UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

February 27, 2020

EPA-SAB-20-003

The Honorable Andrew R. Wheeler
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Science Advisory Board (SAB) Consideration of the Scientific and Technical Basis of the EPA's Proposed Rule titled *The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks*

Dear Administrator Wheeler:

As part of its statutory duties, the Science Advisory Board (SAB) may provide advice and comment to you on the scientific and technical basis of certain planned EPA actions. The Environmental Research, Development, and Demonstration Authorization Act of 1978 (ERDDAA) requires the agency to make available to the SAB proposed criteria documents, standards, limitations, or regulations provided to any other Federal agency for formal review and comment, together with relevant scientific and technical information on which the proposed action is based. The SAB may then provide advice and comments on the adequacy of the scientific and technical basis of the proposed action.

This letter and enclosed report document the SAB's activities related to the proposed rule "The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks" released on August 24, 2018, and provide advice and comments related to the proposal. Briefly, the SAB notes that although the preliminary regulatory analysis is quite extensive, there are significant weaknesses in the scientific analysis of the proposed rule. The Board's major findings and recommendations to strengthen the science supporting the rule are provided below.[1]

[1] The SAB notes that subsequent to its analysis of the proposed SAFE Vehicles Rule, EPA announced a decision to withdraw the waiver it had previously provided to California for that State's greenhouse gas and zero emission vehicle programs (84 FR 51310 – 51363).

Background

The SAB regularly evaluates major planned actions listed in the Agency's Unified Regulatory Agenda to determine whether formal review and comment on science issues by the SAB is warranted. In April 2019, the SAB Work Group on EPA Planned Actions for SAB Consideration of the Underlying Science evaluated the proposed SAFE Vehicles Rule and indicated that it ranked "high" on the five criteria used by the SAB for determining whether an action merits review: "Involves scientific approaches that are new to the agency," "Addresses area of substantial uncertainties," "Involves major environmental risks," "Relates to emerging environmental issues," and "Exhibits a long-term outlook." During its public meeting on June 5-6, 2019, the Board elected to review the scientific basis of the proposed rule.

Subsequent to the June meeting, a working group of chartered SAB members was formed to carry out the review. It considered the relevant scientific literature as well as comments provided by agency representatives and members of the public on the adequacy of the science informing the proposed rule. Members of this working group then took the lead in SAB deliberations on this topic at a public teleconference held on January 22, 2020 where the chartered Board discussed the advice and comments in this letter and the enclosed report.

SAB advice and comment on the science informing the proposed rule

The preliminary regulatory analysis is quite extensive. Given limited available time, the SAB review focused on several areas where there appear to be significant weaknesses in the analysis supporting the 2018 notice of proposed rulemaking (NPRM). In particular, two of the new modules recently added to the Corporate Average Fuel Economy (CAFE) Model, the sales and scrappage equations, have weaknesses in their theoretical underpinnings, their econometric implementation and, in one case, possibly in the interpretation of their coefficients. Together the weaknesses lead to implausible results regarding the overall size of the vehicle fleet, predicting that an increase in vehicle prices due to regulation will cause the fleet to grow substantially when it would usually be expected to shrink.

The fleet results are a serious concern because the CAFE Model uses a fixed schedule to determine how many miles per year each vehicle is driven. The anomalously large fleet thus causes the model to predict significantly higher aggregate miles driven under the standards adopted in 2012 than under the proposed revision, even before accounting for the impact of fuel efficiency on the cost of driving. This, in turn, drives many of the costs and benefits reported in the analysis. Together with other problems and inconsistencies, the issues are of sufficient magnitude that the estimated net benefits of the proposed revision may be substantially overstated. In fact, the weaknesses are sufficiently important that they could reverse the rankings of the policies being considered. In other words, the standards in the 2012 rule might provide a better outcome for society than the proposed revision.

In the body of the report we provide recommendations for addressing the issues in the sales and scrappage models, as well as for improving the modeling of vehicle miles traveled. In addition, we provide recommendations on several other aspects of the analysis, including: the treatment of state-level policies regarding zero emission vehicles; the analysis and modeling of electric vehicles more broadly; the modeling of willingness to pay by consumers for fuel efficiency improvements; the treatment of the rebound effect; the treatment of flexible compliance options; and the need for a stronger scientific basis for providing incentives for electric vehicles. We also provide longer term recommendations regarding the choice of models to be used for future analyses.

It is important to note that while many of the necessary analytic changes will move the results in favor of the standards in the 2012 rule compared to the proposed revision, some of the changes we recommend could move the results in the opposite direction, providing less support. Other changes will have an unpredictable net effect. A revised analysis would help determine the correct ranking of the alternative policies.

Finally, several aspects of the proposed withdrawal of California's waiver from federal preemption under the Clean Air Act are relevant to the scientific basis of the analysis and should be addressed. First, the baseline used for analysis of the 2012 standards should include California's zero emissions vehicle (ZEV) program, other state ZEV programs, and other policies related to electrification. Second, withdrawal of the waiver, which is a significant change in policy on its own, should be explicitly analyzed in order to clarify its independent impacts on social benefits and costs.

Recommendations for next steps

In conclusion the SAB has determined that the available science summarized in the technical documents reviewed by the SAB has significant weaknesses that should be addressed in the regulatory analysis prepared for the final rule. The SAB has made a number of recommendations that would strengthen the current analysis and has also provided recommendations for future analyses. The SAB offers no comment on the best regulatory decision but notes that the analytic concerns that need to be addressed in the Agency's final analysis have strong policy ramifications. We look forward to your response to our comments on the science supporting this proposed action.

Sincerely,

/s/

Dr. Michael Honeycutt, Chair
Science Advisory Board

Enclosure

NOTICE

This report has been written as part of the activities of the EPA Science Advisory Board (SAB), a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The SAB is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names of commercial products constitute a recommendation for use. Reports of the SAB are posted on the EPA Web site at http://www.epa.gov/sab.

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Acronyms and Abbreviations

ALPHA	EPA Advanced Light-duty Powertrain and Hybrid Analysis tool
Autonomie	DOE Argonne vehicle simulation model
BEV	Battery electric vehicle
CAA	Clean Air Act
CAFE	Corporate average fuel economy
CAFE Model	DOT Volpe Center CAFE model
CARB	California Air Resources Board
CO2e	Carbon dioxide equivalent
CY	Calendar year
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EPCA	Energy Policy and Conservation Act
GHG	Greenhouse gases
GW	Gigawatt
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
MTE	Midterm evaluation
MY	Model year
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of proposed rulemaking
NRC	National Research Council
OMEGA	EPA Optimization Model for Reducing Emissions of Greenhouse Gases
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PRIA	Preliminary regulatory impact analysis
RIA	Regulatory impact analysis
TAR	Technical assessment report
VMT	Vehicle miles traveled
ZEC	Zero emissions credit
ZEV	Zero emission vehicle

1. EXECUTIVE SUMMARY

The EPA Science Advisory Board (SAB) regularly evaluates major planned actions listed in the Agency's Unified Regulatory Agenda to determine whether formal review and comment by the SAB on science issues is warranted. In April 2019 the SAB Work Group on EPA Planned Actions for SAB Consideration of the Underlying Science evaluated the proposed SAFE Vehicles Rule and indicated that it ranked "high" on the five criteria used by the SAB for determining whether an action merits review: "Involves scientific approaches that are new to the agency," "Addresses area of substantial uncertainties," "Involves major environmental risks," "Relates to emerging environmental issues," and "Exhibits a long-term outlook." During its public meeting on June 5-6, 2019, the Board elected to review the scientific basis of the proposed rule. Subsequent to the June meeting, a working group of chartered SAB members was formed to carry out the review and develop a draft report. The draft report was then reviewed and approved with revisions by the full SAB at a public teleconference held on January 22, 2020.[2]

The preliminary regulatory impact analysis of the 2018 Notice of Preliminary Rulemaking for the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks is extensive. It runs 1,625 pages and covers eight regulatory alternatives to retention of the 2021-2025 EPA and National Highway Traffic Safety Administration (NHTSA) standards adopted in 2012. The agencies refer to the 2012 rules as the "augural" standards and we will follow that terminology here. The analysis of the proposed revision addresses, at length, topics ranging from the rationale for footprint-based corporate average fuel economy (CAFE) and greenhouse gases (GHG) standards, to details of engine and transmission modifications that manufacturers might adopt to improve fuel efficiency, to the use of original national data on vehicle miles of travel (VMT) derived from odometer readings. It also includes sensitivity analyses for assumptions about eleven distinct issues that can be considered uncertain or contentious.

Recognizing the breadth and depth of the preliminary analysis, the SAB has chosen, given the limited available time, to concentrate its review on several areas where there appear to be significant weaknesses or where other significant improvements are feasible.

Two of the new modules recently added to the Department of Transportation's Volpe CAFE Model, the sales and scrappage equations, have important weaknesses in both their theoretical underpinnings and their econometric implementation. Together, the new modules generate implausible results regarding the overall size of the vehicle fleet, implying that the revised standards would reduce the size of the vehicle fleet relative to the augural standards when economic theory suggests that the fleet should grow due to a decline in the prices of new vehicles.

Moreover, when the fleet impacts are combined with implausible assumptions about the use of older vehicles, as well as with an assumed rebound effect that is large relative to the literature,

[2] One SAB member, Dr. Bob Blanz, concurred with the report with the exceptions of references to the withdrawal of California's waiver from EPA motor vehicle standards, In his opinion, these were policy issues.

and considering other problems and inconsistencies, these weaknesses are of sufficient magnitude that commenters (e.g., Bento et al. 2018) suggest that a corrected analysis could reverse the sign of result, indicating that the augural standards provide a better outcome than the proposed revision preferred by the agencies.

In the body of the report we provide recommendations for addressing the issues in the sales and scrappage models, as well as for improving the modeling of vehicle miles traveled. In addition, we provide recommendations on several other aspects of the analysis, including: the treatment of state-level policies regarding zero emission vehicles; the analysis and modeling of electric vehicles more broadly; the modeling of willingness to pay by consumers for fuel efficiency improvements; the treatment of the rebound effect; the treatment of flexible compliance options; and the need for a stronger scientific basis for providing incentives for electric vehicles. We also provide longer term recommendations regarding the choice of models to be used for future analyses.

In addition, several aspects of the proposed withdrawal of California's waiver from federal preemption under the Clean Air Act are relevant to the scientific basis of the analysis and should be addressed.[3] First, the baseline used for analysis of the augural standards should include California's zero emissions vehicle (ZEV) program, other state ZEV programs, and other policies related to electrification. Second, withdrawal of the waiver, which is a significant change in policy on its own, should be explicitly analyzed in order to clarify its independent impacts on social benefits and costs.

Finally, it is important to note that while many of the necessary analytic changes will move the results in favor of the augural standards compared to the proposed revision, some of the changes we recommend could move the results in the opposite direction, providing less support for the augural standards. Other changes will have an unpredictable net effect. A revised analysis would help determine the correct ranking of the alternative policies.

The SAB offers no comment on the best regulatory decision but notes that the analytic concerns that need to be addressed in the Agency's final analysis have strong policy ramifications. The SAB recommends that the Agency address these issues in the final regulatory analysis for this rulemaking.

[3] The SAB notes that subsequent to its analysis of the proposed SAFE Vehicles Rule, EPA announced a decision to withdraw the waiver it had previously provided to California for that State's greenhouse gas and zero emission vehicle programs (84 FR 51310 – 51363).

2. INTRODUCTION

The EPA Science Advisory Board (SAB) regularly evaluates major planned actions listed in the Agency's Unified Regulatory Agenda to determine whether formal review and comment by the SAB is warranted. In April 2019 the SAB Work Group on EPA Planned Actions for SAB Consideration of the Underlying Science evaluated the proposed SAFE Vehicles Rule and indicated that it ranked "high" on the five criteria used by the SAB for determining whether an action merits review: "Involves scientific approaches that are new to the agency," "Addresses area of substantial uncertainties," "Involves major environmental risks," "Relates to emerging environmental issues," and "Exhibits a long-term outlook." The work group recommended that it would be appropriate for review if the Agency and the California Air Resources Board (CARB) failed to agree on a harmonized national rule. The agencies have not reached such an agreement and, during SAB deliberations during its public meeting on June 5-6, 2019, the Board elected to review the scientific basis of the proposed rule. Subsequent to the June meeting, a working group of chartered SAB members was formed to carry out the review and develop a draft report. The draft report was then reviewed and approved with revisions by the full SAB at a public teleconference held on January 22, 2020.[4]

We begin with a short review of the process leading to the proposed rule and then discuss the modeling approach used by the Agency. Following that we identify several significant shortcomings and provide recommendations for improvement.

