucks. This would be fine if off-cycle technologies were treated the same as on-cycle technologies when determining the next incrementally most cost-effective technology to add to a vehicle. However, the model used by NHTSA arbitrarily forces manufacturers to add off-cycle technologies up to the 15 g/mi cap before evaluating the addition of on-cycle technologies. Further, these off-cycle credit costs were estimated in 2012 with little justification and have a very high cost of $76.31/g/mi in 2026,[34] or over $380 for the 5 g/mi increase in the cap. As many on-cycle technologies can reduce CO_2 emissions at far less cost, arbitrarily forcing high cost off-cycle credits on manufacturers increases the cost of complying with the proposed rule by well over $200 per vehicle. This should be fixed in the final rule by (1) revising off-cycle credit costs to a reasonable level and (2) revising the model to treat off-cycle technologies the same as on-cycle technologies, i.e. both should be evaluated for inclusion based on their relative cost-effectiveness. If NHTSA lacks the time and resources to fix this in the final rule, NHTSA should at least acknowledge that this overstates the costs of complying with the standards and commit to fixing it in future rulemaking.

G. Standard stringency

While the proposed standards, Alternative 2, are an improvement over the existing SAFE requirements, for a variety of technical reasons this level is not the “maximum feasible” level and more stringent standards should be adopted by NHTSA for 2026.

There is little or no increase in conventional technology penetration in 2030 from the SAFE framework to the Alternative 2 proposal. Technology penetration for stand-alone DEAC+ADEAD engines dropped by 3% (although all DEAC increased by 2.3%), all turbocharged engines dropped by 4.2%, and all HCR engineds increased by 5.1%. Almost all of the mpg improvements from the SAFE scenario to the proposed rule are due to increases in the penetration of hybrids, PHEVs, and BEVs. But over 20% of the non-BEV vehicles have only basic engine technologies, including DEAC, and over 8% do not even have DEAC.

ICCT strongly urges NHTSA to adopt Alternative 3 for the final rule, as Alternative 2 does not promote additional engine technology, there are many technology efficiency improvements and cost reductions that have not been incorporated into NHTSA’s modeling (as detailed in the technology sections of ICCT’s comments), the handling of off-cycle credits artificially increases the total cost of compliance by at least $200, and HCR2 technology was not allowed by NHTSA. It is

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[34] NHTSA TSD page 391, “Similar to off-cycle technology costs, DOT used the cost estimates from EPA Proposed Determination TSD for A/C efficiency technologies that relied on the 2012 rulemaking TSD.” Reference Joint NHTSA and EPA 2012 TSD, Chapter 5.1. Also, Table 3-139 on page 392.

clear that additional technology can easily be added to the fleet by 2026 that is more effective and lower cost than modelled in the proposed rule.

Finally, President Biden has outlined a target of 50% electric vehicle sales share by 2030. The proposed CAFE standards may not ensure even the modeled 14.4% market share of electric vehicle, as conventional technology could be implemented at much higher rates than modeled for the proposed rule instead of increasing electric vehicle share to 14.4%. Without the additional stringency of Alternative 3, the standards for years 2027-2030 will have to be that much more ambitious in order to meet the target set by the President and achieve fuel consumption reductions that are clearly feasible and consistent with NHTSA's statutory mandate.

These findings are analyzed in detail in Section 4 of the Appendix.

H. International Comparison

A zero-emission transition of the transportation sector is key to support the achievement of clean air and the climate commitment of the United States. While other major economies (e.g., Europe, China) have been acting on that crucial realization by taking steps to facilitate a transition to electric vehicles, the United States has lagged. That represents not only a setback for the clean air and climate but also a looming crisis for the American manufacturing economy. Since 2010 the U.S. share of global EV production has fallen, from 20% to 18%, and without intervention that trend will continue: a mere 15% of the $340 billion total investment global automakers have planned in EV manufacturing is presently destined for the United States. Strengthening the 2026 standards beyond Alternative 2 would allow the United States to close some of this gap, help the US compete globally on both conventional vehicle technology and electric vehicles, and set the stage for more ambitious post-2026 standards. Therefore, **ICCT strongly supports adoption of Alterntive 3 standards for MY 2026 in the final rule**.

These findings are analyzed in detail in Section 5 of the Appendix.

I. Modeling issues that underestimate the benefit of potential fuel economy regulation

NHTSA is undercounting the benefits of the proposed standards in a variety of ways. NHTSA's assumptions about vehicle price elasticity in modeling sales, modeling of sales shares between cars and light-trucks, assumption of rebound effect, and assumption of post-Covid VMT all have a systematic impact of undercounting potential fuel savings benefits of the potential standards, and thus NHTSA is consistently overestimating the increases in vehicle costs necessary to meet the maximum feasible reduction in fuel consumption from new motor vehicles.

In modeling the sales response, NHTSA assumes a price elasticity to be -1. In a recent report published by RTI (Jacobsen and Beach, 2021) , the authors conduct a literature review of recent papers on the aggregate own price elasticity. They found that studies published in the last decades suggest a price elasticity from -0.37 to -0.78. We suggest NHTSA to put more weight on recent studies since they better reflect the status quos of current vehicle consumers. NHTSA should put more weight on these recent studies, which suggest an aggregate price elasticity ranging from -0.37 to -0.78. **We recommend that NHTSA use a price elasticity around -0.5 instead of NHTSA's assumption of -1.**

The model presented in TSD Equation 4-4 on car VS light truck market share can be further improved to generate a more accurate fleet composition. NHTSA modeling incorrectly assumes that consumers do not value fuel economy and appears to suggest that as fuel economy of both passenger cars and light-trucks improves, the favorability of light-trucks increases in the mind of consumers. We suggest using a simplified discrete choice model that takes into accout fuel economy and performance in addition to vehicle price to predict market share at the segment level for a more accurate result.

In the new rulemaking, NHTSA decreased the rebound effect used in calculation from 20% to 15%. A rebound effect of 15% is too high, especially when applied to the future vehicle fleets. In TSD 4.3.3, NHTSA admitted that some recently published studies suggest that the rebound effect is likely in the range from 5-15 percent, but older studies tend to center around 15%. However, we believe a 5-10% range from recent studies is more reliable and appropriate. We suggest NHTSA to adopt 10% as the upper limit for the rebound effect parameter.

In TSD 4.3.5, NHTSA adjusted the forecast of future VMT, accounting for COVID-19 impact. NHTSA has assumed a 13% average reduction from 2019 in the 2020 light-duty VMT, which is used in the FHWA forecasting model to project future VMT. We believe the COVID adjustment in the current model under-predicts the VMT of the future fleet. We suggest NHTSA discount the impact of the 2020 VMT on future VMT projections.

These issues are discussed in more detail in section 6-10 of the appendix to these comments.

Appendix: Detailed Comments

1. New technology studies

Roush has released two reports commissioned by CAELP to assess the current state-of-the-art in light-duty engines and powertrains (Roush 2021 LDV)[35] and to assess the cost and effectiveness of 48-volt mild-hybrid systems and Battery electric vehicles (Roush 2021 48v).[36] Statements from Roush's executive summaries are copied, below. In addition, ANL made a presentation at a 2020 webinar in Europe that supports many of the Roush comments and recommendations (AVL 2020).[37] References to additional information in the Roush reports and AVL webinar are included below each of the following summaries.

Roush's recommended near-term areas of focus (2025) are as follows:

Naturally Aspirated Engine: "Based on a review of published data, information from major automotive suppliers, and proprietary knowledge of potential product plans, Roush recommends that EPA focus on Atkinson cycle engines with higher geometric compression ratio, lower bore-to-stroke ratios, and increased cooled EGR dilution. For consistent ignition and acceptable burn rates these engines should have some combination of a) Intake, cylinder head, and piston design improvements for high in-cylinder turbulence; b) High energy ignition systems such as high energy spark plugs, plasma ignition, prechamber ignition, etc.; and c) In-cylinder fuel reforming technologies such as Direct EGR or pilot fuel injection during negative valve overlap." (Roush 2021 LDV page 11). Additional information can be found at:

- Roush 2021 LDV Section 2.3 pages 23-25 on higher compression ratios and higher Miller/Atkinson ratios.
- Roush 2021 LDV Section 4.0 pages 31-35
- AVL 2020 slide 24: BSFC for Lambda=1

Turbocharged Engines: "Future turbocharged engines should contain increased use of the Miller cycle with a smaller bore to stroke ratio, higher geometric compression ratio (with higher Miller ratios), and higher EGR dilution rates. Therefore, Roush recommends that EPA focus on Miller cycle engines with advanced boosting technologies such as variable geometry turbochargers, electrically assisted turbochargers, or a combination of a turbocharger and an electric supercharger. Similar to naturally aspirated engines, for consistent ignition and acceptable burn rates EPA should focus on future turbocharged engines which contain combinations of a) Intake,

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[35] Roush report on Gasoline Engine Technologies for Improved Efficiency (Roush 2021 LDV)

[36] Roush report on 48V and BEV costs (Roush 2021 48V)

