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Vehicle fleet turnover and the future of fuel economy

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Abstract

The real-world impacts of the Trump administration's effort to roll back the Corporate Average Fuel Economy (CAFE) standards for new light-duty vehicles are not obvious, because new vehicles are highly durable and remain in the on-road fleet for many years. We demonstrate that freezing CAFE between 2020–2026, one of the proposals circulated by the Trump administration, will increase fleet fuel consumption and greenhouse gas emissions until 2040 and beyond, because relatively less-efficient vehicles sold during this time would remain in use for potentially decades. We argue for stringent fuel-economy standards for new vehicles, and for placing greater emphasis on the retirement and disposal of the oldest and most inefficient vehicles on our roads. These steps will help to build a fleet that is efficient, low-emission, and adaptable as the automotive industry enters a period of unprecedented technological change.

The Trump administration's move to roll-back the Corporate average fuel economy standards (CAFE) for new vehicles sold in the United States appears perplexing at a time of unprecedented technological change in the global automotive industry. The introduction of new electric vehicle models, developments with self-driving cars, and moves to ban fossil fuel vehicles around the world may give the impression that the transition to sustainable mobility is both imminent and inevitable. Attempting to lower the CAFE standards might therefore seem a moot point, if oil-based fuels are already on the way out. The reality, at least in the United States, is dramatically different. Moderate gasoline prices, changing consumer preferences, and a footprint-based CAFE mechanism that provides automakers the perverse incentive to manufacture larger vehicles [1] have seen consumers flock to pickup trucks and SUVs. Most US consumers are buying vehicles that have the capability, in the words of one comedian, to 'tow the boat I do not have up the mountain I do not live near' [2]. In 2017, 99% of new light-duty vehicles sold in the United States ran on gasoline or diesel [3], of which 45% were classified as light trucks for regulatory purposes (i.e. pickups or SUVs) [4]. Now, with little evidence that mainstream consumers want to buy green vehicles at present, automakers are lobbying intensively to receive relief from the costs of CAFE compliance. Responding to their petitions, the US Environmental Protection Agency (EPA) has moved forward with a plan to roll-back the federal greenhouse gas (GHG) and CAFE standards, circulating an unofficial draft that includes a proposal to hold CAFE constant at the 2020 level of 39 miles per gallon (MPG), equivalent to 31 MPG in real-world driving, from 2020 to 2026 [5]. This proposal is in stark contrast to developments in the European Union, where lawmakers recently voted to reduce automotive GHG emissions by an ambitious 35% below 2021 levels by 2030 [6].

The EPA's written decision to relax the Obama-era CAFE standards recognizes that such a change would lead to relatively less-efficient vehicles being sold [7], but does not acknowledge the lasting environmental impacts that this seemingly minor mid-term change might have as a result of the inertia that exists in the vehicle fleet. Here we demonstrate that such a CAFE freeze would increase fuel consumption and GHG emissions from the US light-duty vehicle fleet for decades to come. Because new vehicles are highly durable, usually remaining on the road for many years, these less fuel-efficient vehicles sold as a result of this policy change will remain in operation out to 2040 and

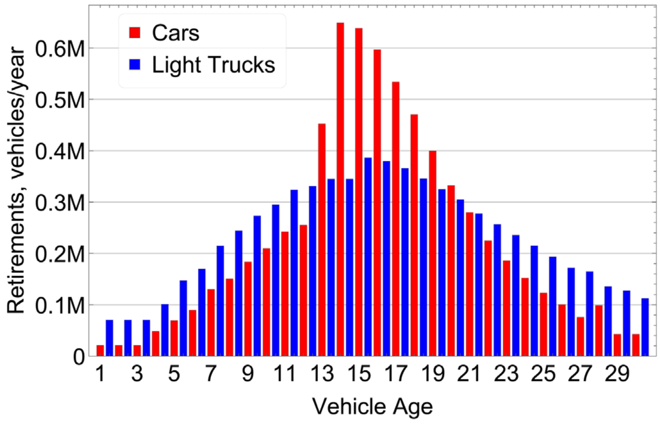


Figure 1. The distribution of vehicle retirement ages in the United States [11].

beyond. We argue that policymakers should set stringent fuel-economy standards over the long-run, and pay increasing attention to the retirement and disposal of the oldest and most inefficient vehicles in the fleet, in order to build a light-duty vehicle fleet for the US that is efficient, low-emission, and adaptable as the world enters period of unprecedented technological change in the automotive industry.