On August 2, 2018, EPA and the U.S. Department of Transportation (DOT), through its National Highway Traffic Safety Administration (NHTSA) ("the agencies"), issued a Notice of Proposed Rulemaking (2018 NPRM) entitled the Safer Affordable Fuel-Efficiency (SAFE) Rule (83 FR 42986). It continues the recent practice of combining implementation of multiple statutes by proposing new corporate average fuel efficiency (CAFE) standards under the Energy Policy and Conservation Act of 1974, as amended by the Energy Independence and Security Act of 2007, and by regulating greenhouse gas (GHG) emissions from motor vehicles under the 1970 Clean Air Act, as amended in 1977 and 1990. The CAFE standard seeks to reduce fuel consumption to the "maximum feasible level" (while considering costs and benefits) while EPA's endangerment finding for GHGs under Title II of the Clean Air Act (CAA) supports EPA's decision to regulate GHG emissions from motor vehicles.

In 2012 the agencies promulgated CAFE and GHG standards for 2017-2025 model year (MY) vehicles (EPA 2012). Partly because NHTSA is not authorized to promulgate standards for more than five years into the future and partly to assess any unforeseen changes in technology, fuel prices, consumer preferences, or energy security, the 2012 rule provided for a mid-term evaluation (MTE). As part of the MTE, the agencies committed to issuing a draft technical assessment report (TAR) by November 2017, and to making a final determination by April 2018 as to whether the standards remained appropriate.

[4] One SAB member, Dr. Bob Blanz, concurred with the report with the exceptions of references to the withdrawal of California's waiver from EPA motor vehicle standards, In his opinion, these were policy issues.

EPA issued a draft TAR in the summer of 2016 (EPA 2016a, hereafter 2016 TAR), took public comment on it, released a proposed determination that the 2022-2025 MY standards were appropriate in December 2016 (EPA 2016b), and then issued a final determination in January of 2017 (EPA 2017). The rule issued in 2012 and evaluated in 2016 is referred to by the agencies as the augural standard and we will follow that terminology.

In March 2017, EPA announced it would reevaluate the augural standard according to the original timeline. In August 2017, it formally announced that it was reconsidering the MTE. In April 2018, it announced that the standards were no longer appropriate, the final determination on the appropriateness of the standards would be withdrawn, and a new rulemaking would be initiated. The culmination of that process was a new notice of proposed rulemaking issued in August 2018 (EPA 2018a). The 2018 NPRM proposes a revised standard for 2022–2025 MY vehicles. In addition, it proposes a new standard for 2026. It also proposes to revise the last year of the 2017–2021 standards. In total, the 2018 NPRM proposal covers 2021–2026 MY vehicles. It includes several regulatory options, and EPA's preferred option – a freeze of standards at 2020 levels – will be referred to below as the revised standard.

Finally, the revised rule proposes to rescind California's waiver from preemption under the CAA. California has on numerous occasions been granted waivers under the CAA from EPA motor vehicle standards, thereby allowing the state to set different standards that are at least as stringent as the federal standards for vehicles sold in the state. Other states are permitted to align with the California standards. In contrast, the 1975 Energy Policy and Conservation Act (EPCA) does not allow waivers for any state seeking to impose fuel efficiency standards that are different from those promulgated by NHTSA. The NPRM argues that, unlike the waivers allowed for conventional pollutants under the CAA, a waiver for a state standard related to GHGs is equivalent to a waiver from the national fuel efficiency standard and is prohibited by EPCA. In this report, SAB focuses on the scientific issues that arise due to the claim of federal preemption; the legal issues are not addressed.[5]

The preliminary regulatory analysis of the 2018 NPRM is extensive (EPA 2018b). It runs 1,625 pages and covers eight regulatory alternatives to retention of augural 2021-2025 EPA and NHTSA standards. It addresses, at length, topics ranging from the rationale for footprint-based CAFE and GHG standards, to details of engine and transmission modifications that manufacturers might adopt to improve fuel efficiency, to the use of original national data on vehicle miles of travel (VMT) derived from odometer readings. It also includes sensitivity analysis for assumptions about eleven distinct issues that can be considered uncertain or contentious.

[5] The SAB notes that subsequent to its analysis of the proposed SAFE Vehicles Rule, EPA announced a decision to withdraw the waiver it had previously provided to California for that State's greenhouse gas and zero emission vehicle programs (84 FR 51310 – 51363).

3. MODELING APPROACH

Evaluating a fuel efficiency or greenhouse gas emissions standard is a complex mix of scientific, engineering, and economic analysis. It requires the agency to: anticipate how the regulation will cause manufacturers to change the characteristics of individual vehicles and the mix of vehicles they offer; determine how sales of new vehicles will respond to that change; determine the impact on the evolution and utilization of the broader vehicle fleet; determine how those changes will affect aggregate fuel consumption, emissions of criteria pollutants and greenhouse gases, fatality rates, congestion, and other outcomes; and, finally, to assess the overall benefits and costs of the proposed rule.

Recent analyses by NHTSA and EPA consist broadly of two key modeling components: (1) full vehicle simulation at the level of the individual model, and (2) fleet-level compliance and projection of regulatory impacts. Full vehicle simulation is used to estimate the impacts of technologies or design strategies that manufactures could adopt, either individually or in combination, on individual vehicles of specific types. Thousands of simulations are run to evaluate the impacts of many potential combinations of technologies on ten different vehicle classes. Those results become an input to the compliance and projection model, which carries out most of the remaining analytical tasks. Those begin with determining cost-effective strategies that individual manufacturers could implement to comply with the standards and end with the overall benefit-cost assessment. Additional models are used for tasks that fall outside the vehicle sector, such as forecasting future energy prices or determining the emissions associated with fuel production and distribution.

NHTSA and EPA have distinct responsibilities, as the statutes governing the programs differ and allow for different degrees of flexibility. In 2012, they carried out their analyses collaboratively but in parallel, with NHTSA focused on the CAFE standards and EPA focused on GHG standards, and they used somewhat different inputs and models in their evaluations. However, in the 2016 TAR EPA's inputs and models dominated the analysis while NHTSA's work was condensed and relegated to chapter 13 near the end of the lengthy report. The 2018 NPRM moved even more strongly in the opposite direction: only a single set of models was used, one for vehicle simulation and one for compliance, and those models were refined versions of models that were previously developed or used by NHTSA.

In the remainder of this section we briefly outline the evolution of the analytical approaches used in recent rulemaking and then provide additional background on the specific compliance model used for the 2018 NPRM: the 2018 version of the Department of Transportation's Volpe CAFE Model. Subsequent sections will provide detailed critiques of specific aspects of the model and the analysis.

3.1. Evolution of the Analysis of CAFE and GHG Rules

In the 2012 regulatory impact analyses (RIAs) both agencies relied primarily on a proprietary vehicle simulation model, Easy 5, produced by Ricardo Engineering. However, EPA augmented that analysis with its own Advanced Light-duty Powertrain and Hybrid Analysis (ALPHA) tool, which it had been developing since 2009. For compliance and future projection of impacts the agencies used different tools. NHTSA used the Volpe CAFE Model developed by the Department of Transportation's Volpe National Transportation Systems Center (hereafter the CAFE Model), while EPA used OMEGA, its Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles. The agencies coordinated on setting CAFE and GHG standards that were largely harmonized but they produced separate analyses.

In preparation for the midterm review, NHTSA asked the National Research Council (NRC) of the Academies of Sciences, Engineering and Medicine to review the approach the agencies had been using, as well as to provide input on the future costs and fuel consumption impacts of a range of vehicle technologies likely to be available through 2030. The result was NRC (2015a), which found "the analysis conducted by NHTSA and EPA in their development of the 2017-2025 standards to be thorough and of high caliber on the whole." (NRC 2015a, p. 2). In addition, the NRC provided dozens of detailed findings and recommendations, including a strong recommendation to analyze carefully how consumers would likely react to regulatory alternatives.

For the midterm 2016 TAR, NHTSA and EPA both switched away from the proprietary Easy 5 model to open alternatives to improve the transparency of the analysis. NHTSA switched to the Autonomie model developed by the Department of Energy's Argonne National Laboratory, and EPA used its ALPHA model. Both agencies used updated versions of their existing compliance and impact-projection models: a 2016 version of the CAFE Model for NHTSA, and OMEGA for EPA.

The 2018 NPRM, in contrast, used only Autonomie and a 2018 version of the CAFE Model. It made no use of EPA's ALPHA or OMEGA models. Moreover, the 2018 CAFE Model differed significantly from the version used in the 2016 TAR. Tracking recent innovations in the economics literature, two new modules were added: a model of new vehicle sales and a model of fleet turnover, including vehicle scrappage. While NHTSA and EPA had previously addressed impacts of CAFE rulemakings on new vehicle sales with simplified models (Zirogiannis et al. 2019), the technical approach to estimating the impacts in the 2018 NPRM was new and more extensive. The next section discusses the new version of the CAFE Model in more detail.

3.2. The 2018 CAFE Model

The CAFE Model was originally developed in 2002, and has been used by NHTSA in every subsequent CAFE rulemaking. Following related innovations in the economics literature, it was substantially altered for the 2018 NPRM. Two major components were added: (1) a new econometric model used to determine how sales of new vehicles would respond to changes in vehicle prices; and (2) a new fleet turnover model that determines how the use and scrappage of older vehicles would change in response to changes in new vehicle prices.

In 2017, the Volpe Center began the first phase of a two-part peer review of the model. The first phase focused on the 2016 version and was carried out by four qualified reviewers selected by a contractor. The reviewers were asked to answer nineteen questions spread across three broad areas: (1) simulation of manufacturers' application of fuel-saving technologies; (2) estimation of impacts; and (3) general comments. The charge explicitly instructed the reviewers to focus on the structure of the model, not on its application: "Past comments have sometimes conflated the model with inputs to the model. The peer review charge is limited to the model itself; in particular, rather than addressing specific model inputs which are provided by DOT staff to facilitate review of the model, peer reviewers should address only the model's application of and response to those inputs" (NHTSA 2018, p. 1). Because the model's inputs are large, complex, and substantially drive its results, this review was in some respects narrower than that of NRC (2015a), which evaluated the full analytical process used for the 2012 regulatory impact analyses. On the other hand, the 2017 review sponsored by the Volpe Center was more in-depth and probing than NRC (2015a) with regard to model structure.

The first phase reviewers of the CAFE Model generally supported the overall modeling approach, although – as would be expected for a large, complex model – they provided many detailed suggestions. Quoting the summarized conclusion of the review:

> "All of the peer reviewers supported much of the model's general approach, and supported many of the model's specific characteristics. Peer reviewers also provided a variety of general and specific recommendations regarding potential changes to the model, outputs, and documentation.
>
> NHTSA and Volpe Center staff agree with many of these recommendations and have either completed or begun work to implement many of them; implementing others would require further research, testing, and development not possible at this time, but we are considering them for future model versions. When NHTSA and Volpe Center staff disagree with certain general and specific recommendations, we note that often these recommendations appear to involve input values and policy choices external to the model itself, and are therefore beyond the scope of peer review." (NHTSA, 2018)

Despite NHTSA's admonition in the reviewing charge to confine the review to the structure of the model, the reviewers also provided a number of suggestions on improving the inputs, emphasizing the point above that a model's results are jointly determined by its inputs and structure. The SAB notes that, because NHTSA and EPA have historically differed with respect to both model structure and inputs, it is not surprising that they have reported somewhat different results. When their results differ, it is not obvious whether differences in model structure are important compared to the differences inputs.