[37] AVL Webinar on Passenger Car powertrain 4.x – Fuel Consumption, Emissions, and Cost on June 2, 2020 https://www.avl.com/-/passenger-car-powertrain-4.x-fuel-consumption-emissions-and-cost plus slides are attached to these comments (AVL 2020)

cylinder head, and piston design elements for high in-cylinder turbulence; b) High energy ignition systems such as high energy spark plugs, plasma ignition, passive prechamber ignition, etc.; and c) In-cylinder fuel reforming technologies such as Direct EGR or pilot fuel injection during negative valve overlap." (Roush 2021 LDV page 11). Additional information can be found at:

- Roush 2021 LDV Section 2.3 pages 23-25 on higher compression ratios and higher Miller/Atkinson ratios.
- Roush 2021 LDV Section 5.0 pages 36-38
- Roush 2021 LDV Section 9.0 pages 48-49
- AVL 2020 slide 24: BSFC for Lambda=1
- AVL 2020 slide 27: E-Turbocharger waste heat recovery
- AVL 2020 slide 62: WLTP % CO2 reduction and slide 63: cost per % FC reduction

Mild Hybrid: "Suppliers are developing 48-volt systems with higher power outputs (20 - 30kW). EPA should focus on the integration of such higher power 48-volt mild hybrid systems to evaluate potential advancements in launch assist, low-speed electric driving, aggressive fuel cutoff, start-stop, and torque assist during driver tip-in. In addition, these higher power ISG systems should be applied to demonstrate further advancements in synergistic technologies such as advanced electric boosting solutions, high energy ignition systems, advanced cylinder deactivation (dampen torsional vibrations), electric accessories (HVAC compressor), and an electrically heated catalyst. The use of heated catalysts will enable fuel economy to be optimized without concern of low catalyst temperatures which may result from aggressive start-stop strategies. Applications of the 48V motor-generator capability should be evaluated in P2, P3, or P4 configurations, opposed to the current P0 geometries." (Roush 2021 LDV page 11).
"Roush believes that in the 2021-2030 time frame, higher power 48-volt systems (in P2, P3, and P4 configurations) along with complementary fuel-saving technologies enabled by the high power output of the 48-volt architecture will play an important role in increasing the fuel economy of light-duty vehicles. Such technologies or synergies have not been considered by the EPA or ICCT or the SAFE analysis." (Roush 2021 48V page 9).
Additional information can be found at:

- Roush 2021 LDV Section 6.0 pages 38-40
- Roush 2021 48V Section 1.0 pages 11-23
- AVL 2020 slide 62: WLTP % CO2 reduction and slide 63: cost per % FC reduction

Full Hybrid Powertrains: "The torque provided by the electric motor partially decouples engine output from the driver pedal. This effectively makes the hybrid system an energy management tool that can optimize engine speed-load demands to maximize the time spent in the high-efficiency parts of the engine operating map. Accordingly, low load engine operation is minimized by using the electric drive. EPA should focus on the expanded application of energy management capabilities in full hybrid powertrains to also minimize operation under the low-speed high torque areas of the engine which are prone to knocking by torque augmentation with the electric motor. The instantaneous torque capability of the electric motor can effectively support transient torque demand. This will allow both naturally aspirated and turbocharged engines that are part of a hybrid powertrain to be optimized for a narrow operating range incorporating higher compression ratios and increased EGR dilution (maintaining stoichiometric operation), thereby prioritizing efficiency over peak torque at low engine speeds and transient response, while maintaining good drivability." (Roush 2021 LDV page 12). Additional information can be found at:

- Roush 2021 LDV Section 7.0 pages 41-44
- AVL 2020 slide 24: BSFC for Lambda=1
- AVL 2020 slides 25-26: Dedicated Hybrid Engine Efficiency Roadmaps (45% Lambda=1, 51% ideal)
- AVL 2020 slides 35-42: WLTP CO2 reduction potential of various hybrid configurations
- AVL 2020 slide 43: Relative comparison of attributes for three powertrain architectures
- AVL 2020 slide 62: WLTP % CO2 reduction and slide 63: cost per % FC reduction

Roush also made several project recommendations, with estimated GHG reductions:

Future Pickup /Full-Size SUV GHG Reduction: "Two powertrain configurations are recommended for study and could support future rulemaking. The first option synergistically combines available technologies (without a major redesign of the underlying engine architecture) to give maximum fuel economy benefit for a relatively low cost, hence high effectiveness. It combines a naturally aspirated DI engine with advanced cylinder deactivation and a 30kW 48V P2 mild hybrid system. The 48V hybrid system is used to actively smooth out crankshaft torque pulsations to enable aggressive cylinder deactivation strategies (advanced deac – like the Tula Skipfire System). Such a system will also enable start-stop, electric creep, regen braking, slow-speed electric driving, and a heated catalyst. Depending on system integration factors Roush estimates a reduction in GHG emissions of 20% or more, compared to a baseline naturally aspirated direct-injection V8." (Roush 2021 LDV page 13). Additional information can be found at:

- Roush 2021 LDV Section 13.1 page 65

Compact SUV GHG Reduction: "A 30kW 48-volt P2 system mated to a low bore-to-stroke ratio miller cycle engine with electrified boosting, advanced cylinder deactivation, cooled EGR and a heated catalyst can provide a fuel economy benefit close to a full high voltage hybrid powertrain at a much lower cost. The 48V electric motor can supplement the engine torque under low- speed high load conditions, thereby avoiding this knock-prone area of the engine map. Also, the use of an advanced boosting system, combining a turbocharger and a 48V electric supercharger, will reduce engine backpressure (larger turbine) and improve scavenging, reduce combustion residuals, and reduce the propensity for knock. This combination enables the use of a higher compression ratio, thereby increasing engine efficiency. A combination of a high-energy ignition system (high energy spark plug/ plasma ignition) and fuel reforming by pilot fuel injection during NVO can be used to increase cEGR tolerance at low loads. The initial part of such a project should include engine and combustion modeling, followed by prototype engine testing. The overall GHG reduction potential will require modeling and optimization of engine design, calibration parameters, and boosting system sizing and control. Roush estimates a reduction in GHG emissions exceeding 30% is possible compared to a level 1 (NHTSA) turbocharged engine.” (Roush 2021 LDV page 14). Additional information can be found at:

- Roush 2021 LDV Section 2.3 pages 23-25 on higher compression ratios and higher Miller/Atkinson ratios.
- Roush 2021 LDV Sections 2.4 and 2.5 pages 26-28 on low bore-to-stroke ratio benefits
- Roush 2021 LDV Section 13.2 page 66

Effect of Negative Valve Overlap (NVO) fuel reforming on EGR tolerance on an engine: “In-cylinder fuel reforming by using pilot fuel injection during NVO has shown to significantly improve cooled EGR (cEGR) tolerance, combustion stability, and engine efficiency. Such a system can have wide application in turbocharged and NA engines across different vehicle segments with minimal hardware requirements. Depending on the base engine, Roush estimates an efficiency improvement, and the corresponding reduction in GHG emissions, in the range of 5 to 10% is possible and low cost, therefore correspondingly high effectiveness.” (Roush 2021 LDV page 14). Additional information can be found at:

- Roush 2021 LDV Section 10.0 pages 50-52
- Roush 2021 LDV Section 13.3 page 66

Benchmarking a production passive prechamber engine for knock resistance and EGR tolerance: “Prechamber combustion systems are one of the most promising technologies for improving the dilution limit of engines, thereby improving system efficiency. It can also enable extremely fast burn rates increasing the knock tolerance of turbocharged engines, allowing higher compression ratios and the associated efficiency improvements. The Maserati Nettuno engine in the 2021 Maserati MC20 will be the first application of a passive prechamber engine in production. However, the primary objective in the MC20 is high performance. It would be very valuable to study the effect of the system on knock tolerance, burn rates, dilution tolerance (EGR and air), and emissions. The effort should focus on quantifying possible efficiency gains in a non- performance application.” (Roush 2021 LDV pages 14-15). Additional information can be found at:

- Roush 2021 LDV Section 13.4 page 67
- AVL 2021 slides 29, 31, and 33

Evaluation of production-intent high energy ignition systems: “High energy volume ignition systems can enable combustion of dilute (cEGR or air diluted) in-cylinder mixtures resulting in a step-change in engine efficiency compared to conventional spark plugs. Such systems can be a drop-in replacement for a spark plug, thereby representing a cost-effective GHG improvement option. Such systems should be evaluated for maximum efficiency potential, in conventional, 48V mild hybrid, and full HV hybrid applications. Roush estimates that systems such as plasma ignition can support good combustion stability with high amounts of cooled EGR, thereby achieving engine efficiency improvements in the range of 5-10% over a baseline turbocharged DI, dual VVT engine. Microwave ignition systems, on the other hand, have the potential to achieve levels consistent with prechamber ignition systems. This would enable lean-burn engines with low engine-out NOx emissions which can achieve brake thermal efficiency which exceeds 45% in light-duty vehicle applications, compared to a level of 36-38% for a baseline turbocharged DI, dual VVT engine." (Roush 2021 LDV page 15). Additional information can be found at:

- Roush 2021 LDV Section 11.0 pages 53-62
- Roush 2021 LDV Section 13.5 page 67

2. Strong hybrid cost and availability

Cost Estimates

NHTSA's proposed rule TSD Table 3-98 compared powersplit hybrid costs from the CAFE analysis with the 2021 NAS analysis. NHTSA asked for comments on the relative accuracy of the CAFE and NAS cost estimates.