Fleet turnover takes much longer than people expect

The composition of the stock of vehicles driving on our roads today reflects the accumulation of new vehicle sales less vehicle retirements over time. People tend to have a poor intuitive understanding of such processes that involve stocks, flows, and accumulation [8], and therefore the impact that introducing relatively less-efficient vehicles into the fleet, which will remain in use for many years, will have on fleet fuel consumption and GHG emissions into the future. Surveys we have undertaken on both the general public and highly-educated MIT graduate students indicate that people systematically underestimate how long it takes for new vehicles to move through the fleet, and underestimate how long new vehicles last on average (figure 1), which has increased over time with improving new vehicle quality [9]. These misperceptions are likely to lead people to underweight the effect that the vehicles we purchase today will have into the future, and be overly optimistic about how quickly new technologies can diffuse into the on-road vehicle fleet.

To illustrate the dynamics of vehicle fleet turnover, we developed a fleet cohort model [10] that is accurately calibrated to the current patterns of vehicle ownership and use in the US light-duty vehicle fleet, with cohort-specific rates of vehicle retirement and vehicle-miles travelled [11]. We consider how the stock of vehicles on the road evolves following the introduction of a new technology (e.g. electric vehicles) that we assume is so attractive that it immediately achieves 100% of new vehicle sales. This scenario is deliberately extreme, ignoring factors such as current low consumer acceptance of alternative vehicles and the lack of charging infrastructure that could slow adoption. The scenario establishes a lower-bound on the time it takes for the fleet to turn over, assuming that all vehicles remain in the fleet for the term of their useful life. Simulating the evolution of the fleet, we find that it takes 19.6 years for the new technology to account for 90% of the on-road fleet (figure 2), even though the average vehicle lifetime is only 16.6 years (figure 1), because some vehicles remain in use much longer than average, light trucks in particular.

The lasting consequences of a 2020–2026 CAFE freeze

The real-world consequences of a CAFE freeze are not obvious, not only because of these time delays in fleet turnover, but also because of the confusing use of MPG to measure fuel economy in the United States. CAFE regulations are defined in 'unadjusted' MPG, the vehicle fuel economy that can be achieved on a standardized dynamometer driving cycle test, which is unrealistically high compared to real-world driving. The EPA discounts its test results by about 20% on average to calculate the more realistic 'adjusted' MPG that is reported on showroom window stickers [12]. However, taking this adjustment into account, along with credits available for 'off-cycle' technologies such as improved refrigerants, the much-reported Obama-era target of 54.5MPG in 2025 (the fuel economy-equivalent of the GHG emissions standard set by the EPA) is only 39MPG in real-world fuel economy terms. Having multiple MPG numbers referring to the same standard has not only led to much confusion, but also given the perception that CAFE compliance is substantially more challenging than it is in reality.

This situation is further complicated because MPG is a unit of measure that does not scale linearly with

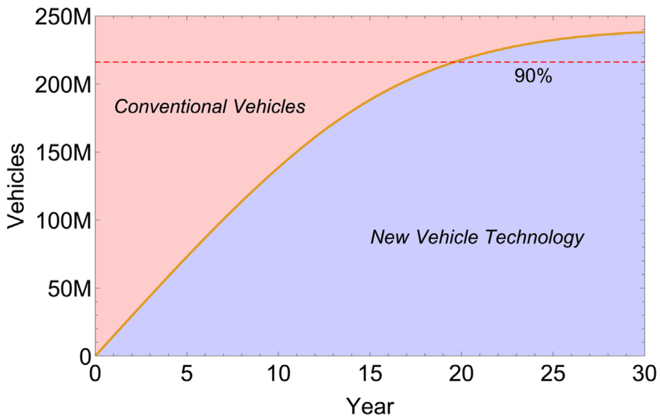


Figure 2. Simulated introduction of a new vehicle technology in the United States.

fuel consumption, with each additional MPG representing successively less fuel consumption. This nonlinearity leads people to systematically underestimate the benefits of replacing the most inefficient vehicles in the fleet [13]. It is widely misunderstood that the shift from a 31MPG vehicle to a 39MPG vehicle (the real-world average difference between the Obama and Trump policies in 2025) would result in a greater reduction in fuel consumption and GHG emissions than a shift from a 39MPG vehicle to a 52MPG vehicle.