The second phase of the review focused on the new components added to the model after the 2017 review. We will refer to the revised version as the 2018 CAFE Model. Four new reviewers with appropriate expertise were selected and asked to answer ten questions distributed across three topics: (1) the sales model; (2) the scrappage model; and (3) labor utilization calculations (we do not address the third topic in this report). In addition, the charge was broadened since key parts of the new modules are, in fact, inputs to the 2018 CAFE Model: "However, an evaluation of new relationships within the model is expected to require evaluation of the model's characterization of those relationships – through statistical model coefficients, for example. While those enter the model as "inputs" that can be modified by the user, they are a critical component of the relationships in the model. Thus, it is appropriate to evaluate those coefficients – as they relate to the sales response, scrappage response, and employment response on which this review is focused – as part of this review" (NHTSA 2019, p. 1). The review was released in July of 2019, ten months after the NPRM and seven months after the closing date of the public comment period.[6]

The second phase reviewers supported the introduction of sales and scrappage models but had a number of significant reservations about the specific implementation in the 2018 CAFE Model. Particularly important was the fact that the sales and scrappage models were not integrated with one another in a logical fashion, leading to anomalous results for the size and utilization of the vehicle fleet. The reviewers' concerns will be discussed in detail in Section 5 but the following excerpts from NHTSA's summary of their comments indicates the nature and severity of the issues they raised (NHTSA 2019, B-3):

- "Their analysis raises fundamental issues regarding the model's specification and implementation. Reviewers suggest that a discrete choice model might be more appropriate in describing the sales response and might have a more solid grounding in economic theory than the aggregate sales/scrappage responses validated on historical data that frames the sales and scrappage models embedded in the CAFE model."

- "A related issue raised by the reviewers is the calculation of VMT based on the vehicle's vintage. The reviewers suggest that VMT attributable to an additional vehicle in a household may be dependent on the number of vehicles already in the household and may not be only dependent on the vehicle's vintage as implied by the inputs to the CAFE model. The reviewers indicate that these issues could be better addressed by a household transportation modal choice model."

- "Reviewers also note that regardless of the model's formulation, the new and used car markets should be integrated. In other words, the reviewers suggest that more reliable estimates could be generated by integrating the sales and scrappage models and by including the used car market in the specification."

- "Other specification issues warranting further examination or explication include: the extent to which manufacturers pass-through technology development and manufacturing costs to the consumer; the omission of consequential variables, such as disposable income, that are causally related to the dependent variable; and the method used to determine the distribution of sales across vehicle types.

- "Reviewers point to the implausibility of the fleet size results where the relaxation of the fuel economy standards of the "preferred alternative" [that is, the revised standard] leads to a smaller fleet of cheaper vehicles than the size of the "baseline alternative's" [augural standard] fleet of more expensive vehicles. Along with the independent specifications of sales and scrappage, the reviewers observe that the high degree of simultaneity and

[6] The release occurred during the SAB's review and the discussion here does not reflect any changes NHTSA may have made to the model subsequent to July 2019.

> endogeneity in the models might lead to the questionable result and call into question the reliability of the models' estimates."

As will be discussed in more detail in Section 5, the reviewers generally argue that the theoretical specifications behind the sales and scrappage models are inadequate or incorrect, and that the econometric methods used overlook endogeneity and omit a number of important variables. Also, outside experts submitted comments to the agencies arguing that the parameters in the sales model appear to have been interpreted incorrectly in a way that overstates the impact of price increases on sales of new vehicles.

Looking to the future, the SAB recommends that the EPA consider several different analytical strategies. One option is to return to the approach it used prior to the 2018 NPRM in which it carried out analysis of the GHG standards using its own analytical tools and inputs. The Agency already has the expertise and peer-reviewed models needed to do so, and its overall analytical approach has been reviewed by NRC (2015a). Moreover, independent analyses allow incorporation of differences in the agencies' statutory authority, such as the scope of flexibility mechanisms (discussed in more detail below). Most importantly, the complexity of the analysis, the large numbers of uncertainties involved in both the functional forms and parameter estimates required, and the extensive number of decisions needed about inputs to the models all suggest that parallel analyses are helpful for cross-checking overall results for plausibility and comparability. A downside of this option, which was apparent to readers of the 2016 draft TAR, is that, when the two agencies do not employ the same model structure, it is difficult to discern whether differences in results are attributable to differences in inputs or differences in model structure.

A second option is for the Agency to work more closely with NHTSA on the modeling structure and inputs employed in the Volpe model. Since several of the most important concerns raised by experts concern inputs to modeling (rather than model structure), it is productive for analysts to show, with the same model, how sensitive the results are to plausible changes in modeling inputs.

Finally, instead of working with the Volpe model, the agencies could work together to enhance EPA's modeling approaches, also showing how sensitive the results are to plausible changes in the chosen inputs.

Both agencies could choose to work with multiple sets of models but this strategy introduces considerable complexity and, potentially, inefficiency. The second and third options make more sense if the contentious issues relate primarily to choice of model inputs; the first option makes more sense if differences in model structure need to be explored formally and compared. Section 9 will discuss methods for analyzing both input and model uncertainty in more detail. A well-considered decision on these options is recommended for future CAFE and GHG rulemakings.

4. ESTIMATED COST OF COMPLIANCE

Estimating the cost of complying with a CAFE or GHG rule requires three conceptual steps: (1) constructing a baseline scenario that projects the future size and characteristics of the vehicle fleet if standards follow a reference trajectory in the absence of the regulatory change; (2) constructing an alternative scenario in which manufacturers revise their choices about technologies and flexibility mechanisms in light of the new standards; and (3) evaluating the benefits and costs of moving from the baseline to the alternative scenario.

Constructing each of the scenarios is challenging and involve extensive scientific, engineering, and economic uncertainties. Projecting the baseline requires the agencies to account for a wide range of variables including: the number of new vehicles sold, future fuel prices, consumer demand for fuel efficiency, sales of electric vehicles, evolving consumer preferences for performance and other vehicle attributes, state regulatory policies, the mix of vehicles between cars and light trucks and of different footprint sizes (wheelbase times track width), the number of miles driven by vehicles of different types and vintages, and the rate at which older vehicles are scrapped. Projecting the alternative scenario then requires the agencies to determine how the most cost-effective mix of compliance strategies will change as manufacturers bring their fleets into compliance with the new standards. The cost differences from these strategies, relative to what would have happened in the baseline, drive the remainder of the analysis.

The 2018 NPRM starts with a baseline projected forward from the MY 2016 vehicle fleet and then assumes that manufacturers will comply with the augural standards. It then constructs an alternative scenario that starts from the MY 2016 fleet but freezes CAFE and GHG standards at their 2020 values. It then computes the costs and benefits of the revised policy relative to the augural standards. The same approach is used for analyzing seven other regulatory options but we focus here on EPA's preferred freeze option.

A key driver of the analysis is the estimated compliance cost to manufacturers of producing vehicles that satisfy one standard or the other. Bento, et al. (2018) note that the 2018 NPRM reports compliance costs for the augural standards relative to the 2016 reference vehicle fleet that are more than twice those reported in the 2016 TAR. Identifying and evaluating all of the causes for the change is beyond the scope of this review. However, several contributing factors are discussed below.

4.1. Change in Reference Year for Baseline Standards

The 2016 TAR evaluated the impact of the MY 2022-2025 standards relative to a baseline that froze CAFE and GHG standards at the 2021 standards adopted in 2012. In contrast, the 2018 NPRM evaluates the existing standards relative to the revised alternative that freezes them at their 2020 levels. In effect, the 2018 analysis adds the cost of meeting the 2021 standard to the cost of achieving the augural 2022-2025 standards. Bento et al. (2018) show that this change raised the compliance cost reported in the 2018 NPRM substantially relative to the 2016 TAR. However, this part of the difference is the result of a component of the revised policy—rolling back the 2021 standard—and does not indicate a change in the underlying scientific basis of the analysis.

4.2. Manufacturer Beliefs About Consumer Willingness to Pay for Efficiency

The 2016 and 2018 analyses make different assumptions about the degree of fuel efficiency manufacturers will choose to offer voluntarily. The 2016 TAR assumed that manufacturers believe consumers will pay for all fuel efficiency technologies having payback periods of three years or less, but only up to the point where the manufacturer achieves compliance with the standard. Beyond that, the analysis assumed that manufacturers would only adopt technologies with payback periods of one year or less. The 2018 NPRM, in contrast, assumed that manufacturers believe that consumers are willing to pay for all fuel efficiency technologies that have payback periods of 2.5 years or less, and those technologies are incorporated into the vehicle fleet even in the absence of a standard. It thus assumes greater voluntary adoption of fuel efficiency technologies by manufacturers under both the augural and revised standards.

The literature on consumer willingness to pay for fuel efficiency is both extensive and somewhat inconclusive. The payback periods used in both the 2016 and 2018 analyses are low relative to several recent studies that focus on fuel-price changes, but are within the range of both the broader literature and the literature that focuses on technology change. We discuss this literature in more depth in Section 5. The issue at hand is slightly different and less well understood: it is not the actual willingness to pay by consumers but rather what manufacturers believe about it when making decisions about fuel efficiency technologies to include in their fleets. The National Research Council (NRC 2015a) notes that 2-3 year payback periods are consistent with comments it received from manufacturers about their perceptions of consumer willingness to pay. However, it did not examine whether the behavior of manufacturers was consistent with those beliefs.

The change is a significant departure from the Agency's prior practice, and it will affect both the costs and the benefits of the augural standards relative to the proposed freeze. EPA (2018a,b) does report sensitivity analyses for 12, 24 and 36 month payback periods. However, the SAB, like NRC (2015a), recommends that future work be done to provide a stronger empirical basis for the payback value assumed to be used by manufacturers. This is particularly important since, as discussed in Section 5, it differs from the treatment of consumer willingness to pay for fuel efficiency elsewhere in the regulatory analysis.

4.3. Treatment of ZEV Mandates in California and Elsewhere

The State of California has standards in place for MY 2018–2025 that require automakers to commercialize an increasing number of zero emission vehicles (ZEVs) such as plug-in electric vehicles and hydrogen fuel cell vehicles (CARB 2017). Nine other states in the West and Northeast have joined the ZEV program, and Colorado, Minnesota and New Mexico have announced plans to join in the near future.

The 2018 NPRM does not account for state ZEV mandates in the baseline scenario, which represents the augural standards. This omission follows the assumption used by NHTSA for the CAFE standards in the 2016 TAR. However, it departs from the approach used by the EPA for analysis of the GHG standards in the 2016 TAR, which did include ZEV mandates in the baseline against which the augural standards were evaluated.

State ZEV mandates affect the number of electric vehicles (EVs) in the absence of the federal rule, which can affect the incremental compliance costs of both the national CAFE and GHG standards. Greater deployment of EVs reduces federal compliance costs because both EPA and NHTSA count EVs in their compliance data for vehicle manufacturers. Since EPA provides especially generous compliance credits for EVs from 2017 through 2021, the state ZEV mandates also make it easier, temporarily, for automakers to comply with the 2017-2021 EPA standards.

The SAB thinks that analysis of the augural standards should be consistent with policies that would prevail in the absence of the rule change. As a result, and as also discussed in Section 8, including compliance with state ZEV mandates in the baseline when computing the impacts of the augural standards, as EPA did in the 2016 TAR, is the appropriate approach. The SAB recommends that analysis be revised accordingly.

4.4. Accounting for Non-Regulatory Electric Vehicle Policies

The SAB thinks that there are important non-regulatory policies in place that may boost commercialization of plug-in electric vehicles, possibly beyond the market penetration that will be required by state ZEV mandates. Examples of those policies include the $7,500 federal income tax credit for qualified plug-in electric vehicles, and the Volkswagen diesel settlement, which calls for Volkswagen to make a large nationwide investment in public education and recharging stations to support electric vehicles (Roberts 2017). At the state level, a coalition of ZEV states signed a 2018 memorandum of understanding calling for a wide range of measures to promote the commercialization of electric vehicles (Spector 2018). The coalition's goal is to achieve 35% market share for ZEVs by 2030. The measures to be considered by each state include state-level purchase incentives, public education and promotion about electrification, and subsidies for recharging infrastructure. The overall impact of these policies is highly uncertain but there is strong evidence that purchase incentives, public awareness, and recharging infrastructure boost sales of plug-in electric vehicles (NRC 2015b).