Our response is based upon tear-down cost analyses conducted by FEV in 2012, 2013, and 2015 reports for ICCT. The most recent report, FEV 2015, assessed direct manufacturing costs for P2 strong hybrid high volume production in 2015 EU midsize cars (Table A.1). Unfortunately, this report did not assess powersplit hybrid costs, but earlier 2012 (FEV 2012) and 2013 (FEV 2013) FEV reports[38] assessed both P2 and powersplit costs (Table A.2).

Table A.1 FEV hybrid technology manufacturing costs for 2015 production EU midsize car, assuming 450,000 production volume. (FEV 2015)

	P2 hybrid
ICE power [kW]	110
Electric machine power [kW]	35
Battery capacity [kWh]	1.1
Battery voltage [V]	350
Battery type	Li-ion
Costs*	
Battery	€610
Transmission modifications	€220
ISG, PowerUnit, DC/DC Converter	€980
HV wiring, HCU/VCU modifications, electric A/C	€315
Delete Alternator, Starter, Auxillary drive	(€180)
TOTAL	€1,945

*Values in parentheses are savings, i.e. negative cost

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[38] Kolwich, G. (2012). *Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market (Phase 1)* (BAV 10-449-001). FEV North America, Inc. https://theicct.org/sites/default/files/FEV_LDV%20EU%20Technology%20Cost%20Analysis_Phase1.pdf
Kolwich, G. (2013). *Light-Duty Vehicle Technology Cost Analysis European Vehicle Market Result Summary and Labor Rate Sensitivity Study* (BAV 10-683-001_2B). FEV North America, Inc. https://theicct.org/sites/default/files/Phase_1_2_Summary%20080713B_Trans.pdf

Table A.2 FEV hybrid technology manufacturing costs for a 2010 production EU midsize car (e.g. VW Passat), assuming a production volume of 450,000 units. FEV 2012 Tables E-20 and E-22

	Power-split hybrid	P2 hybrid
Power transmission/clutch system	€434	€214
Integrated electric motor/generator/sensors/controls	€1,084	€482
Battery Subsystem	€982	€982
Electricity power distribution, inverters/converters	€271	€271
Brake, body, climate control systems	€329	€329
Transmission, engine, service battery, alternator*	(€869)	(€197)
TOTAL	€2,230	€2,080

*Values in parenthesis are cost savings

Costs in FEV 2012 for the battery, electric power distribution, inverters/converters, and modifications to brake, body and climate control systems were the same for both P2 and powersplit systems. Powersplit costs were €220 higher for the eCVT system (compared to conventional transmission modifications for P2 systems) and €602 higher for the motor/generators with related controls, with these costs largely offset by €671 savings from eliminating the conventional transmission.

Note the €135 cost reduction for the P2 hybrid system from 2010 to 2015 model year vehicles, reflecting 1.3% annual learning. Such learning should be expected to continue in the future.

Table A.3 adds the FEV 2012 power-split costs from Table E-20 to the comparision of the CAFE analysis and the 2021 NAS analysis in Table 3-98 of the TSD. The NHTSA, NAS, and FEV costs are all direct manufacturering costs, although there are two potential corrections needed to compare the FEV costs to the NHTSA and NAS costs. The FEV costs are expressed in Euros instead of dollars and the exchange rate on October 15, 2021 was 1.16 dollars per Euro. However, this 16% increase in costs expressed in dollars is likely more than offset by the learning factor from the 2012 MY used by FEV to the 2025 MY used for Table 3-98 in the NHTSA TSD.

Some significant observations:

- **eCVT costs are far lower than CVTL2 costs**. FEV separated the cost of eCVT from the savings due to eliminating the conventional transmission. FEV's eCVT costs independent of the electric motors and controls are only €434,[39] far less than the cost of CVTL2 assumed by NHTSA. This reflects the simplicity of the planetary gear system used by the eCVT compared with the belt system used in conventional CVTs. Note that FEV's net

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[39] Cost are from FEV 2012 Table E-20. The Transmission (e-CVT) System cost, Parameter B, includes Electric Motor & Controls Subsystem cost (Parameter B.5) and Transmission – Baseline Credit (Parameter B.8). These costs were subtracted from Parameter B cost to determine the cost of the mechanical planetary gear system without motors and controls. Thus, the e-CVT costs include Case (B.1), Gear Train (B.2), Launch Clutch (B.3), Oil Pump and Filter (B.4), Transmission Cooling (B.6), and OE Transmission Assembly (B.7) system costs.

transmission cost savings of €292 is similar to the NAS 2021 estimated savings of $435, supporting the lower cost of eCVT compared with conventional CVT systems.

- **NHTSA high-voltage cable costs are too high**. NHTSA's cost estimate of $350 is more than twice that of both NAS ($130) and FEV (€155).
- **Battery costs are too high due to oversized battery.**
    - NHTSA's battery cost per kWh is reasonable, but its assumption of a 1.7 kWh battery pack is not. Both NAS and FEV assume a 1.0 kWh battery pack for similar functions in similar vehicles – in fact, FEV 2012 assumes larger motors and generators than either NHTSA or NAS.
    - FEV 2015 estimated substantial reductions in battery cost from FEV 2013, from €982 for a 1.0 kWh battery in 2010 to €610 for a 1.1 kWh battery in 2015.
    - Hybrid battery pack size is driven by the amount of available power, not energy. Until very recently, hybrids have used Li-ion batteries designed primarily for BEVs or in the case of Toyota have continued to use NiMH batteries. These batteries have relatively poor power to energy characteristics and, thus, they must be oversized from an energy point of view in order to supply the needed power for acceleration assist and regenerative braking. For example, NHTSA implicitly assumes a power/energy (kW/kWh) of about 22 (37 kW/1.7 kWh) for its powersplit batterey pack. A new generation of batteries are now available with far higher power to energy ratios, which will allow much smaller batteries to provide the same amount of power. For example, the company A123 Systems has developed a Lithium Iron Phosphate (LFP) battery optimized for higher power density,[40] with a power to energy ratio of over 40 kW/kWh. This allows a peak power of 37 kW at a capacity of only about 0.93 kWh or, for the NAS assumption of 28 kW, the pack size would be about 0.70 kWh. Mahle Powertrain announced a new 48 V hybrid battery in November 2019 using Lithium Titanate (LTO) chemistry to boost power output.[41] Their new battery also achieves a power to energy ratio of 40 kW/kWh.
    - In addition, LFP does not use any cobalt or nickel and does not need active cooling for most applications due to very low impedance, all further reducing cost.

- **General agreement on motor+inverter+generator+regen brake costs.** FEV did not separate motor and generator cost, but FEV's total cost of €1,177 (including €172 for regenerative braking and a €79 credit for deletion of conventional alternator) is quite similar to the CAFE net cost of $1,111 and the NAS net cost of $1,120.
    - However, the CAFE analysis has **$432 for power electronics and thermal management** that appear to be already be included in the motor/inverter/ generator/regen brake costs for NAS and FEV

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[40] A123 Systems. (2016). *48V Lithium-ion Battery—8Ah UltraPhosphate™ Technology*. http://www.a123systems.com/wp-content/uploads/48V-Battery-Flier_2016.pdf

[41] MAHLE GmbH. (2019). *New 48-volt battery boosts mild-hybrid performance*. https://www.mahle.com/en/news-and-press/press-releases/new-48-volt-battery-boosts-mild-hybrid-performance-73216

Table A.3 Comparison of power-split hybrid components included in CAFE Model Analysis, 2021 NAS Study, and 2012/2013 FEV study for mid-size car. CAFE and NAS costs are DMC in 2025. FEV costs are DMC in 2012.

Component	CAFE Analysis	CAFE net cost	2021 NAS	NAS net cost	2012/13 FEV	FEV net cost
ICE Engine	eHCR	$178	Base	0	Base	(€61)
eTransmission	AT6 to eCVT	$292	AT8 to eCVT	($435)	eCVT delete AT6	€434
Delete transmission						(€726)
Motor + Inverter	73 kW	$732	~74 kW	$810	78 kW	€1,177*
Generator + regen brake	37 kW	$379	~28 kW	$310	55 kW	
Battery + BMU	1.7 kWh	$1,013	1.0 kWh	$880	1.0 kWh	€979
High-voltage cable	Yes	$350	Yes	$130	Yes	€155
DC/DC converter	2 kW	$140	1.1 kW	$90		€116
ECU				$45		
AC mods				$170		€157**
Water pump				$55		
Power electronics & thermal management		$432				
TOTAL		$3,516		$2,055		€2,230

* FEV motor/generator/controls cost includes €172 for regen brake and €79 credit for deletion of conventional alternator

** FEV AC mods cost includes €6 for body modifications

Strong hybrid applicability, or all vehicles can benefit from hybrid technology.