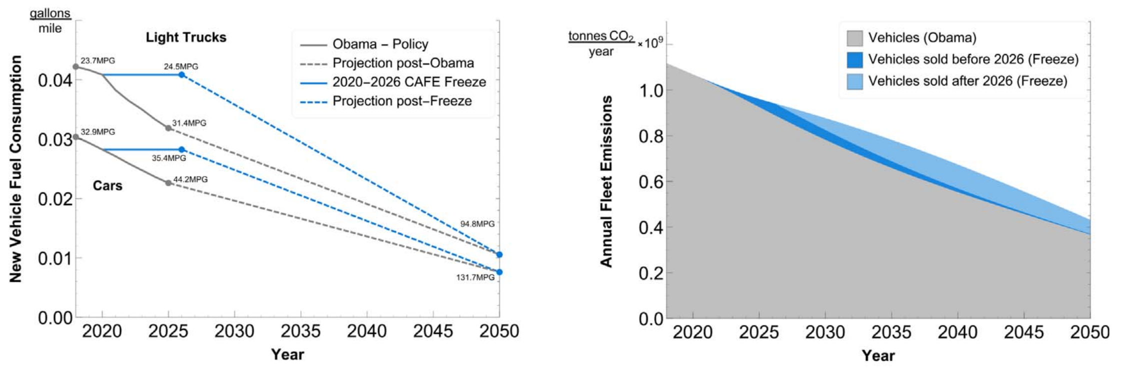
We use the fleet model to simulate the effect of both the Obama-era and 2020–2026 CAFE freeze fuel economy standards on fleet GHG emissions nationally from year 2018 out to year 2050, capturing the effect of the new vehicle sales mix on the composition and environmental impact of the on-road fleet in subsequent years. We assume that allowable GHG emissions from new vehicles are reduced by 75% by 2050, a target that is aggressive but plausible, with linear progress towards that target assumed from the end of the current policy period. These policies are shown in figure 3(a) in gallons per mile, a linear measure of fuel economy that more realistically reflects changes in fuel consumption and tailpipe GHG emissions.

The need to pursue immediate and continued improvements in new vehicle fuel economy is clear if a major reduction in automotive GHG emissions is to be achieved in the 2050 timeframe. Time delays in fleet turnover mean that improvements in the performance of the on-road fleet lag improvements in the performance of the new vehicles being added to the fleet. Conversely, freezing CAFE in the near-term will lead to a significant increase in fleet emissions to 2050 and beyond, because relatively less fuel-efficient vehicles sold between 2020 and 2026 will remain on the road for decades and place us on a trajectory of sustained higher vehicle emissions subsequently. The effect of this policy change is to diminish the fleet emissions reduction achieved between years 2020 and 2050 from 65%, projecting forward the Obama-era policy, to 60%, contributing cumulative emission of an additional 2.5 gigatonnes of CO_2 nationally over this time. An interactive version of our model available at http://bit.ly/future_of_fuel_economy allows the consequences of other near-term fuel economy targets to be rapidly simulated.

The road ahead

The future of mobility is both exciting and uncertain, with emerging technologies such as electric and self-driving vehicles having the potential to make driving fundamentally safer, cheaper, and cleaner. Yet enormous inertia exists in the fleet of more than 250 M vehicles on our roads today, limiting the rate at which the fleet may be transformed to the natural rate of fleet turnover, all else being equal. Even if a future technology is so attractive that drivers sell their gasoline vehicles, the used vehicle market will push back, with used vehicle prices falling until those gasoline vehicles are sufficiently inexpensive that they will be purchased and returned to use. It is therefore critical that the efficiency of conventional gasoline vehicles continues to improve alongside efforts to bring transformational vehicle technologies and business models to market.

Understanding the dynamics of fleet turnover provides guidance on how fuel economy policy may be designed to effectively manage the composition of the on-road fleet. Energy-efficiency is a property that must accumulate in the fleet over time, requiring clear and consistent fuel economy standards for automakers that extend far beyond the current 2025 time-horizon. Making progress in the near-term is particularly important, contrary to the CAFE freeze from 2020–2026 that has been floated by the Trump administration, because lower MPG vehicles consume disproportionately more fuel than higher MPG vehicles. Implementation of a feebate that levies a fee on inefficient vehicles while providing a rebate for efficient vehicles will incentivize consumers to purchase efficient new vehicles, and can be self-financing.



(A) New vehicle fuel economy **(B) Annual fleet GHG emissions**

Figure 3. The lasting consequences of a 2020–2026 CAFE Freeze.

We also advocate for greater attention to the retirement and disposal of the oldest and least-efficient vehicles from the on-road fleet. In the management of complex systems, people tend to focus on inflows such as new vehicle sales more readily than on outflows such as vehicle retirements [14]. Policies such as 'cash for clunkers' vehicle retirement incentives will encourage the replacement of the most polluting vehicles from the fleet, which may be particularly useful at a time when mainstream consumers favor SUVs and light trucks, and do not yet appear ready to purchase hybrid and electric vehicles. A lifecycle perspective is required, because accelerating the turnover of the fleet will lead to an increase in new vehicle sales and associated GHG emissions from vehicle manufacturing in the short-term. However, managing the fleet proactively to comprise mostly new and efficient vehicles with reduced operating emissions, while responding to the potential for changing patterns of vehicle ownership and use, will provide a credible path to the deep de-carbonization of automotive transportation in the coming decades.

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Author contributions

DK conceived of the presented idea. SH and SN developed the model and carried out simulations. DK wrote the manuscript in consultation with SH and SN, and SN developed the interactive simulation.

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