On the other hand, some policy trends are working against commercialization of electric vehicles (Carley et al. 2017). An increasing number of states (now more than half) are enacting special, annual registration fees that are applied to plug-in electric vehicles, since owners of those vehicles do not pay the gasoline taxes that are used for road maintenance and repair. In addition, some states that once had purchase incentives for electric vehicles (e.g., Georgia and Illinois) have repealed those incentives and the budgets for purchase incentives in some other states are exhausted or near exhaustion. In addition, while some state public utility commissions are adopting rate policies that favor electric vehicles, other state commissions are opposing rate structures and other reforms that would favor plug-in electric vehicles.

Thus, the SAB thinks there is considerable uncertainty about the baseline market penetration of electric vehicles in the time frame of this rulemaking (2020-2026). To address this uncertainty, SAB recommends that the agencies add electric-vehicle penetration in the baseline as an additional issue to be addressed in sensitivity analysis.[7] Sensitivity analysis and other methods for addressing this and other uncertainties will be discussed in more detail in Section 9.

4.5. Updated Lifecycle Analysis of Electric Vehicle Compliance Incentives

EPA's augural 2017-2025 GHG standards included special compliance incentives for a limited period of time to encourage vehicle manufacturers to offer plug-in electric vehicles (PEVs) and other advanced propulsion systems. Specifically, two forms of temporary compliance incentives for PEVs were offered: (1) when computing upstream emissions from power generation, each battery-powered electric vehicle (BEV) is treated as if it contributes zero g/mi CO_2 (until a cap on production volume is reached), independent of the actual carbon intensity of the regional electric grid; and (2) a manufacturer is permitted to count a BEV as more than one vehicle in the company's fleet-wide emissions averaging for model years 2017 to 2021. The compliance "multiplier" for BEVs starts at 2.0 in 2017 and declines to 1.5 in 2021; less generous multipliers are provided for plug-in hybrid electric vehicles (PHEVs): 1.6 in 2017 declining to 1.3 in 2021. Both compliance incentives assist manufacturers in meeting their national fleet-wide GHG obligations, assuming that PEVs are produced and sold. NHTSA does not offer similar incentives under the CAFE standards because the agency believes it lacks statutory authority to do so.

EPA argued in 2012 that the incentives were justified to promote commercialization of technologies that "have the potential to transform the light-duty vehicle sector by achieving zero or near-zero GHG emissions and oil consumption, but which face major near-term market barriers." The Agency did not expect the vehicles to reduce aggregate GHG emissions through 2025, a position that was consistent with the subsequent literature examining the policy (see Jenn et al. 2016). Indeed, EPA acknowledged that the incentives would "decrease the overall GHG emissions reductions associated with the program in the near term" (77 FR 62811) due to offsetting changes in the other vehicles offered by manufacturers, as well as upstream emissions from electricity generated to charge the vehicles. The increase in emissions relative to a rule with no such incentives was expected to be 56-101 million metric tons over 2017-2025, or 2.7% to 5% of the total GHG reduction expected from the rule. From the outset, therefore, the PEV incentives were understood to impose a near-term cost in terms of GHG emissions in the hope of achieving larger reductions in the longer run. The incentives were not subjected to a formal cost-benefit analysis in 2012 or 2016.

Because EPA is considering an extension of the incentives beyond MY 2021, and because the national generating mix and other factors have changed substantially since 2012, the SAB recommends that an updated and strengthened analysis of the PEV incentives be carried out. Moreover, an updated analysis takes on added importance because the recent voluntary agreement between the State of California and four large automakers includes an extension of the compliance incentives for electric vehicles. The 2018 NPRM provides some limited discussion

[7] EPA's 2012 analysis did not discuss non-regulatory EV policies. The 2016 TAR considered a number of state EV policies but did not attempt to predict their impact on EV adoption (the literature does not yet support that). Rather, it considered them in a chapter evaluating whether the charging infrastructure for EVs was likely to be sufficient to support EPA's projected increase in the size of the EV fleet.

of the incentives when requesting comment on alternatives (83 FR 43464) but a more detailed and transparent analysis is needed.

Because the well-to-wheel efficiency of EVs, as well as their impact on emissions, depends on the characteristics of the electric grid, the key issues in assessing the marginal lifecycle emissions of PEVs relative to internal combustion engine (ICE) vehicles are: (1) the GHG intensity (g CO_2 e/kWh) of the electric grid where and when the PEVs are expected to charge, and (2) the lifecycle GHG emissions associated with the petroleum supply chain for gasoline- and diesel-powered vehicles. Both are important and vary widely across the country (Graff-Zivin et al. 2014; Tamayao 2015; Holland et al. 2016; Yuksel et al. 2016). In regions of the country that rely on low-carbon electricity sources, PEVs can reduce GHG emissions; in regions that rely heavily on coal and natural gas, BEVs can raise GHG emissions. Research has also considered that as the fractions of coal, natural gas, and renewable energy change, the relative trade-off between ICEs and PEVs will also change (Weis et al. 2016). Other air pollutants, such as PM and ozone, do have decreased emissions with PEVs, particularly when operated in urban areas (Nopmongcol et al., 2017 and Requia et al. 2018).

Revaluating the incentives requires updated projections of the impact of the rule on BEV adoption at the regional level, as well as updated projections of the near-term evolution (2021-2039) of the carbon intensity of the corresponding sections of the electric grid. The former task could be approached by looking at how cost-effective BEVs are as a compliance strategy for vehicle manufacturers, with and without the compliance incentives. See NRC (2015b) for a discussion of this perspective.

The second task, projecting the evolution of the electric grid over the time horizon of this rulemaking (2021-2039), is far from clear cut. As discussed below, the analysis should address seven broad drivers: changes in the electric generating mix at the national and regional levels; regional and temporal differences in power sector GHG emissions; emissions from the supply chains of the relevant fuels; challenges posed to nuclear power and coal by both intermittent renewables and inexpensive natural gas; the impact of other national policies that may change the evolution of the grid; the impact of growing exports of natural gas; and new technologies for electricity storage and demand management.

First, direct GHG emissions from the national power sector have declined due to a shift away from coal and toward natural gas and renewables. Looking forward, the U.S. Energy Information Administration's (EIA) short-term and long-term forecasts call for low natural gas prices to shift the U.S. grid toward even more dependence on natural gas and relatively less dependence on coal. The forecast does not anticipate the elimination of coal: rather, it predicts coal-fired generating capacity will stabilize at 150 GW by 2030, a 40% decline from its value in 2017, and coal-fired generation will stabilize around 900 billion kWh, a 25% decline from 2017 (EIA, 2019). EIA expects that nuclear power will be relatively stable through most of this period but retirements of nuclear plants are expected to increase somewhat in the later years, leading to about a 10% decrease in nuclear generation in 2040. Finally, renewables are expected to grow rapidly from their small base share but natural gas is nonetheless projected to be the dominant source of energy in the U.S. for power production through 2050 (EIA, 2019).

Second, differences in GHG intensity are pronounced at the regional level. California, the state accounting for almost 50% of the BEVs that have been sold to date in the U.S., has an in-state generating mix that is relatively low in GHG intensity. In addition, it has adopted policies aimed at reducing its net carbon emissions from electricity generation to zero by 2045. New York, which also has relatively low GHG intensity, has a similar target for 2040. However, determining the impact of state-level policies on national GHG emissions associated with PEVs will require careful analysis of flows of electricity across state lines. Some states with ambitious renewable goals have had difficulty generating sufficient amounts of electricity and thus have imported significant amounts of power. In 2018 California met 25% of its electricity demand with imported supplies from nearby states (EIA, 2019). Imported electricity may be directly or indirectly provided by coal-based plants: Arizona, for example, exports some of its clean power to California while importing cheaper coal-fired power from neighboring states.

Moreover, growing deployment of solar has caused California to face an increasing challenge in bringing low carbon generation on line quickly in the late afternoon when demand is high and solar generation is waning. A careful lifecycle analysis would need to account for the carbon intensity of those resources, particularly because some PEV owners may charge their vehicles after arriving home during that period. More broadly, an updated analysis should account for temporal variations in the GHG intensity of the grid when owners are likely to be charging their vehicles.

Thus, the EPA should look carefully at the grid in states where BEV sales are likely to be high in the future. The inquiry should include not only the GHG intensity of a state's electric generation, but also consider whether the state imports a significant amount of electricity, determine how those imported supplies are generated, and account for the likely mix of generating resources operating during periods when PEVs are likely to be charging. Such analysis might support differentiated compliance incentives favoring vehicles sold in states that have lower-than-average GHG intensities in their sources of electric power. However, during their long lifetimes, vehicles are often sold across state lines or recharging occurs in states that are different than the state of initial registration.

A third important issue that must be considered is GHG emissions from the supply chains for different fuels (the lifecycle-analysis perspective). Shifting a kilowatt-hour of generation from coal to natural gas cuts direct CO_2 emissions from power generation roughly in half, as the carbon content per unit of energy released from burning natural gas is about half that of coal. The 2012 EPA analysis accounted for this effect. However, the natural gas and coal supply chains are a significant source of methane, an especially potent short-lived greenhouse gas. Recent studies indicate that the rate of methane emissions from both coal and natural gas sectors are larger than previously understood (e.g., Barkley et al. 2019; Cornwall 2018). Until methane emissions are controlled throughout the supply chains for both natural gas and coal, the net radiative forcing of the two fuels will differ from that of the direct CO_2 emissions alone. Current rates of methane emissions from the two supply chains in the U.S. are highly variable and uncertain. Industry and some state governments are working to lower methane emissions from the natural gas supply chain, further emphasizing the uncertainty in estimates of future methane emissions. Nonetheless, given current average emissions rates, methane reduces, but does not eliminate, the short run net GHG advantage of fuel switching from coal to natural gas. The net long term GHG advantage of switching is likely to be significantly larger (Tanaka et al. 2019). The temporal difference reflects the fact that methane has an average atmospheric half-life of about a decade, while that of carbon dioxide is more than a century (Alvarez, et al. 2012; Alvarez, et al. 2018).

Methane emissions take on greater importance in cost-benefit analysis than in lifecycle analysis because time preferences are incorporated into cost-benefit analysis whereas lifecycle analysis is typically time-neutral in preferences. The CO_2 advantages of natural gas will be heavily discounted in cost-benefit analysis because they accrue so far in the future whereas the methane emissions have a potent, near-term impact.

A fourth important issue to consider is the impact of renewables and inexpensive natural gas on the commercial future of nuclear power plants. Both renewables and natural gas have tended to push down wholesale power prices, presenting a difficult financial challenge for nuclear power. Recent reports indicate that even relatively new nuclear plants have an increasingly uncertain commercial future due to competition from other sources (Osborne 2019). Some states, such as New York, have reacted by adopting zero emission credit (ZEC) policies or other measures to raise the financial returns to the operation of nuclear power plants. Although EIA does not currently project a net decline in nuclear generation for the next 15 years or so, EIA's forecasts are updated annually and the situation could change. Replacing a nuclear power plant with a mix of renewables and natural gas generation could increase significantly the GHG intensity of the grid. A careful lifecycle analysis of the PEV incentives, therefore, should include an assessment of the risk of early retirements of nuclear plants.

A fifth set of issues that should be considered are changes in federal policies that may cause the grid to evolve differently from EIA's projections. In particular, the most recent EPA GHG rule for the power sector imposes less compliance pressure on coal-fired power, which may slow the shift from coal toward natural gas. In its recent rulemaking on GHG emissions from coal plants, EPA noted that the new rule is associated with a slight increase in the projected coal share of the market and a slight decrease in the projected natural gas share of the market (EPA 2019). In addition, incentives have been proposed for coal and nuclear power on the grounds that the on-site fuel storage capabilities of those plants may reduce the vulnerability of the grid to disruptions in natural gas supplies. The impact of such incentives on GHG emissions is unclear: increasing coal generation would raise GHG emissions, but keeping nuclear power online would have the opposite effect.

Sixth, changes in natural gas prices could impact projected natural gas generation. For example, growing exports of natural gas to Asia and Europe may place a floor on natural gas prices in the U.S., which could cause the rate of decline of coal's share of electricity to be smaller than previously thought (Moody's Investor Service 2019).