Regenerative braking, acceleration assist, improved load points for engine operation, and electrification of accessories are all benefits to all vehicles. Further, how the hybrid system is used is highly flexibile. If maximum efficiency is desired, the hybrid system can be used to downspeed and downsize the engine. If maximum performance is desired, the engine can be unmodifided so it can produce the same amount of power, while the hybrid system provides additional boost on demand for even higher performance. Electric motors are particularly useful for towing and hauling high loads, as they can deliver their full torque at zero rpm to help launch the vehicle from a stop, which is particularly hard on conventional transmissions. Some examples of hybrid applicatons:

- When the Porsche 918 plug-in hybrid was first launched in 2015, it was arguably the fastest production car in the world. It boosted 887 combined horsepower, 608 from the ICE and 286 from two electric motors, with a top speed of 211 mph.
- One of the first 48V hybrids was the 2019 Dodge Ram 1500 pickup truck. The P0 mild hybrid system, dubbed eTorque, was offered with both the 3.6L V6 and 5.7L V8 engines.
- The 2021 Ford F150 pickup truck pairs a P2 parallel hybrid with a 47 kW motor with its 3.6L twin-turbo engine.

This last example may reflect a torque limitation with the planetary gear system used in the powersplit hybrid system. ICCT is not aware of any research on torque limits with powersplit systems and there may not be any. However, the largest vehicle offered by Toyota with its powersplit hybrid is the Toyota Highlander SUV and the upcoming hybrid system on the 2022 Toyota Tundra full-size pickup truck appears to maintain the conventional 10-speed automatic, instead of using a planetary gear system.[42] However, even if there is a powersplit torque limitation, a similar limitation does not exist for parallel hybrid systems, whether P0, P1, P2, P3, or P4 architecture. This is because for any parallel hybrid system, the engine output can always be routed through the transmission independent of the motor, as demonstrated by the parallel strong hybrid systems on the F150 and Tundra full-size pickup trucks.

3. Atkinson Cycle engine restrictions (HCR0, HCR1, HCR2)

We suppport NHTSA's expansion of the availability of HCR1 engines (although the remaining restrictions are still unreasonable as discussed below) and for allowing cylinder deactivation to be added to HCR1 (although the efficiency benefit is too low as discussed in Section B, above). However, the exclusion of HCR2 engines from NHTSA's modeling through 2026 is not supportable.

Exclusion of HCR2 engines

While EPA's proposed rule allowed HCR2 technology to be used in their modeling for some segments of the fleet, NHTSA's proposed rule still continues to ignore HCR2 engines. NHTSA states in the proposed rule:

> "We are currently developing an updated family of HCR engine map models that will include cEGR, cylinder deactivation and a combination thereof. The new engine map models will closely align with the baseline assumptions used in the other IAV-based HCR engine map models used for the agency's analysis. The updated engine map models will likely not be available for the final rule associated with this proposal because of engine map model testing and validation requirements but will be available for future CAFE analyses. We believe the timing for including the new engine map models is reasonable, because a manufacturer that could apply this technology in response to CAFE standards is likely not do so before MY 2026, as the application of this technology will require an engine redesign. We also believe this is reasonable given manufacturer's statements that there are diminishing returns to additional conventional engine technology improvements considering vehicle electrification commitments."[43]

Comments previously submitted and previous EPA documentation provide extensive justification for HCR technology benefits beyond just HCR1D. For example:

Technical Support Documents for EPA's Proposed and 2017 Final Determination
ICCT 2018 Camry study
ICCT 2018 comments, pages I-2 to I-12
ICCT 2019 supplementation comments[44]

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[42] *https://www.cnet.com/roadshow/news/2022-toyota-tundra-first-drive-review/*

[43] NHTSA proposed rule page 49665

[44] Supplemental Comment from the International Council on Clean Transportation responding to Toyota comments on ICCT's study of LPM and OMEGA modeling of the 2018 Camry, dated April 2019, Docket #NHTSA-2018-0067-12387 https://www.regulations.gov/comment/NHTSA-2018-0067-12387 , #NHTSA-2018-0067-12388 https://www.regulations.gov/comment/NHTSA-2018-0067-12388 (ICCT 2019 comments)

In addition to these extensive comments on the feasibility and benefits of HCR2, both cooled EGR and cylinder deactivation have been in production for several years. For example, in the interagency review documents for the SAFE rulemaking, EPA observed:

> "There are Atkinson engine vehicles on the road today (2018 Camry and Corolla with cooled EGR and the 2019 Mazda CX5 and Mazda6 with cylinder deac) that use high geometric compression ratio Atkinson cycle technology that is improved from the first generation, MY2012 vintage "HCR1" technology. While it is true that no production vehicle has both cooled EGR and cylinder deac, as the EPA "HCR2" engine did, nonetheless, these existing engines demonstrate better efficiency than estimated by EPA. Therefore, it would be appropriate to continue to use EPA's cooled EGR + deac engine map to represent "HCR2" engines."[45]

Cylinder deactivation has also been added to the Atkinson Cycle engine in the 2019 Mazda 3 and Toyota has applied its range of "Dynamic Force" Atkinson cycle engines with cooled EGR to a broad range of non-HEV passenger cars and crossover vehicles.[46]

Given the applications of both cooled EGR and cylinder deactivation on Atkinson cycle engines in model year 2018, it is not credible to assume no further advances in HCR technology prior to 2027. Further, the manufacturer claim of "diminishing returns to additional conventional engine technology improvements" is also not credible, given the extensive engine technologies under development that can reduce GHG emissions by over 30%, as discussed in Section 1 of the Appendix.

ICCT certainly supports developing an updated family of HCR engine map models that incorporate many of the technologies discussed in Section 1, above, for future rulemakings. But in the intertim, HCR2 should be allowed in the Final Rule using EPA's engine map for HCR2 developed in the Technical Support Documents for EPA's Proposed and 2017 Final Determination.

HCR application restrictions

NHTSA argued Atkinson Cycle engines (HCR0, HCR1, HCR2) cannot be used on engines with more than 405 horsepower, pickup trucks and vehicles that share engines with pickup trucks, or performance-focused manufacturers. For example, the proposed rule states:[47]

> "DOT does not allow vehicles with 405 or more horsepower to adopt HCR engines due to their prescribed duty cycle being more demanding and likely not supported by the lower power density found in HCR-based engines."
>
> "Pickup trucks and vehicles that share engines with pickup trucks are also excluded from receiving HCR engines; the duty cycle for these heavy vehicles, particularly when hauling cargo or towing, are likely unable to take full advantage of Atkinson cycle use, and would ultimately spend the majority of operation as an Otto cycle engine, negating the benefits of HCR technology."

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[45] Docket Entry: E.O. 12866 Review Materials for The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks NPRM, Docket ID EPA-HQ-OAR-2018-0283, File: "EO_12866_Review_EPA_comments_on_the_NPRM_sent_to_OMB,_June_29,_2018" at 82, https://www.regulations.gov/document?D=EPA-HQ-OAR-2018-0283-0453

[46] EPA DRIA page 2-12

[47] NHTSA proposed rule, Chapter III.D.1, pages 49661-49662

These arguments are backwards and wrong. Engines in pickup trucks and high-performance vehicles are sized and powered to handle higher peak loads. This means larger engines that operate at lower loads relative to their maximum capacity on the 2-cycle – and during most real-world driving. According to supplemental tables for the 2020 EPA FE Trends report found online, pickups have 18% to 19% higher power to weight than both cars and truck SUVs (Table 2). Which in turn means that pickup trucks and high-performance vehicles will spend more time in Atkinson Cycle operation than lower performance vehicles on both the test cycles and in the real world, not less.

Table 2. 2019 vehicle weight and horsepower from 2020 EPA FE Trends Report

Vehicle class	Average weight (lb)	Average power (hp)	Hp to weight ratio
Pickup	5085	342.7	0.067
Car (inc. car SUV)	3565	201.2	0.056
Truck SUV	4444	254.6	0.057

As acknowledged by the agencies, these engines have the ability to switch between Otto cycle and Atkinson cycle. Thus, the specific need for "additional torque reserve" is met by switching to Otto cycle. NHTSA's claim that these vehicles "would ultimately spend the majority of operation as an Otto cycle engine" is ludicrous. Given the high output of these engines, the vehicle would have to be driven on a race track to spend most of the time in Otto cycle.

The one exception is towing, which does impose constant high loads on the engine. However, even pickup trucks spend relatively little time towing. Strategic Vision data finds that "75 percent of [pickup] truck owners use their truck for towing one time a year or less".[48] Thus, only 25 percent of pickup trucks tow even occasionally. This means that the large majority of pickup trucks spend the vast majority of driving at low loads relative to the engine's capability, where Atkinson Cycle engines are very effective.

Note that Atkinson Cycle engines have been used on the Toyota Tacoma pickup V6 engine since 2017, illustrating that Atkinson Cycle engines are cost-effective for use on pickups and the claim that an Atkinson Cycle engine that switches to Otto cycle on demand cannot provide the additional torque reserve is not accurate.