Seventh, innovation in technology and management of the electric grid could lower GHG emissions by allowing easier integration of intermittent renewables. Accelerated development and deployment of new energy storage technologies, combined with demand response measures such as time-of-use pricing, real-time pricing, or direct load control, could make it possible for the majority of U.S. electricity to be produced with renewables in the long run (Jenkins et al. 2018).

Eighth, an updated assessment of PEVs should consider any social costs associated with the lifecycle of the vehicles beyond those associated with charging. For example, it would include impacts associated with the supply chain for rare earths used in manufacturing PEVs, as well as the cost of disposing of vehicle batteries at the end of their useful lives.

In summary, the current EPA incentives for PEVs, which extend through model year 2021, were a policy decision made by EPA in 2012, before a major expansion of the lifecycle analysis literature, before recognition of the extent of methane emissions in the natural gas and coal supply chains, and before the collapse of natural gas prices in the U.S. The SAB respects that the decision whether to terminate or extend the PEV incentives is a policy judgment outside the SAB's purview. However, PEVs do not appear to be more fuel efficient than modern internal combustion engine vehicles that are similarly equipped. In addition, at this time an increased load on the nation's electricity grid caused by an increase in PEV use could lead to an increase in GHG emissions rather than a reduction. Taken together it is not clear that there is an adequate scientific basis for incentivizing PEVs as a means for reducing GHG emissions at this time. The SAB recommends that the agency undertake an updated lifecycle analysis to provide improved information about the GHG consequences of the incentives, and then use those findings in a robust cost-benefit analysis of alternative options for PEV incentives.

4.6. Treatment of Flexibility Mechanisms

The CAFE and GHG programs both contain a number of mechanisms that allow manufacturers some degree of flexibility in how they comply with the standards. Although the programs differ in some details, they both broadly allow manufacturers to earn credits on vehicles that exceed the standards and then to use those credits in various ways: applying them to other vehicle fleets which fail to comply (for example, shifting credits from cars to light trucks); trading them to other manufacturers; carrying them forward for future use; or applying them against a prior year deficit (known as a carry-back).

When estimating compliance costs the 2016 TAR and the 2018 NPRM do not fully account for optimal use of flexibility mechanisms by manufacturers and thus may overstate costs (Bento et al. 2018; Institute for Policy Integrity 2018, p. 18). As noted in the 2018 NPRM, the CAFE Model does not incorporate trading between manufacturers even though that is allowed under the GHG standards (83 FR 43181) and sensitivity analysis shows that full trading across manufacturers would reduce costs by 12.7% (83 FR 43367).

The 2018 NPRM argues that vehicle manufacturers may be reluctant to rely on flexibility as a primary compliance strategy (83 FR 43231). Possible reasons include: reliance on such mechanisms can expose a company to potential adverse publicity and hostile shareholder resolutions, since companies can be framed as failing to innovate; agencies have the power to change (devalue) flexibility mechanisms and have done so in the past, and thus it is risky for companies to rely heavily on them; and there are statutory and administrative restrictions on the flexibility mechanisms that limit their real-world utility (Leard and McConnell 2015). Some companies see accumulated credits not as a primary compliance strategy but as an insurance policy to cover unexpected compliance shortfalls in future years. Thus, even though economic models predict that extensive use of flexibility mechanisms would reduce compliance costs, the real-world use of flexibility mechanisms has been quite limited in the auto industry.

In the future, use of flexibility mechanisms could become a more accepted practice. Fiat Chrysler recently made a major investment in an alliance with Tesla that will supply Fiat Chrysler with CO_2 compliance credits in the European Union's CO_2 regulatory system. Tesla has also generated significant revenue by selling CAFE, GHG and ZEV credits to global automakers engaged in the U.S. and California markets.

If use of flexibility mechanisms expands over the 2021-2026 period, the compliance costs estimated in the 2018 NPRM will be overstated in several ways. The 2018 CAFE Model assumes that manufacturers are reluctant to use averaging across vehicle fleets even when that would reduce compliance costs: "[...] the model prefers to hold on to earned compliance credits within a given fleet, carrying them forward into the future to offset potential future deficits" (83 FR 43185). As a consequence, the model will not minimize the joint cost of compliance for the fleets (e.g., cars and light trucks together). In addition, the model does not account for the extended life span of GHG credits earned during MY 2009–2011: they are treated as expiring after five years even though EPA has extended their expiration dates to MY 2021. As noted in the NPRM, the model "thus underestimates the extent to which individual manufacturers, and the industry as a whole, may rely on these early credits to comply with EPA standards between MY 2016 and MY 2021" (83 FR 43183).

The 2018 NPRM notes that NHTSA is prohibited by statute from considering some flexibility mechanisms in setting the stringency of CAFE standards but EPA is under no such restriction. The SAB recommends that the Agency should more fully account for flexibility mechanisms when evaluating GHG standards. However, in doing so it should account for constraints imposed on manufacturers in using these mechanisms since companies must comply with both the NHTSA CAFE standards and the EPA GHG standards (Leard and McConnell 2015).

5. FLEET SIZE AND COMPOSITION

An important aspect of the 2018 NPRM is that it examines the impact of regulation on use of older vehicles, as older vehicles are associated with higher levels of pollution and safety risks than newer vehicles. If stringent regulations increase the price spread between new and old vehicles, the rate of turnover of old vehicles may be slowed, the so-called "Gruenspecht effect" in the economics literature (Gruenspecht 1982).

In this section, we review how the 2018 NPRM estimates the impact of less-stringent standards on the volume of new vehicle sales, the number of older vehicles in use, and the total number and mix of vehicles on the road. We focus on several key issues: consumer willingness to pay for fuel efficiency; the impact of less-stringent standards on the volume of new vehicle sales; and the impact of less-stringent standards on the total size and mix of the vehicle fleet.

5.1. Consumer Willingness to Pay for Fuel Efficiency.

The NPRM 2018 does not take an analytically consistent position on consumer valuation of fuel economy. At different stages it takes alternative positions – implicitly or explicitly – as to how much the average consumer is willing to pay for increases in vehicle fuel efficiency, and the positions are mutually inconsistent. The SAB recommends that the agencies should adopt a consistent position, and then perform sensitivity analysis to illustrate the ramifications of alternative consistent positions. In the remainder of this section we consider first the inconsistencies, and then present a practical, consistent step forward.

As noted above, the NPRM 2018 presumes that average fuel efficiency levels from MY 2017 to 2025 for specific models will gradually improve relative to MY 2016 as manufacturers adopt fuel efficiency technologies with short payback periods. The payback period refers to the number of years of savings in fuel expenditures that are required to cover the incremental cost of the fuel-saving technology. In this aspect of the NPRM 2018, manufacturers are projected to implement voluntarily any unused fuel-saving technology that has a consumer payback period of less than 2.5 years (EPA 2018b). If a technology's payback period is longer than 2.5 years, it is assumed that vehicle manufacturers will not implement it unless it is determined to be an optimal compliance response to binding regulatory standards. Thus, the assumption in the CAFE Model is that the average consumer does have an interest in fuel economy – at least as perceived by the manufacturer – but the payback period must be quite attractive to motivate the consumer to pay for the enhanced fuel economy and for the manufacturer to offer it voluntarily.

The 2.5-year required payback is supported by a recent National Research Council assessment of the evidence concerning consumer willingness to pay for fuel efficiency (NRC 2015a). The NRC, based on a survey of industry experience, found that the required payback period for the average consumer buying a new vehicle is somewhere between 1 and 4 years (2.5 years is the midpoint of the range). The evidence considered includes the decades of efforts by companies to offer fuel-saving technologies on new vehicles (Carley et al. 2017), marketing experiences of manufacturers and dealers, surveys where consumers are asked directly whether they are willing to pay a price premium for vehicles with higher fuel economy (e.g., see Greene et al. 2013), and the academic literature exploring associations between vehicle prices and vehicle characteristics, including fuel-economy ratings (discussed below).

The NPRM 2018 does present some new evidence from a national time-series model of new vehicle sales (the "sales response model") using quarterly data from 1980 to 2015 (EPA 2018b, 950-955). As expected, the model finds that new vehicle prices and selected macroeconomic variables (gross domestic product and labor force participation) are associated with the national counts of new vehicle sales. Exploration of alternative measures of vehicle fuel economy did not improve the model's explanatory power and thus the fuel-economy variables were excluded from the final sales-response model. This result is consistent with the hypothesis that consumer willingness to pay for fuel economy is quite limited, though the NPRM 2018 also notes – appropriately in our view – that the national time-series data may be too aggregated to capture consumer interest in fuel economy (EPA 2018a).

When the sales-response model is used to compute the impact on new vehicle sales, the 2018 NPRM implicitly assumes that the average consumer has zero willingness to pay for enhanced fuel economy, since none of the fuel savings of mandated technology are deducted from the gross cost premium for mandated technology. The SAB recommends that the final rule incorporate a more realistic assumption about consumer willingness to pay for fuel savings when sales impacts are computed. Specifically, it might be assumed, as is already assumed in the CAFE Model, that the average consumer acts as if fuel savings in the first 2.5 years of vehicle life are valued when deciding whether to pay a price premium for vehicles with superior fuel efficiency. This approach could be implemented in the simulation of future vehicle sales by using net price, rather than gross price, when forecasting the impacts of regulatory alternatives on new vehicle sales. Net price is operationalized by deducting 2.5 years of fuel savings from the gross price premium for new technology. Following NRC (2015a), sensitivity analyses could be conducted using consumer time horizons of 1 year and 4 years for future fuel expenditures, as 2.5 years is the midpoint of the NRC range.

In a different section of the 2018 NPRM, the agencies review the modern economics literature on consumer demand for fuel economy (EPA 2018a, 182-184). Three recent econometric studies with strong research designs are highlighted (Sallee et al. 2016; Busse et al. 2013; Allcott and Wozny 2014). The basic finding of this literature is that, when fuel prices change, the transactions prices for new and old vehicles with different fuel efficiency ratings adjust accordingly. When fuel prices rise (other factors equal), transactions prices for high efficiency cars rise while transactions prices for low efficiency cars fall. For new vehicle purchases, the 2018 NPRM interprets this literature – relying primarily on one study (Busse et al. 2013) – to mean that the average consumer is willing to pay for at least 75% of the fuel savings that will occur over the life of a new vehicle with superior fuel efficiency. A more recent working paper by Leard et al. (2017) with a somewhat similar research design produces a much lower estimate of consumer valuation of fuel economy than reported by the three original published studies. The NPRM 2018 seeks comment on the question of whether this literature supports a radically different assumption in the final regulatory impact analysis (RIA): one that would build dramatic enhancements of fuel economy into the non-regulatory baseline.

The SAB finds that caution is warranted in the interpretation of the three recent econometric studies of consumer valuation. They evaluate how consumers respond to changes in fuel prices, not changes in the technologies offered on new vehicles. In a rational-choice framework, changes in fuel price and changes in technology can have an equivalent impact on the present value of fuel expenditures. From a behavioral perspective, however, seemingly equivalent changes in fuel price and technology may be perceived quite differently by consumers (Greene and Welch 2016).

Consumers are more familiar with changes in fuel price than with changes in technology, since consumers experience fuel prices each time they refill their tank. New vehicle purchases are much less common in the consumer's experience, especially purchases that involve different fuel-saving technologies or propulsion systems. Many consumers – excluding the limited pool of adventuresome "early adopters" – may be reticent to purchase vehicles at a premium price that are equipped with unfamiliar engines, transmissions, materials or entirely new propulsion systems, even when such vehicles have attractive EPA fuel-economy ratings (Carley et al. 2017). Insofar as consumers do undervalue future fuel savings, the undervaluation is unlikely to be attributable to a pure information effect, as experiments show little impact of perfect fuel efficiency information on measures of consumer choice such as intended and actual vehicle transactions (Allcott and Knittel 2017; Dumortier et al. 2016). A sustained program of behavioral economics research is necessary to fully understand consumer attitudes and decision making about vehicles.

Some natural experiments observed in recent years raise concerns about the notion that consumers are willing to pay, as the 2018 NPRM assumes, 75% of the present value of the fuel savings they will receive as a price premium for a vehicle with new technology. When Hyundai and Kia were forced to downgrade their EPA mileage ratings on selected 2011-2013 models, the resulting changes in vehicle prices imply that consumers of these vehicles value savings in fuel expenditures at a much lower rate (approximately 15-38%) than full valuation (Gillingham et al. 2019). Moreover, while most hybrid-electric vehicles (HEVs) have been offered to consumers at unattractively large price premiums, a minority of HEVs offered in the U.S. from 2004 to 2015 have estimated fuel savings that more than pay for their after-tax price premiums over the life of the vehicle. Nonetheless, fewer than 20% of consumers opt for the HEV option, even when the HEV is visually identical to a gasoline version of the same model and requires no significant compromises in performance, trunk space or other vehicle attributes (Duncan et al. 2019). An especially sharp example of this phenomenon is the HEV version of the Toyota RAV4, which has a short payback period for its $700 price premium and no apparent compromise in performance, seating capacity, or other desired vehicle characteristics. Toyota reports that fewer than 25% of consumers are selecting the HEV version of the RAV4 (Neil 2019). However, in each of the HEV cases above, it is not clear whether consumers are choosing conventional vehicles over HEVs because they undervalue the fuel savings of the HEVs, or because the fuel savings are insufficient to overcome a possible preference for vehicles with traditional powertrains. Further research would be needed to separate the effects.

In summary, the SAB is concerned that the 2018 NPRM is taking analytically inconsistent positions on consumer willingness to pay for fuel efficiency gains. We have recommended an evidence-based, practical approach that can resolve the inconsistency and be implemented with the data already available to the agencies. Sensitivity analyses can be conducted by modifying the assumed consumer time horizon with regard to savings in fuel expenditures.

5.2. Impact of Regulatory Alternatives on New Vehicle Sales

The 2018 NPRM posits that less stringent standards for fuel economy and GHG emissions will boost new vehicle sales by shaving some of the price premiums caused by compliance with the 2021-2025 federal standards. It is also possible that less stringent standards will liberate vehicle manufacturers to offer new vehicles with more desired (fuel-expending) characteristics such as seating capacity, horsepower, torque, trunk space, cargo space, towing capability, safety features and advanced information and entertainment systems. We concur with the agencies that it is not yet feasible to quantify the impact on new vehicle sales of additional vehicle characteristics (beyond fuel economy) that are desired by consumers but restrained by federal standards. Hence, we focus on how the 2018 NPRM quantifies regulatory price impacts on new vehicle sales.

Historically, NHTSA and EPA have used a price elasticity of demand for new vehicles of -1.0 when estimating the impacts of regulation in RIAs. The -1.0 figure seemed to be chosen as illustrative of the possible long-run impact, as it had no forecasted timing (that is, no set date by which vehicle sales were to have fully responded to price changes) and was not based on a particular analysis or study in the academic literature (Zirogiannis et al. 2019).

The 2018 NPRM uses a much lower elasticity of -0.20 to -0.30, based on the national time series model described above. Note that this price elasticity applies to the industry as a whole, and is much lower than published elasticity estimates for individual vehicle manufacturers. It makes sense that industry-wide elasticity is much lower than the price elasticity faced by any individual manufacturer, since the product of one manufacturer can serve as a viable substitute for a product by another manufacturer (Center for Automotive Research 2015). In the regulatory setting, it is assumed that all major vehicle manufacturers (Tesla is a notable exception) will raise prices since they are all incurring costs due to binding CAFE and GHG regulations.

Based on the lagged structure of the time series model, the NPRM argues that a $1,000 increase in average new vehicle price is associated with a loss of about 170,000 vehicle sales in year 1, followed by a reduction of 600,000 vehicle sales over the next ten years. The sales losses seem large but they are modest in size compared to the assumed annual volume of approximately 17 million new vehicle sales each year. Stock et al. (2018) discovered that these values are inflated by several errors in the econometric specification, as well as by an incorrect interpretation of coefficients in the underlying regression. They assert that correcting the interpretation error alone reduces the first year impact from 170,000 to 115,000 vehicles and the cumulative impact from 600,000 to 120,000.

More discussion in the final RIA is needed concerning what the short-run and long-run price elasticities might be in accordance with basic economic principles. New vehicles should have a relatively high price elasticity in the short run, since a consumer can easily hold on to their existing vehicle a bit longer. However, an old vehicle will not be functional forever, and thus the long-run price elasticity for new vehicles is likely to be smaller than the short-run price elasticity (Center for Automotive Research 2015). Thus, it would seem that any boost in new vehicle sales from deregulation would taper over time, which is consistent with the corrected values noted above.

The structure of the national time-series model cannot readily measure the causal effect of changes in new vehicle prices on new vehicle sales. Vehicle prices and vehicle sales are jointly determined in the marketplace: higher prices curtail sales but manufacturers curb prices in response to unexpectedly low sales and raise them when vehicle sales rise unexpectedly. The 2018 NPRM interprets the time-series modeling results as if vehicle prices are exogenous, which is not valid (theoretically) and may not be a reasonable approximation. There are also some omissions of key variables from the sales-response model (e.g., interest rates on car loans and fuel prices) that are known to be causally related to new vehicle sales. It is not obvious whether these omissions create bias in the estimated price coefficients and what the magnitudes of any such biases might be. It would be worthwhile to compare the estimated elasticity from the time series model to the available literature estimates, even though much of the economics literature on this matter is a bit dated. The SAB concludes that some sensitivity analysis with alternative price elasticities – both larger and smaller than -0.2 to -0.3 – is warranted.

The dynamic feature of the sales-response modeling results, uncertain as it is, serves an important role because the 2018 NPRM uses the year-by-year sales impacts to populate a model of future vehicle sales until 2029 under different regulatory alternatives. Use of a single long-term price-elasticity estimate from the literature will not provide the dynamic information required to inform a yearly forecast of new vehicle sales for 10+ years. Thus some combination of the national time series modeling with literature-based estimates of elasticity may be the most tractable path forward. It is reassuring that the projected volumes of new vehicles sales based on the dynamic time series model are roughly consistent with independent sales projections by established forecasters (EPA 2018a, Table 8-2, 956).

5.3. Impact of Alternative Regulatory Policies on the Total Fleet Size, Older Vehicles, and Characteristics of the Vehicle Fleet

The 2018 NPRM takes an important analytic step forward compared to previous RIAs by estimating the impact of regulatory alternatives on new vehicle sales, the size of the total vehicle fleet, and the fleet distribution by vehicle characteristics (age and size). However, the SAB concurs with other commenters and reviewers that there are severe simplifications and flaws in the technical implementation of the fleet turnover modeling that appear to have produced misleading results (e.g., see Bento et al. 2018; NHTSA 2019). Some important features of the fleet-turnover issue are not modeled at all. Thus, the SAB recommends a variety of improvements to the fleet turnover modeling.

In order to account for the rapid market shift from cars to light trucks, the 2018 NPRM uses information from the Energy Information Administration to adjust future-year forecasts for a changing mix of cars and light trucks and for the growing popularity of cross-over vehicles. This adjustment is fine as far as it goes, but the analysis does not address the possibility that regulatory stringency is influencing the types and size-mix of vehicles offered to consumers. Recent market trends and academic studies suggest that, given the current design of the program, stringent fuel-economy and GHG standards have an "upsizing" effect – that is, manufacturers offer more light trucks than cars and more high-footprint vehicles than low footprint vehicles in order to secure the less stringent compliance requirements accorded to light trucks and to vehicles with large footprints (Whitefoot and Skerlos 2012; Jacobsen 2013b; Ito and Sallee 2014; Archsmith et al. 2017; Killeen 2017; Dawson 2018; Neil, 2018). If substantial upsizing is occurring due to stringent regulation, then slowing the pace of increasing stringency could attenuate the upsizing phenomenon. Since upsizing undercuts environmental gains and may create safety risks (due to greater vehicle aggressiveness in multi-vehicle crashes), it is worth exploring the possible impacts of less stringent standards on upsizing, at least qualitatively. In the long run, it may be useful for the agencies to explore some alternative policy instruments that discourage upsizing.

Reviewers have pointed to a concerning feature of the 2018 NPRM modeling of total fleet size (Bento et al. 2018). As deregulatory options shave some of the price premiums from new vehicles, one might expect total fleet size to increase a bit, as car-based mobility is made cheaper relative to alternative modes of transportation (whose prices are unaffected by the rule). The modeling in the 2018 NPRM shows the reverse: deregulation shrinks the size of the vehicle fleet relative to the augural standards by 2029 (by as much as 6 million vehicles in the case of the revised standard).

To fix this apparent flaw in the modeling, the final rule needs to integrate more logically the impacts on new vehicle sales, the likely changes in the prices of old vehicles, and the scrappage rates on old vehicles. Since used cars are a substitute for new cars, their prices are interrelated and move together. There are illustrations in Jacobsen (2013a), Jacobson and van Benthem (2015) and Bento et al. (2018) as to how scrappage rates can be derived as an equilibrium market outcome rather than imposed through a separate statistical exercise. Specifically, the final rule needs to model how changes in new vehicle prices will influence prices of old vehicles, as prices of old vehicles influence scrappage rates. The lower the sales price for an old vehicle, the more likely an owner is to sell it for scrap value than to resell it to another motorist (Jacobsen 2013a). Fixing the fleet-turnover model in the final rule is crucial, since this modeling influences strongly the estimated impacts on GHG emissions, conventional pollutants and safety outcomes.

In summary, the 2018 NPRM takes an important step forward compared to previous RIAs by considering regulatory impacts on vehicle prices, new vehicle sales, sales of old vehicles, and scrappage rates for old vehicles. However, flaws in the technical implementation of the fleet-turnover modeling need to be fixed before it is used in setting policy. Otherwise, misleading results are likely being reported to policy makers. Moreover, the potentially important effects of moderating the upsizing phenomenon also need to be considered, at least qualitatively.

6. FLEET UTILIZATION

Other than the direct costs of compliance discussed in Section 4, which affect the prices of new vehicles, the benefits and costs of both the augural and revised standards arise from the use of the vehicles and are strongly determined by assumptions affecting vehicle miles traveled (VMT).

The 2018 NPRM makes two key assumptions regarding VMT. First, VMT per vehicle is assumed to depend only on the vehicle's age and the price of fuel, and is not adjusted to account for changes in scrappage. In particular, the "scrappage model assumes that the average VMT for a vehicle of a particular vintage is fixed—that is, aside from rebound effects, vehicles of a particular vintage drive the same amount annually, regardless of changes to the average expected lifetimes" (83 FR 43099). Second, it uses a rebound coefficient to capture increases in VMT that occur for new vehicles that have lower fuel costs per mile. We discuss each of these briefly below.

6.1. Use of Fixed Schedules for Vehicle Miles Traveled

A consequence of the fixed-schedule assumption, when combined with the increase in the size of the vehicle fleet discussed in Section 5, is that aggregate VMT rises under the augural standard relative to the revised policy, prior to incorporating rebound. That is, the CAFE Model predicts that under the augural standards, when vehicles are more expensive and fewer new vehicles are purchased, the overall demand for transportation (VMT) will be higher than under the revised standards even before accounting for the lower fuel costs of the new vehicles. Reviewers of the 2018 CAFE Model argued that the VMT schedule should not be independent of the size of the vehicle fleet. Some of their comments are listed below:

> "Predict national VMT demand based on economic indicators, demographic changes, and characteristics of vehicles, and scale the VMT schedules to determine VMT by age."
>
> "Increase the VMTs assigned to older vehicles in the B case versus the P case such that total non-rebound VMT would remain constant between the two cases."
>
> "VMT likely scales less proportionately with fleet size. Adding more vehicles to the fleet should cause age-specific VMT to decline. Start with a fundamental classic economic choice model where the input to utility is VMT to determine the effect of adding an additional vehicle to a household on VMT."
>
> "Fuel economy regulations should not affect household demand for travel [apart from the rebound effect] so the VMT effect could be zero. Hold VMT constant, but vary share of VMT allocated to differently aged vehicles."
>
> "VMT schedule is related to fleet size. More vehicles in the fleet leads to lower VMT per vehicle. Current methodology likely overestimates VMT per vehicle."
>
> "The impact of the change in vehicle stock (both total number and average age) on total VMT should be vetted against expected trends in VMT demand."