The only legitimate concern with Atkinson Cycle engines (and related Miller cycle turbocharged engines) for pickup trucks and high-performance vehicles is compression ratio. The HCR engines evaluated by EPA have very high compression ratios, which can raise combustion temperatures and necessitate a modest reduction in peak power. However, combustion temperatures can be lowered with cooled EGR and any remaining peak performance effect can be handled by modestly

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[48] Berk, B., You Don't Need a Full-Size Pickup Truck, You Need a Cowboy Costume. Thedrive.com, March 13, 2019. https://www.thedrive.com/news/26907/you-dont-need-a-full-size-pickup-truck-you-need-a-cowboy-costume

decreasing compression ratio. Based on a 2014 paper by Speth et al.,[49] the brake efficiency improvement for increasing compression ratio from 13:1 to 14:1 is 0.9%.[50] Modeling with Autonomie found that the fuel-consumption reduction, if performance is maintained, is 1.32 times the brake efficiency improvement. So, increasing the compression ratio from 13:1 to 14:1 would reduce fuel consumption by only 1.19%.

Overall, HCR technology (both Atkinson cycle for naturally aspirated engines and Miller cycle for turbocharged engines) is likely to have higher benefits on pickup trucks and high performance engines, due to the higher power-to-weight of the engines used on these vehicles. Any concerns NHTSA might have with compression ratio can easily be handled by determining the compression ratio reduction needed to maintain performance during Otto Cycle operation and analytically adjusting the HCR0, HCR1, and HCR2 modeling output efficiency for pickup trucks and high-performance vehicles. Thus, all restrictions on HCR engines should be removed.

Further information is contained in previously submitted comments:

Joint NGO 2020 Reconsideration Petition pages 68-73
UCS 2020 Reconsideration Petition, pages 63-68
ICCT 2018 Camry study
ICCT 2018 comments, pages I2-I12

4. Standard stringency

NHTSA requested comments on the the stringency of the standards (*see* page 49603 of the NHTSA NPRM):

> "The proposed amended CAFE standards would increase in stringency from MY 2023 levels by 8 percent per year, for both passenger cars and light trucks over MYs 2024–2026. NHTSA tentatively concludes that this level is maximum feasible for these model years, as discussed in more detail in Section VI, and seeks comment on that conclusion."

While the proposed standards, Alternative 2, are an improvement over the existing SAFE requirements, the following discussion demonstrates that this level is not "maximum feasible" and more stringent standards should be adopted by NHTSA for 2026.

While NHTSA failed to provide any tables of technology penetration rates in their proposal documents, Table A.4 compares the technology penetration rates from the NHTSA model central case runs for the proposed standards (Alt 2) in 2030 versus the 2020 baseline and versus the 2030

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[49] Raymond L. Speth, Eric W. Chow, Robert Malina, Steven R. H. Barrett, John B. Heywood, and William H. Green, "Economic and Environmental Benefits of Higher-Octane Gasoline," Environmental Science & Technology, 2014, 48 (12), 6561-6568 DOI: 10.1021/es405557p. https://pubs.acs.org/doi/ abs/10.1021/es405557p

[50] This is extrapolated from the modeled results, as the benefits of increasing compression ratio decrease as the baseline compression ratio increases. For example, the paper found that increasing the compression ratio from 10.5:1 to 11.5:1 would improve brake efficiency by 1.9%, or more than twice the 0.9% benefit of increasing from 13:1 to 14:1.

SAFE framework standards. Overall, there is little or no increase in conventional technology penetration in 2030 from the SAFE scenario to the proposal: technology penetration for stand-alone DEAC+ADEAD engines dropped by 3% (although all DEAC increased by 2.3%), all turbocharged engines dropped by 4.2%, and all HCR engineds increased by 5.1%.

Almost all of the mpg improvements from the SAFE scenario to the proposed rule are due to increases in the penetration of hybrids (7.2% BISG and 2.5% strong hybrids), PHEVs (5.4%), and BEVs (1.9%). But total hybrid (including PHEV) penetration increased by 15.1% while turbo plus HCR penetration increased by only 0.8%, meaning that few of these added hybrids have turbocharged or HCR engines. Finally, note that only 72.3% of the fleet has turbocharged or HCR engines, plus another 8.7% with DEAC and 2.7% with ADEAC. This means that over 20% of the non-BEV vehicles (non-BEV vehicles are 92.1% of the fleet) have only basic engine technologies, including DEAC, and over 8% do not even have DEAC.

Table A.4 Proposed rule technology penetration comparison for 2020 versus 2030 and for proposed rule versus SAFE framework in 2030 (NHTSA model central case runs)

	2020	2030		Proposal 2030 v 2020	Proposal 2030 v SAFE 2030
		SAFE	Proposal		
DEAC	8.0%	11.0%	8.7%	0.7%	(3.3%)
ADEAC	2.7%	2.4%	2.7%	0	0.3%
All DEAC	13.6%	32.7%	35.0%	21.4%	2.3%
Turbo1	31.3%	26.9%	16.5%	(14.8%)	(10.4%)
All Turbo	33.8%	45.5%	41.3%	7.5%	(4.2%)
HCR1	5.9%	23.4%	23.6%	17.7%	0.2%
HCR1D	0.9%	0.9%	0.9%	0	0
All HCR	9.9%	25.9%	31.0%	21.1%	5.1%
MHEV	1.9%	7.5%	14.7%	12.8%	7.2%
All strong hybrid	2.8%	5.1%	7.6%	4.8%	2.5%
All PHEV	0.5%	1.1%	6.5%	6.0%	5.4%
All BEV	1.9%	5.8%	7.9%	6.0%	1.9%

ICCT strongly urges NHTSA to adopt Alternative 3 for the final rule. NHTSA's proposal adoption of Alternative 2 standards violates NHTSA's statement in the Executive Summary of the NPRM:

> "The California Framework and the clear planning by industry to migrate toward more advanced fuel economy technologies are evidence of the practicability of more stringent standards. Moreover, more stringent CAFE standards will help to encourage industry to continue improving the fuel economy of all vehicles, rather than simply producing

> a few electric vehicles, such that all Americans can benefit from higher fuel economy and save money on fuel." (NHTSA NPRM page 49604)

As demonstrated in Table 3 and the related discussion, Alternative 2 does not promote additional engine technology and, thus, Alternative 2 does not "help to encourage industry to continue improving the fuel economy of all vehices".

Further, as detailed in the technology sections of ICCT's comments, above, there are many technology efficiency improvements and cost reductions that have not been incorporated into NHTSA's modeling, plus how the model handles off-cycle credits artificially increases the total cost of compliance by at least $200 and HCR2 technology was not allowed by NHTSA. Given the essentially zero increase in conventional technology penetration from the SAFE rule to the proposed rule and the overstatement of costs and understatement of benefits in the proposed rule, it is clear that additional technology can easily be added to the fleet by 2026 that is more effective and lower cost than modelled in the proposed rule.

Finally, President Biden has outlined a target of 50% electric vehicle sales share by 2030. The proposed CAFE standards may not ensure even 14.4% market share of electric vehicle (PHEV + BEV) sales by 2030 as modeled by NHTSA, as conventional technology could be implemented at much higher rates than modeled for the proposed rule instead of increasing electric vehicle share to 14.4%. Adoption of Alternative 3 standards will provide additional incentive for vehicle manufacturers to deploy electric drive vehicles beyond the agency's projection. Without the additional stringency of Alternative 3, the standards for years 2027-2030 will have to be that much more ambitious in order to meet the target set by the President and achieve fuel consumption reductions that are clearly feasible and consistent with NHTSA's statutory mandate. We note in the section below that the United States is already falling behind the European Union and China in terms stringency of greenhouse gas regulations as well as deployment of electric vehicles. Strengthening the 2026 standards beyond Alternative 2 would allow the United States to close some of this gap, set stage for more ambitious post-2026 standards, and increase the net benefits of the standards. Therefore, ICCT strongly supports adoption of Alternative 3 in the final rule.

5. International Comparison

Figure 1 and 2 show the progression of global fuel efficiency or CO_2 emission standards in major vehicle markets for passenger cars and light trucks respectively.[51] The recent regulatory proposal in EU includes a new CO2 target value for new vehicles by 2035. From that year onward, manufacturers must ensure a 100% reduction in CO2 for their new passenger car and light commercial vehicle fleets compared to the 2021 standard. In plain language[52], this corresponds to a phase out of new combustion engine light-duty vehicles in Europe by 2035. This proposal, once

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[51] International Council on Clean Transportation, 2021. Global passenger vehicle standards. http://www.theicct.org/info-tools/global-passenger-vehicle-standards (ICCT 2021)

[52] Peter Mock. (2021). The European Commission's fitness program for climate protection sluggards https://theicct.org/blog/staff/european-commission-fitfor55-jul2021

approved, will greatly drive global technology innovation and investment in zero emission transition.

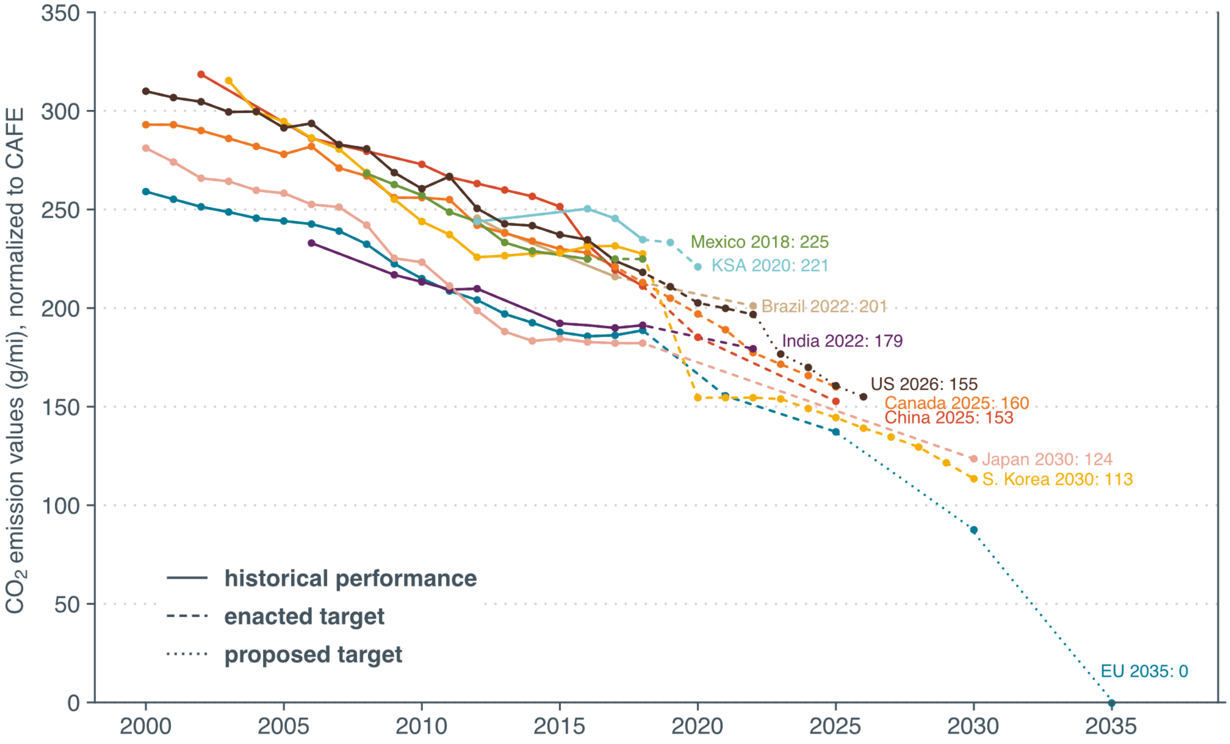

Figure 1 Passenger car efficiency standard with proposed U.S. standards, converted to CO2 emissions (ICCT 2021)

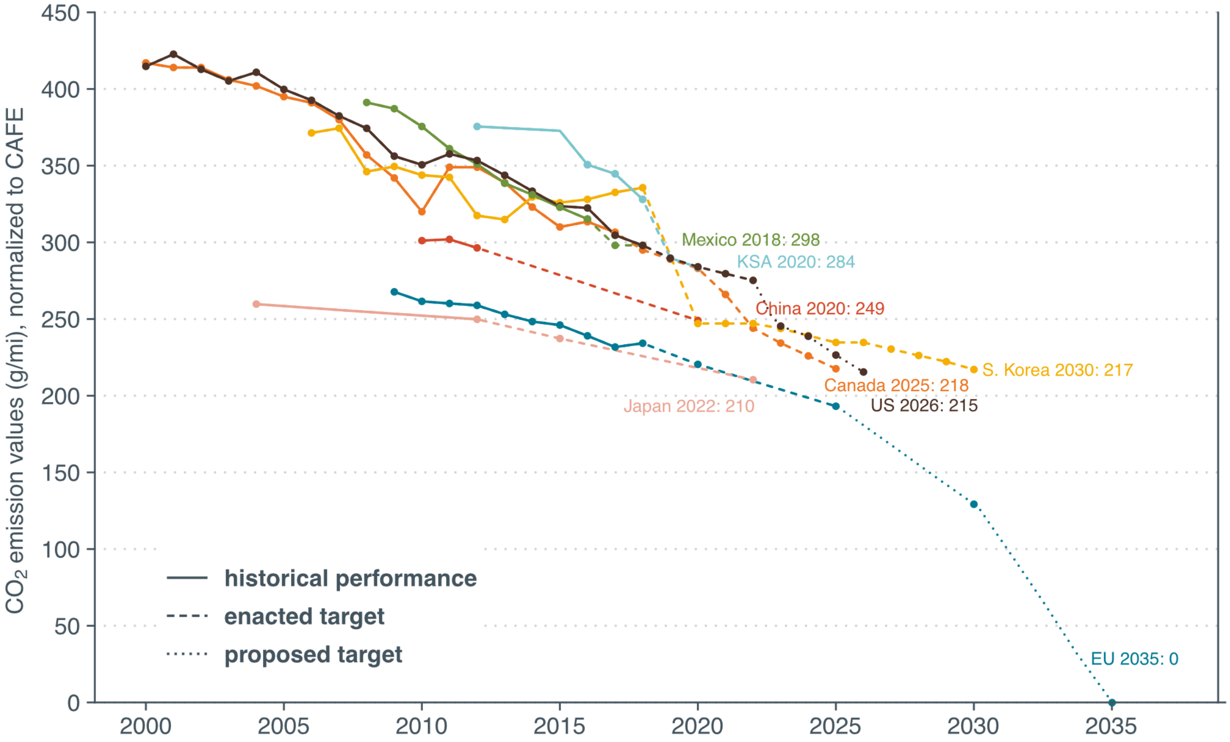

Figure 2 Light truck efficiency standard with proposed U.S. standards, converted to CO2 emissions (ICCT 2021)

As a result, the number of national and sub-national governments committed to fully end the sale or registration of new passenger cars equipped with an internal combustion engine (ICE) keeps growing. The national and sub-national governments listed in the map (Figure 3) made up 12% of the about 54 million global new passenger car sales in 2020.[53]

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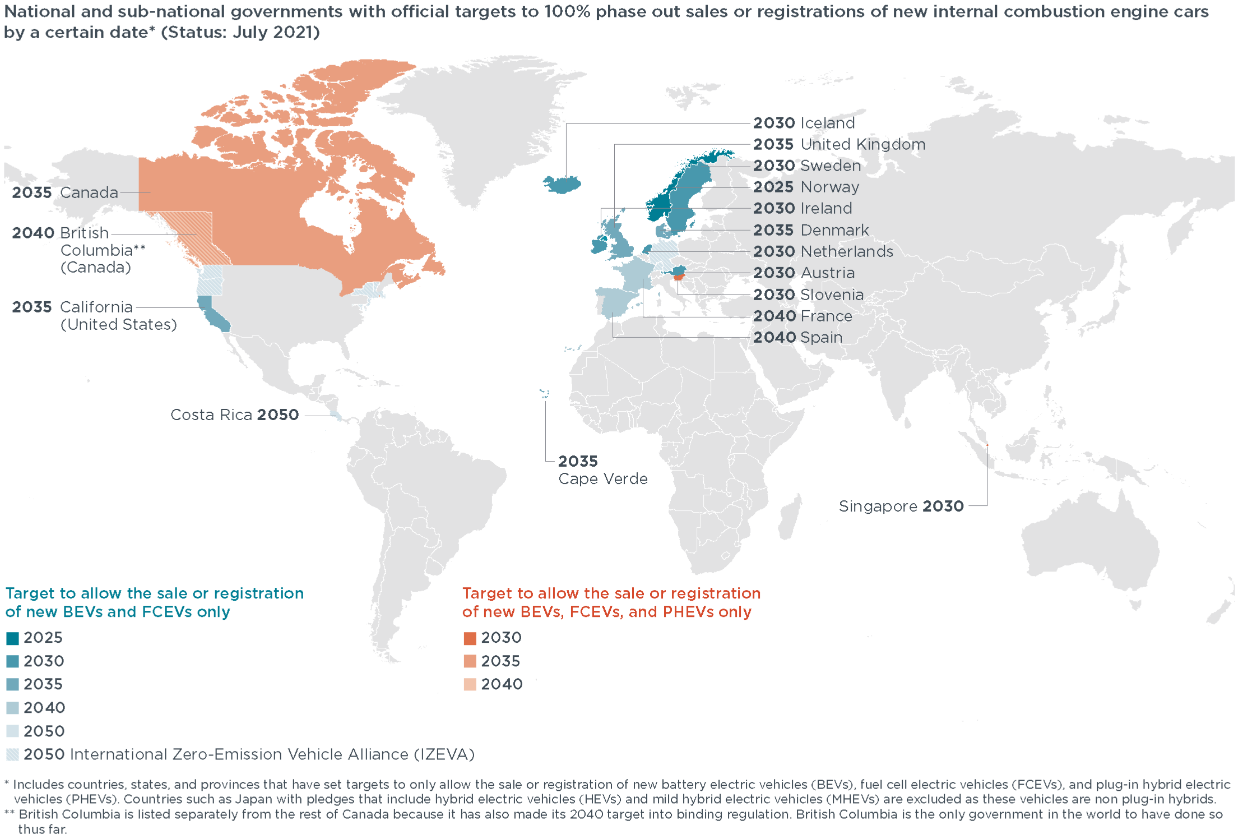
[53] Sandra Wappelhorst. (2021). Global market share of new passenger cars sales in countries planning to put an end to the combustion engine (to be published)



* Includes countries, states, and provinces that have set targets to only allow the sale or registration of new battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and plug-in hybrid electric vehicles (PHEVs). Countries such as Japan with pledges that include hybrid electric vehicles (HEVs) and mild hybrid electric vehicles (MHEVs) are excluded as these vehicles are non plug-in hybrids.
** British Columbia is listed separately from the rest of Canada because it has also made its 2040 target into binding regulation. British Columbia is the only government in the world to have done so thus far.