In addition, ongoing demographic changes may cause VMT patterns to change in ways that are not reflected well in the current schedules. Given the shift in mobility patterns–of particular note is the drop in car ownership of Millennials as compared to prior generations at the same age, and the rise in shared mobility opportunities—it is important that assumptions about ownership patterns are examined with recent data rather than assumed to follow past patterns. These factors are likely to affect VMT by vehicle age as the role of older vehicles changes under these altered use patterns. Ride sharing vehicles are required to be newer, and later entry into the car market by younger Americans has the potential to also influence the pattern of new and first car purchases.

The SAB recommends that over the longer run the Agency move toward an integrated household choice model to determine VMT simultaneously with the demand for new vehicles and the decision to scrap old ones. In the interim, it should follow the recommendations of the peer reviewers and hold aggregate VMT fixed, apart from effects induced by rebound (NHTSA 2019).

6.2. Magnitude of the Rebound Effect

The rebound effect stems from an increase in driving (VMT) that results when higher fuel efficiency lowers a vehicle's operating cost per mile. The additional driving raises fuel consumption relative to what it would have been with no increase in VMT and it thus offsets a portion of the fuel savings from the efficiency improvement. The effect is typically measured as the elasticity of VMT with respect to the cost of driving. The value used in the 2016 TAR was 0.1 or 10%, indicating that, say, a 15% reduction in the cost of driving would lead to a 1.5% increase in miles traveled. The larger the value of the rebound elasticity, the lower the net reduction in fuel consumption from a given improvement in fuel efficiency.

The magnitude of the assumed rebound effect differs significantly between the 2016 TAR and the 2018 NPRM, as the NPRM doubled its magnitude from 10% to 20%. The 2018 NPRM argues that 20% is close to the mean and median of the results obtained in a large number of studies that it surveys. Bento et al. (2018) contend that the NPRM overlooks much of the relevant literature from the last decade. Many of those papers are based on empirical odometer data (rather than self-reported VMT) and suggest an effect of less than 10%. Relevant literature includes: Langer et al. (2017); West et al. (2017); Knittel and Sandler (2018); and Wenzel and Fujita (2018).

In addition, the assumption of a 20% rebound effect is consistent with an over-generalization of the importance of the rebound effect, assuming the implications of increased efficiency will be seen uniformly across sectors (Gillingham et al. 2013). The relative saturation of demand for VMT will tend to reduce the degree of rebound. Also, for a variety of reasons, the travel behaviors of the Millennial and Baby Boom generations may be less sensitive to changes in the operating costs of their vehicles than is suggested by the older literature on the rebound effect. Looking forward, the size of the rebound effect for ride-sharing services also needs to be considered.

Due to these concerns, the SAB recommends that the rebound estimate be reconsidered to account for the broader literature, and that it be determined through a full assessment of the quality and relevance of the individual studies rather than a simple average of results. A more in-depth analysis will allow the Agency to weight papers based on their quality and applicability: recent papers using strong methodology and U.S. data should be weighted more heavily than older papers, or those from outside the U.S., or those with weaker methodology.

7. IMPACTS AND VALUATION

The aggregate costs and benefits in the 2018 regulatory analysis are strongly influenced by the size of the vehicle fleet and the number of miles the vehicles travel. As a result, the modeling concerns discussed in Sections 5 and 6 suggest that many analytic results reported in the 2018 NPRM need to be redone. For example, the NPRM notes that "the fleet is 1.5% bigger in CY [calendar year] 2050 for the augural baseline than it is for the proposed standards" and "the total non-rebound VMT for CY 2050 is 0.4%" larger (83 FR 43099). As discussed above, both numbers should almost certainly be smaller under the augural standards than under the revised alternative, not larger.

Bento et al. (2018) argue a larger fleet size and higher non-rebound VMT would affect many aspects of the analysis of the proposed revision: fuel costs would be higher, as would be refueling time; benefits from mobility would increase due to increased driving; fatal and non-fatal accidents would increase; emissions of criteria and GHG pollutants from both fuel consumption and upstream fuel production would increase; and national security costs due to vulnerabilities to world oil price shocks would increase, as would noise and congestion. These impacts would be exacerbated by the relatively large rebound assumption discussed in Section 6: a smaller rebound value would lower VMT under the augural standards, further raising VMT under the revised policy in comparison.

Some of these effects would largely net out: increased fuel costs and refueling time would be largely offset by larger mobility benefits. However, others may not. Bento et al. (2018) argue that the increase in non-rebound-related accidents, in particular, is likely to eliminate $88 billion (CAFE) or $110 billion (GHG) in reported net benefits to owners of used vehicles under the proposed freeze, or about half of the $176 billion (CAFE) or $200 billion (GHG) total net benefits. They suggest that these gains appear to be related almost entirely to differences in the size of the fleet and the concomitant change in VMT rather than changes in the mix of vehicles or in vehicle mass.

The magnitudes of these impacts indicate the importance of revising the analysis. However, the overall effect of the changes we recommend on the relative ranking of the augural and revised standards is ambiguous prior to carrying out the analysis. Revisions to the fleet model are likely to reduce the net benefits of the revised standard but other analytical changes we recommend could push the results in the other direction.

8. WITHDRAWAL OF THE CALIFORNIA WAIVER

The 2018 NPRM asserts federal preemption of state-level GHG and ZEV programs and possible withdrawal of the California waivers for programs that are inconsistent with the revised federal programs. Without commenting on the legal issues, we note that the PRIA does not examine the societal consequences (benefits or costs) of this legal interpretation, even though it represents a substantial change in policy. For the final rule, we recommend changes in the final RIA to shed light on the societal consequences.[8]

First, as mentioned above, the augural federal standards for MY 2021 to 2025 should be modeled assuming that they are accompanied by the California ZEV program (2018-2025) and related ZEV requirements in ten other states, since the revised final standards will presumably be relaxing the stringency of the 2021-2025 federal standards and preempting California's authority to implement the ZEV program. The California ZEV mandate is designed to stimulate commercialization of plug-in electric vehicles (PEVs) and/or hydrogen fuel cell vehicles, with plug-in vehicles expected to be the preferred compliance strategy in the pre-2025 period (CARB 2017).

The 2018 NPRM does not include much PEV penetration in the baseline (augural standards) for model years 2021-2025. The PRIA notes that PEVs accounted for roughly 1% of new vehicle sales in model year 2016. In the PRIA baseline, the agencies did not assume steady growth in PEV sales, although EPA, in the 2016 TAR, projected that the PEV penetration rate would rise significantly to 3.5% of the fleet in the 2022-2025 timeframe for reasons unrelated to the federal standards (EPA 2016a, ES-10).

The ZEV program is expected to increase PEV sales steadily through 2025 in both California and the ten aligned states. Specifically, compliance with the ZEV program is predicted to have the practical effect of increasing the PEV penetration rate to somewhere between 6% and 15.4% in the ZEV states by 2025, depending on what types of PEVs are sold by vehicle manufacturers (Shulock 2016; CARB 2017). The PEV sales are expected to be concentrated in California and the other ZEV-mandating states, since PEV sales in other states do not contribute to ZEV compliance. Roughly half of the PEVs sold to date have been sold in the state of California (CARB 2017). State-specific compliance obligations did not begin in the other 10 ZEV states until 2018. Since the ZEV states account for roughly 30% of the new vehicle population, it appears that the ZEV program alone might cause the national PEV penetration rate to rise from 1% in 2016 to 1.8% to 4.7% by 2025.

A 2015 report by the National Research Council agreed with CARB's assessment that state-level ZEV programs (especially CARB's program) have been a key driver of PEV commercialization efforts in the U.S. (NRC 2015b; CARB 2017). Thus, it is questionable whether the PEVs being offered today in the U.S. would continue to be offered in the absence of state-level ZEV programs.

[8] The SAB notes that subsequent to its analysis of the proposed SAFE Vehicles Rule, EPA announced a decision to withdraw the waiver it had previously provided to California for that State's greenhouse gas and zero emission vehicle programs (84 FR 51310 – 51363).

There is a $7,500 federal tax credit for PEVs but it has already been exhausted by Tesla and General Motors, and more manufacturers will soon reach the volume limit in federal tax policy. There were also special advanced-vehicle compliance credits for PEVs in EPA's 2012 final rule but those incentives expire by 2021 (see Section 4.5) and NHTSA does not offer such credits. Tesla and global manufacturers can be expected to continue offering PEVs in Europe and China due to the separate regulatory requirements in those regions of the world but the U.S. market for PEVs, which is restrained by low fuel prices, appears to be driven heavily by state-level ZEV requirements (Carley et al. 2017).

Building ZEV-related PEV penetration into the regulatory baseline will permit the federal agencies to make a rough assessment of the benefits and costs of removing the state-level ZEV mandates. The federal agencies, with CARB's assistance, have already done much of the groundwork necessary to perform a benefit-cost analysis of the state-level ZEV requirements and a previous report from the RAND Corporation lays out the key issues (Dixon et al. 2002; CARB 2017).

On the benefits of removing the state-level ZEV requirements, there are two offsetting effects that need to be considered (Carley et al. 2017). Since PEVs are estimated by the federal agencies to be one of the least cost-effective technologies for increasing fuel economy and reducing GHG emissions (because battery production costs, though declining, remain relatively high), removing the ZEV requirements should lower compliance costs on vehicle manufacturers and reduce costs to consumers (assuming pass through of savings in compliance costs). However, the growing presence of PEVs in the fleets of automakers will make it somewhat less costly for vehicle manufacturers to comply with the federal CAFE and GHG standards, since the federal compliance credits awarded for PEVs will permit fewer costly changes to vehicles equipped with internal combustion engines. The net effect of these two impacts is the anticipated benefit (cost savings) from removing the state-level ZEV requirements.

One recent study considered the offsetting effects and found that the incremental net costs of adding the ZEV requirements to the augural federal standards (2017-2025) is about $660 per vehicle, averaged on a national basis (Jenn et al. 2019). This estimate does not account for the most recent information on either battery production costs or the number of PEVs necessary to minimally comply with state-level ZEV requirements. Nonetheless, it appears that the potential cost savings nationwide from removing the state-level ZEV requirements are large enough to justify serious consideration in the final RIA.

The costs of removing the state-level ZEV requirements – which can be considered the foregone benefits of the ZEV mandates – need to be analyzed with care since there are complicating factors. GHGs are a global pollutant and it does not matter whether the emissions originate in a ZEV state or a non-ZEV state. Moreover, EPA is giving compliance credit in the federal GHG program for PEVs, which means that manufacturers will be free to sell other vehicles that emit more GHG emissions due to the PEVs stimulated by the state-level ZEV programs (see a related analysis of California's GHG program by Goulder et al. 2012). As long as the federal GHG requirements are binding on all vehicle manufacturers, there is no reason to expect that PEVs sold due to state-level ZEV programs will reduce (on net) national GHG emissions (Jenn et al. 2016; Siddiki et al. 2018).

Proponents of the ZEV program argue that the presence of the state-level ZEV requirements causes vehicle manufacturers to innovate, thereby allowing PEVs to become more commercially viable in the post-2025 period than they would be in the absence of the state-level ZEV programs (Lutsey and Sperling 2018). That innovation could cause more GHG control in the long run, and other states and the federal government can learn from California's experience (Lutsey and Sperling 2008; Siddiki et al. 2018). While it is difficult to quantify the foregone GHG benefits of the state ZEV program in the post-2025 period, the agencies should qualitatively consider how likely it is that PEVs will be necessary to address global climate change in the post-2025 period, given the promise of other strategies to further clean the internal combustion engine. Moreover, agencies might consider that other policies could advance PEVs in a more cost-effective manner than ZEV requirements (Dixon et al. 2002; Carley et al. 2017). Some countries (e.g., Norway and the Netherlands) have achieved PEV penetration rates that are much larger than achieved by California, without imposing any ZEV requirements on vehicle manufacturers. Those non-ZEV policies merit serious consideration (IEA 2018).