Figure 3 Government targets to 100% phase out the sale or registration of new ICE cars, status August 2021[54].

*** This map is presented without prejudice as to the status of or sovereignty over any territory, the delimitation of international frontiers and boundaries, and the name of any territory, city, or area.**

Figure 4 compares the passenger car EV market shares in the US, EU, and China. As of July 2021, the EV market share for light-duty vehicle in the US is 3.6% compared with 17% in the EU (passenger cars) and 12.9% in China (passenger cars). The sharp increase in EV sales in EU came about due to 2020-2021 vehicle CO2 standards, whereas the increase in EV sales in China is supported by a combination of vehicle fuel consumption standards and a new energy vehicle mandate.

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[54] Sandra Wappelhorst. (2021). Global market share of new passenger cars sales in countries planning to put an end to the combustion engine https://theicct.org/publications/pvs-global-phase-out-FS-oct21

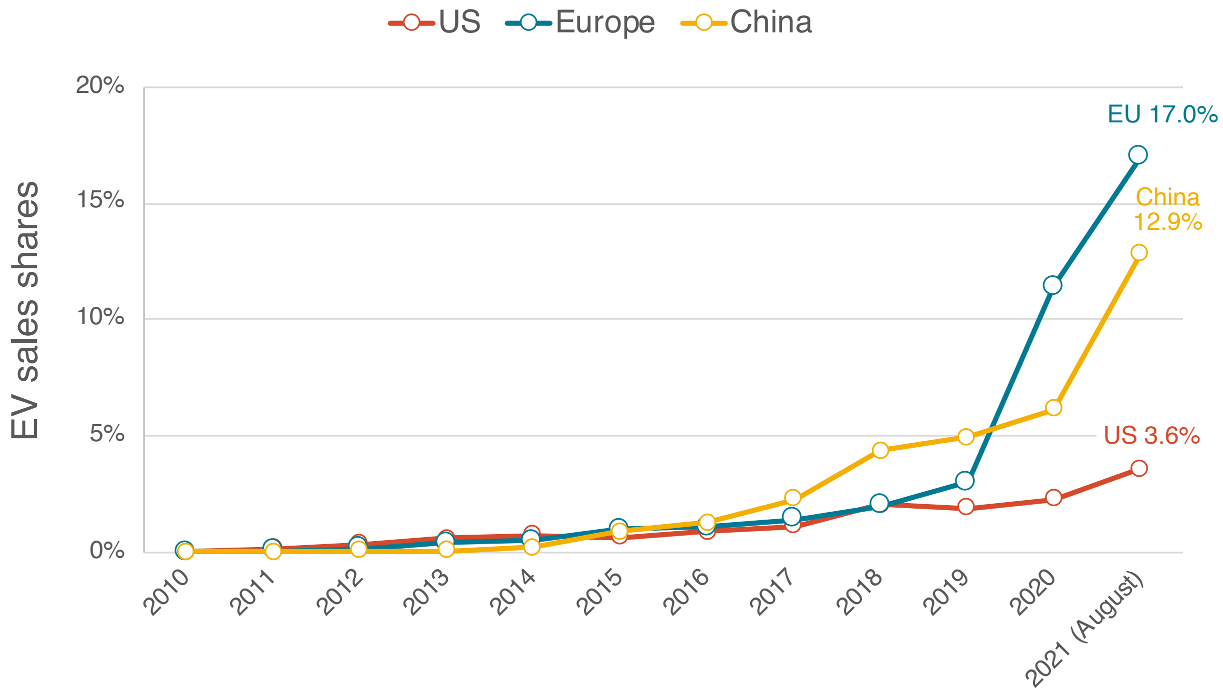

Figure 4 Electric vehicle sales share from 2010 to 2021 (January to August) in the US (light-duty vehicles), EU (passenger cars), and China (passenger cars)

Not only is the US lagging in terms of EV deployment, it is falling behind in terms of manufacturing of electric vehicles as well. From 2017 to 2020, the U.S. share of cumulative global electric vehicle production since 2010 decreased from 20% to 18%, while manufacturing increased in China and the EU, and the US share was held up largely because of a single manufacturer.

Based on automakers' announcement by June 2021, approximately 15% out of $345 billion of global electric vehicle investment were destined for the US, while the majority are going to non-US markets, especially China and Europe. Several industry statements have indicated that markets with zero-emission policy development are prioritized by automakers to deploy low to zero-emission vehicles. In November 2020, Volkswagen said that the EU's stringent emission target had influenced its target sales share of hybrid and EV in the European market, from 40% to 60% by 2030.[55] In addition, Honda Motor Europe's Vice President Tom Gardner commented on the EV deployment pace in the EU "The pace of change in regulation, the market, and consumer behavior in Europe means that the shift towards electrification is happening faster here than anywhere else

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[55] "VW boosts investment in electric and autonomous car technology to $86 billon," Reuters, November 13, 2020, https://www.reuters.com/article/volkswagen-strategy/vw-boosts-investment-in-electric-andautonomous-car-technology-to-86-billon-idUSKBN27T24O

in the world."[56] US domestic production from announced electric vehicle assembly plants would represent up to 10% of global electric vehicle production by 2025. [57]

If the US auto industry is to remain competitive globally then these trends reinforce the need for the United States to achieve the electric vehicle sales outlined by President Biden. Even if NHTSA doesn't directly consider electric vehicles when setting future CAFE standards, NHTSA can still include electric vehicles in other parts of their analyses, such as baseline vehicles, inclusion of the ZEV program in their business as usual scenario, and real world benefits. The strongest possible CAFE standards are needed to help the US compete globally on both conventional vehicle technology and electric vehicles, providing a strong additional rationale for the feasibility of NHTSA increasing the stringency of 2026 fuel efficiency standards to Alternative 3.

6. Assumption of price elasticity in modeling sales response

In modeling the sales response, NHTSA assumes a price elasticity to be -1. NHTSA cited several papers in footnote 576 of section 4.2.1.2 in TSD to back up this assumption. However, those papers appear to be quite old (with publication years ranging from 1990 to 1996) and could be outdated to model current and future situations. For example, with rising household income, consumers should be more inelastic (less sensitive) to price changes compared with two decades ago.

In a recent report published by RTI (Jacobsen and Beach, 2021) , the authors conduct a literature review of recent papers on the aggregate own price elasticity. They found that studies published in the last decades suggest a price elasticity from -0.37 to -0.78. For instance, Leard (2021) use 2014-2015 data and find price elasticity to be –0.37; McAlenden et al. (2016) use a long panel from 1953 to 2013 and conclude a price elasticity to be -0.61. We suggest NHTSA to put more weight on recent studies since they better reflect the status quos of current vehicle consumers.

We suggest a price elasticity around -0.5 instead of NHTSA's assumption of -1. We encourage NHTSA to put more weight on recent studies, which suggest an aggregate price elasticity ranging from -0.37 to -0.78—adopting -0.5 as price elasticity implies a less dramatic sales response from regulation change. Since the price elasticity of vehicle demand is an important parameter at many stages of the modeling process, we suggest a sensitivity analysis that applies a range of values to gauge its impact on the cost-benefit analysis.

NHTSA assumes a universal price elasticity of demand for all types of vehicles. In reality, consumers' responses are quite different among different vehicle segments. For instance, luxury cars and sports cars have larger engine sizes and might incur higher technology costs to comply with the new standard. Still, the increased cost will barely affect the sales of such types of vehicles, given the potential buyers are generally more well-off and are more insensitive to price changes.

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[56] "Honda accelerates its 'electric vision' strategy with new 2022 ambition," Honda European Media Newsroom, October 23, 2019, https://hondanews.eu/eu/en/cars/media/pressreleases/193797/honda-accelerates-itselectric-vision-strategy-with-new-2022-ambition

[57] Bui, A., Slowik, P., & Lutsey, N. (2021). Power play: Evaluating the U.S. position in the global electric vehicle transition. International Council on Clean Transportation. https://theicct.org/publications/us-position-global-ev-jun2021

On the other hand, consumers of pick-up trucks with the same engine size might be very responsive to the added cost. It would be great to model the price elasticity based on vehicle price tiers using historical data. This exercise is also crucial in terms of estimating the effect of fuel economy standards on social equity.