The original purpose of the ZEV program, which was adopted by California in 1990, was to accelerate the rate of progress in the control of smog and soot (CARB 2011). The agencies should consider carefully whether removal of the ZEV requirements would significantly compromise efforts to enhance local air quality in the ZEV states, since many communities in California and the other ZEV states have persistent problems meeting EPA's health standards for smog and soot. The case for ZEV requirements as a local air-quality control measure is weakened by the fact that, since 1990, California and EPA have adopted several new standards on vehicles and fuels that have caused more than a 90% reduction in the emissions (tailpipe and evaporative) related to formation of smog and soot (Carley et al. 2017). Those standards are designed to ensure that pollution-control equipment works for at least 150,000 miles of vehicle use, though equipment malfunctions occur and state motor-vehicle inspection and maintenance programs are uneven in both stringency and enforcement. Thus, whether removal of the state ZEV requirements would compromise efforts to control smog and soot requires careful analysis.

With regard to both local air quality and GHG control, the final RIA should also consider emissions on lifecycle basis (see Section 4.5). A growing body of literature compares the environmental impacts of PEVs to gasoline vehicles on a state-by-state basis, accounting for state variation in the source of electricity and other factors (e.g., see Michalek et al. 2011; Peterson et al. 2011; Graff-Zivin et al. 2014; Archsmith et al. 2015; Holland et al. 2016). The ZEV states tend to have cleaner electricity systems than the non-ZEV states, so the final RIA needs to consider carefully the lifecycle emissions consequences of removing the state-level ZEV requirements.

9. HANDLING OF UNCERTAINTY

Modeling a system that is driven by factors such as human behavior, technological innovation, dynamic economics, and unpredictable external events is notoriously difficult and complex.[9] In such situations, a model's results may depend as much or more on the assumptions and specific processes chosen to represent the way the system behaves rather than on the first principles of the underlying physical laws. Estimates of future outcomes from such models are often characterized by high uncertainty and low precision.

The 2016 TAR and the 2018 NPRM each make many critical assumptions about uncertain input parameters and model structures. To emphasize the scope of the problem, important assumptions are involved in all of the following: the trajectory of gasoline prices over the next twenty years; the rebound effect; the damages to society from additional CO_2 emissions; the number of vehicles scrapped as new vehicles are manufactured and purchased; the per-vehicle cost of including technological advancements which lower emissions; responses by consumers, including their willingness to buy higher-cost vehicles or continue driving old vehicles; costs to manufacturers as they include improvements in the production stream; the impact on safety; the number of EVs in the mix, including the roles of state mandates, incentives, and battery technology; the value of reduced vulnerability to world oil price shocks; and the accumulation and transfer of credits for overcompliance. Each of these issues introduces complexity and uncertainty into the analysis.

Consider just two of the issues embedded in the estimation of climate benefits: the social cost of carbon (SC-CO_2) and the sensitivity of the climate system to the atmospheric concentration of CO_2. There is a large scientific literature underlying the SC-CO_2 as an approach to quantifying the damages from CO_2 emissions; for a detailed discussion, see National Academies of Sciences, Engineering, and Medicine (NAS) (2017). The 2016 TAR used a global value for SC-CO_2 set at $48 per ton, indicating that a ton of additional emissions causes damages worldwide with a present value of $48. In contrast, the 2018 NPRM took the position that rulemaking in the U.S. should be based on impacts to U.S. residents and used a domestic value of $7 per ton. The $7 domestic SC-$CO_2$ is about 15% of the global value, which is consistent with prior practices of the Interagency Working Group (IWG) when scaling global estimates to domestic values. With that said, the National Academies observed that the IWG's approach to determining a domestic SC-CO_2 should be considered a rough approximation and that further research is needed to develop a more comprehensive measure. The change from a global SC-CO_2 to a domestic value resulted in a decline in estimated benefits from $27.8 billion to $4.3 billion.

Whether measured at the global or domestic level, the social cost of carbon is a complex and highly uncertain construct. Here we note that it is based on three main components, each which contains considerable uncertainty: (a) the sensitivity of the climate system to the concentration of

[9] The challenges of modeling complex systems involving large numbers of uncertain variables describing human behavior has been discussed by Hayek (1974). He argues that failing to acknowledge those uncertainties can lead to misplaced confidence on the part of policy makers, potentially leading to the adoption of undesirable policies. Other observers come to similar conclusions. The National Research Council, approaching the issue from technical perspective, also emphasizes that inadequate understanding of uncertainty can lead to false confidence in the likely outcome of a policy (NRC 2002).

CO_2, (b) the damage function used to assess changes in the climate, and (c) the discount rate. As with many complex models, the assumptions used to generate the SC-CO_2 heavily influence the result. For example, Dayaratna et al. (2017) applied recent empirical estimates for the key assumptions in two integrated assessment models used in computing the SC-CO_2. They showed that doing so reduced the average SC-CO_2 by 50% to 80% relative to values obtained by the IWG. Others have shown that plausible assumptions can lead to distributions of the SC-CO_2 having either significantly higher values or negative portions; i.e. that carbon emissions could produce a net benefit. In this report the SAB has not evaluated the SC-CO_2 and does not take a position on what value is appropriate; rather, we emphasize that the uncertainties in the SC-CO_2 are large. As noted above, the National Research Council (2017) discusses the major uncertainties in the SC-CO_2 in detail and provides research recommendations for how it should be updated over time.

The 2018 NPRM estimates that the proposed rule will raise the atmospheric concentration of CO_2 relative to the augural standards by an extra 0.65 ppm by 2100 (83 FR 42996). That corresponds to cumulative emissions of 5.1 gigatons of CO_2, which is roughly equal to total U.S. emissions of CO_2 in 2017. It concludes that global average temperatures in 2100 are likely to be about 0.003 °C higher as a result (83 FR 43216).[10] The predicted change in temperature depends on both the estimated sensitivity of the climate system and the cumulative change in emissions, both of which are uncertain. Lower emissions or lower climate sensitivity would reduce the change in temperature while higher emissions or higher sensitivity would raise it.

Returning to the broader issue, the challenge for agency analysts is how to characterize and report the degree of scientific uncertainty in the results of benefit-cost analyses when there are numerous uncertain inputs and some of the inputs are associated with huge uncertainty. Although it is a formidable task, extensive guidance is available. Methods for categorizing and analyzing the uncertainties arising in environmental regulations have been discussed in detail by the National Research Council (NRC 2002) and the Institute of Medicine (IOM 2013); both reports were written at the request of EPA. The 2018 NPRM, and the 2016 TAR before it, apply only a subset of those practices and thus provide an incomplete characterization of the uncertainty in the analysis. As noted by the NRC, inadequate attention to uncertainty will leave decision-makers with false confidence in the results of the analysis (NRC 2002, p.141).

To address this issue, the SAB recommends that the agencies move toward more fully implementing the recommendations made by the NRC and the IOM. A detailed discussion of the appropriate approach is beyond the scope of this review but in short it should: (1) characterize the uncertainties in the model's input variables and parameters; (2) characterize the uncertainties in the model's assumptions and specification; and (3) test the sensitivity of the model's results to those uncertainties to determine which have policy-relevant impacts. Together, those steps will allow the agencies to provide improved guidance for policy-makers on the overall precision of the results.

[10] Some members of the Board noted that the direct impact on global temperatures would be very small even if the change in GHG emissions due to moving from the augural standards to the proposed revision were twice as large as estimated by the Agency.

EPA's current approach, which was used in both the 2016 TAR and the 2018 NPRM, is deterministic sensitivity analysis. In this report we have recommended an expansion of the number of inputs that are treated in this manner. Under sensitivity analysis the values of uncertain inputs are changed one at a time and the corresponding results are reported. The approach is a standard tool in policy analysis. It helps separate uncertainties into two groups: those that have important impacts on the results and others that are less relevant for the issue at hand.[11] It thus helps sharpen the focus of the uncertainty analysis to the variables that matter most, keeping it more manageable in scope.

However, single-variable deterministic sensitivity analysis alone does not provide guidance about the likelihood of different outcomes, nor does it reveal for policy makers the cumulative effect of multiple uncertain inputs.[12] In future rulemakings on this issue, the SAB recommends that the agencies consider adding supplementary methods of uncertainty analysis. One approach is deterministic scenario analysis, where each of several scenarios is characterized by a different set of inputs. For example, one scenario could include plausible inputs that are favorable to the augural standards while another scenario could include plausible inputs that are favorable to the proposed revision. Some scenarios of this form are already included in the 2018 NPRM but we are suggesting a more systematic exploration of alternative scenarios.

Better yet would be to move toward comprehensive probabilistic analysis, allowing the agencies to report confidence intervals for modeling results. OMB Circular A-4 (2003) instructs agencies, when engaged in billion-dollar rulemakings, to undertake a probabilistic uncertainty analysis, in addition to deterministic sensitivity and scenario analyses. The uncertain inputs are characterized as probability distributions, and then simulation methods are employed to generate probability distributions on the results of cost-benefit analyses. This approach can be usefully combined with scenario analysis to examine the impacts of assumptions and inputs that have large effects on the analysis but are not themselves probabilistic, such as decisions about whether to use a domestic or global SC-CO_2, or the choice of the social discount rate. EPA and NHTSA both developed some experience with probabilistic analysis in the years immediately after Circular A-4 was issued but the practice appears have been used less frequently over the last decade. Some form of probabilistic uncertainty analysis would be consistent with NRC (2002) and should be considered for inclusion in CAFE and GHG rulemakings.

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[11] For one approach to evaluating large numbers of uncertain variables, see Santner (2003).

[12] In a system composed of many components, single-variable uncertainty analysis can provide misleading results. For example, statistically independent uncertainties will lead to larger uncertainty in output variables than would be indicated by any of the uncertainties in isolation. Uncertainties that are correlated, on the other hand, can lead to either larger or smaller uncertainties in output variables than would be expected from the individual uncertainties alone.

10. CONCLUSION

The scope of this review was tightly constrained by time and resources. It focused on the most critical aspects of the 2018 NPRM and is not in any way a complete peer review of the analysis. The Board notes that many additional concerns have been raised in public comments on the rule. However, the SAB has generally not reviewed the scientific and technical basis of aspects of the NPRM other than those discussed here.

The review identified several areas where there appear to be significant weaknesses in the analysis underlying the 2018 NPRM. In particular, two of the new modules recently added to the CAFE Model, the sales and scrappage equations, have weaknesses in their theoretical underpinnings, their econometric implementation and, in one case, possibly in the interpretation of their coefficients. Together they generate implausible results regarding the overall size of the vehicle fleet.

Moreover, when combined with the CAFE Model's assumptions about vehicle miles traveled, and considering other smaller problems and inconsistencies, these issues are of sufficient magnitude that the estimated net benefit of the proposed revision may be substantially overstated. In fact, the weaknesses are sufficiently important that they could reverse the sign of result, indicating that the augural standards provide a better outcome than the proposed revision.

While many of the necessary analytic changes will move the results in favor of the augural standards compared to the proposed revision, some of the changes could move the results in the opposite direction, providing less support for the augural standards. For example, if the manufacturers respond to less stringent standards with diminished upsizing of their vehicle fleets, some beneficial environmental and safety outcomes may occur.

Moreover, some of the necessary analytic changes have an unpredictable net effect on the results. Consider what may happen if the state-level ZEV requirements are analyzed as we recommend. Inclusion of the state-level ZEV requirements in the baseline should reduce the incremental costs of the augural standards. However, preemption of the state-level ZEV programs under the revision would reduce the price premiums on new vehicles that are attributable to compliance with the ZEV requirements. The net effects on the compliance costs to manufacturers and on consumer welfare are not obvious without careful analysis.

Finally, the withdrawal of California's waiver from federal preemption under the Clean Air Act will ultimately affect more than a dozen states and a large fraction of the national population. Without commenting on the legal issues underlying the change, the SAB notes that it is a substantial change in policy and should be explicitly analyzed in order to shed light on the societal consequences.

The SAB strongly recommends that the Agency address the analytical weaknesses discussed in this report in the regulatory analysis prepared for the final rule. In addition, the SAB provides longer term recommendations for future rulemakings regarding the choice among modeling frameworks and the treatment of uncertainty.

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