7. Modeling the market share of cars and light truck

The model presented in TSD Equation 4-4 on car VS light truck market share can be further improved to generate a more accurate fleet composition. The regression result shown in Table 4-4 is not convincing, as some of the coefficients do not make much sense. For instance, the result suggests that car buyers do not value horsepower and fuel economy at all: A decrease in horsepower and MPG will make cars relatively more attractive than light trucks. This is contradictory to both common sense and literature. For instance, Greene et al. (2018)[58] conducted a literature review of 52 U.S. focused papers, and the average estimates from these papers show consumers do value better fuel economy and larger horsepower.

We suggest using a simplified discrete choice model to predict market share at the segment level for a more accurate result. Vehicle price is an essential attribute and should not be ignored in the model.

Our comments on the market share model can be summarized in the following three points:

- NHTSA does not give a clear explanation on why it include the lags of vehicle attributes (MY-2) when the same attributes from the immediately preceding year (MY-1) are controlled. By doing so, NHTSA assumes the presence of autocorrelation: the MY-2 fleet, aside from affecting MY-1 fleet, will have a separate channel and extra effect on influencing the current year's market share. NHTSA needs to provide more evidence for such an assumption. Including such lags is unnecessary and might introduce collinearity issue into the regression model and generate a biased estimate.

- Vehicle price is a key variable in predicting the market share, most visible to consumers when making purchasing decisions, but is missing in the model. Without including the price, the model ignores how an increase in vehicle price from complying with stricter fuel economy standards and potential fuel savings co-determine the market share for each vehicle class.

- The share of cars and light trucks should not be modeled and estimated completely independently since they are substitute goods for a section of consumers. When a

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[58] *Greene, David, Anushah Hossain, Julia Hofmann, Gloria Helfand, and Robert Beach. "Consumer Willingness to Pay for Vehicle Attributes: What Do We Know?" Transportation Research Part A: Policy and Practice 118 (December 2018): 258–79.*

> consumer is making vehicle purchasing decisions, both car and light truck are in the candidate pool. The consumer evaluates the utility of each type of vehicle, then selects the one that is relatively more attractive. Therefore, the decision-making processes for buying a car and a light truck are not completely independent.

To address these issues, we suggest NHTSA consider a simple version of the discrete choice model. Understandably, NHTSA has stated in TSD 4.2.1.4 that there are many practical challenges to implementing a discrete choice model at a large scale and at a detailed level. However, some adaptations can be made to fit this study. For instance, although the discrete choice model is often used to simulate market share at trim level, a simplified version can be applied to predict market share at vehicle segment level using recent data, avoiding too much complication but still considering a wealth of vehicle attributes including price, horsepower, curb weight, vehicle size and so forth. The coefficient can be applied to the simulation of the future fleet.

8. Assumption on the rebound effect

In the new rulemaking, NHTSA decreased the rebound effect used in calculation from 20% to 15%. However, we think 15% is still too high, especially when applied to the future vehicle fleets. In TSD 4.3.3, NHTSA admitted that some recently published studies suggest that the rebound effect is likely in the range from 5-15 percent, but older studies tend to center around 15%. However, we believe a 5-10% range from recent studies is more reliable and appropriate. We suggest NHTSA to adopt 10% as the upper limit for the rebound effect parameter.

The rebound effect essentially measures consumers' price elasticity of travel demand. The literature on this topic has been pointing out that the rebound effect will be decreasing over time, so it is more accurate to use a value that lies toward the lower end of the range to model future fleet. First, similar to the previous argument that consumers will become more inelastic to vehicle price over time as a result of increasing disposable income, the rebound effect is also likely to decrease when consumers are more affluent and less sensitive to fuel costs. Such trend is analyzed and discussed by Small and VanDender[59]. Furthermore, NHTSA has argued in the TSD that VMT should not be modeled without constraint since VMT would not grow indefinitely: There is a finite travel need for each individual. VMT in the United States has constantly been growing, and consumers' travel needs are increasingly met. Therefore, driving an additional mile has decreasing marginal utilities, and VMT will be less sensitive to fuel costs. For example, for consumers whose travel needs are completely met, decreasing in fuel prices is unlikely to further increase VMT. Thus, we believe the rebound effect will continue to decrease in the future and is likely to be well under 10% by 2025.

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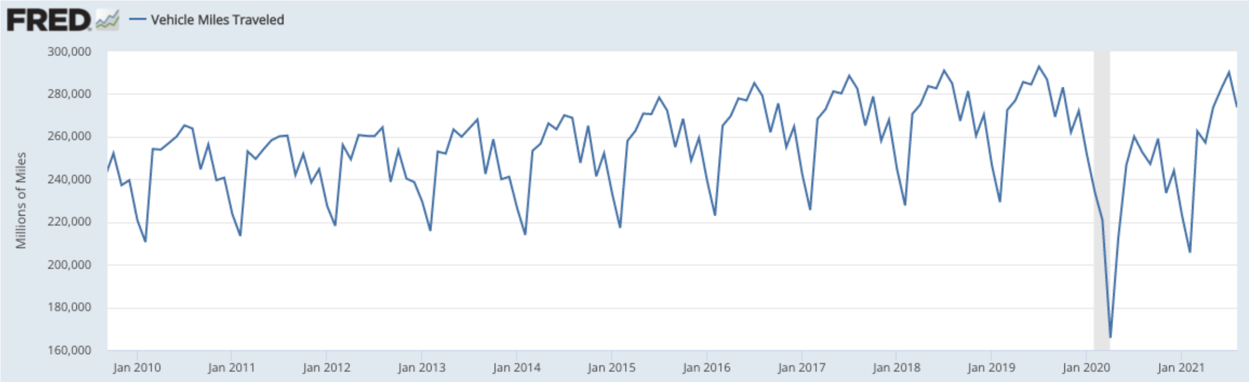
[59] *Small, K. and Van Dender, K., 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect." The Energy Journal, vol. 28, no. 1, pp. 25-51.*

9. Assumption on post-covid VMT

In TSD 4.3.5, NHTSA adjusted the forecast of future VMT, accounting for COVID-19 impact. NHTSA has assumed a 13% average reduction from 2019 in the 2020 light-duty VMT, which is used in the FHWA forecasting model to project future VMT. We believe the COVID adjustment in the current model under-predicts the VMT of the future fleet. We suggest NHTSA discount the impact of the 2020 VMT on future VMT projections.

By adopting an auto-regressive distributed lag (ARDL) specification with error correction, FHWA's model assumes VMT from previous years has a meaningful and long-lasting implication on the VMT of the future fleet. While this is most likely to be true for normal years, where VMT from previous years could reflect the underlying growth in the economic activity and transportation infrastructure, we think the model might overreact to shocks like the pandemic when modeling future VMT. It is true that the transportation sector took a great hit at the start of the first wave of the pandemic. However, according to the recent data from the U.S. Federal Highway Administration (figure is downloaded from FRED Economic Data[60]), the VMT has already recovered to the pre-pandemic level in July 2021.



We believe the COVID adjustment under-predicts the VMT of the future fleet. We suggest NHTSA discount the impact of the 2020 VMT on future VMT projections.

10. Modeling mileage accumulation schedule

NHTSA uses the IHS-Polk dataset to estimate mileage accumulation schedule, which has tracked odometer readings from over 200 million vehicles. We appreciate the effort NHTSA has made to use a panel dataset for a more accurate estimate instead of simple cross-section data such as the National Household Travel Survey.

We suggest some further improvement on the current mileage accumulation schedule to better utilize this comprehensive dataset. In the current model, it seems like NHTSA treats all vehicles of

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[60] *https://fred.stlouisfed.org/series/TRFVOLUSM227NFWA*

the same age as equal and imposes the same VMT, regardless of their model year. The model imposes that the VMT of 5-year-old cars should all be the same, whether the car is an MY 2005 car recorded in 2010 or an MY 2012 car recorded in 2017. Such an assumption is oversimplified, and the current schedule might underestimate the VMT of recently produced cars when they reach an older age. Given the improvement in vehicle technology, the cars produced later can hold up better. Additionally, grouping vehicles by age regardless of the model year might introduce survival bias, as mentioned by NHTSA.

We suggest that NHTSA should model the mileage accumulation schedule based on both MY and age. Using the IHS-Polk data, NHTSA should be able to estimate for each model year, how does the annual driving decline with age, and investigate if there are significant changes in driving schedules of recent vehicles compared with earlier vehicles of the same age.

The suggested correction could better capture recent trends in consumers' driving behavior, generate a more accurate mileage accumulation schedule, which later on could help develop a more precise calculation of fuel savings benefit, pollutant emissions, congestions, and fatalities. We believe the current model underestimates the VMT of the future fleet and therefore underestimates the fuel-saving benefit.