SCIENCE ADVISORY BOARD

A Federal Advisory Committee to the U.S. Environmental Protection Agency

December 15, 2022

EPA-SAB-23-001

The Honorable Michael Regan
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Final Science Advisory Board Regulatory Review Report of Science Supporting EPA Decisions for the Proposed Rule: Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (RIN 2060-AU41)

Dear Administrator Regan,

The Environmental Research, Development, and Demonstration Authorization Act of 1978 (ERDDAA) requires the Environmental Protection Agency (EPA) to make available to the Science Advisory Board (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 make available to the Administrator, within the time specified by the Administrator, its advice, and any comments on the adequacy of the scientific and technical basis of the proposed action. Thus, the SAB is submitting the attached regulatory review report on the scientific and technical basis of the proposed rule titled "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (RIN 2060-AU41), published in the Federal Register on March 28, 2022 (87 FRN 17414).

The EPA has proposed a rule that would reduce air pollution from highway heavy-duty vehicles and engines, including ozone, particulate matter, and greenhouse gases. The proposal would change the heavy-duty emission control program—including the standards, test procedures, useful life, warranty, and other requirements— to further reduce the air quality impacts of heavy-duty engines across a range of operating conditions and over a longer period of the operational life of heavy-duty engines.

In conducting this review, the SAB followed the engagement process for review of science supporting EPA decisions outlined in the memo of February 28, 2022, signed by the Associate Administrator in the Office of Policy, the Deputy Assistant Administrator for Science Policy in the Office of Research and Development, and the Director of the Science Advisory Board Staff Office.

The SAB met by video conference on May 31, 2022, and June 2, 2022, and elected to review the scientific and technical basis of the proposed rule. The SAB discussed providing advice on the proposed rule and future regulatory actions the agency would consider. A workgroup consisting of a subset of SAB members was assembled to review the proposed rule and respond to charge questions developed by the SAB on several topics of interest including air quality, costs and benefits, and environmental justice considerations. The workgroup took the lead in SAB deliberations at the November 3-4, 2022, public virtual meeting on the science supporting the proposed rule. Oral and written public comments were considered throughout the process. The SAB's advice and comments on the science supporting the proposed rule are provided in the enclosed regulatory review report. Appendix A to the report provides additional context for considering justice in EPA regulations from SAB member Dr. Sacoby Wilson. While the SAB is not providing recommendations on these points for the Heavy-Duty Engine and Vehicle Standards rule specifically, the SAB interprets justice as broader than environmental justice. The Board acknowledged that this review was relatively narrowly focused in terms of environmental justice and expects the EPA to continue to develop approaches for addressing other dimensions of justice in its activities.

The SAB appreciates the opportunity to provide comments on the science supporting the proposed rule. We look forward to receiving the Agency's response.

Sincerely,

/s/

Alison C. Cullen, Sc.D.
Chair
Science Advisory Board

Enclosure

NOTICE

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Science Advisory Board Regulatory Review of Science Supporting EPA Decisions for the Proposed Rule: Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (RIN 2060-AU41)

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ACRONYMS AND ABBREVIATIONS

ATS	American Thoracic Society
CARB	California Air Resources Board
CO_2	Carbon Dioxide
COI	Cost-of-Illness
EJ	Environmental Justice
EO	Executive Order
EV	Electric Vehicle
ERDDAA	Environmental Research, Development, and Demonstration Authorization Act of 1978
ISA	Integrated Science Assessment
NAAQS	National Ambient Air Quality Standards
NPRM	Notice of Proposed Rulemaking
NO_2	Nitrogen Dioxide
NO_X	Nitrogen oxide
PM	Particulate Matter
RIA	Regulatory Impact Analysis
SAB	Science Advisory Board
TRAP	Traffic-Related Air Pollution
U.S. EPA	United States Environmental Protection Agency
VSL	Value of Statistical Life
WTP	Willingness to Pay

PREAMBLE

The Science Advisory Board reviewed the regulatory support documents for the EPA's proposed rule, Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards ("proposed heavy-duty vehicles emissions standards"). The SAB commends EPA for proposing to strengthen heavy-duty vehicles nitrogen oxide (NOx) emissions standards, which is necessary to protect health, particularly for children. Research shows that traffic-related air pollution is inequitably distributed, with communities of color and those with lower educational attainment and income levels experiencing higher pollution concentrations compared with averages for the general population. Research also shows that heavy-duty vehicles are a major contributor to inequitable traffic-related air pollution distributions. In addition, reducing heavy-duty vehicle NOx emissions is necessary to reduce air pollution disparity, which persists across the U.S. despite declining regional average pollution levels over decades.

Despite the potentially large improvements the proposed heavy-duty vehicle emissions standards may have for reducing traffic-related air pollution in overburdened communities, current methods used in EPA's Draft Regulatory Impact Analyses (RIAs) are not sufficient to capture community-scale benefits. Therefore, **the SAB strongly recommends that EPA develop a strategy for systematic, quantitative evaluation of the environmental justice (EJ) impacts of air pollution regulations**.

Since 1994, Executive Order (EO) 12898 has required federal agencies to "identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations, to the greatest extent practicable and permitted by law," and since 1993, EO 12866 has required federal agencies to conduct distributional analysis as part of regulatory impact analysis (Revesz and Yi 2022). In 2020, President Biden's Memorandum on Modernizing Regulatory Review further emphasized the need to broadly implement distributional analysis in the regulatory process. Nonetheless, recent studies suggest that while agencies like EPA have responded to these and other "presidential pronouncements" on the distributional consequences of regulation, these concerns are rarely addressed in a rigorous quantitative manner in individual rules and have never been addressed systematically across rules (Revesz and Yi 2022).

The SAB appreciates EPA's efforts to highlight distributional concerns in air quality regulation. However, present data and computation limitations hinder the EPA's ability to conduct detailed distributional analyses for every pollutant, for this rule and others. The SAB finds that substantial advancements can be made beyond the analyses contained within the EPA's RIA for the proposed heavy-duty vehicle emissions standards, and that data and computational improvements in recent years and expected in the coming years can help overcome some of these constraints. For example, the research community has been developing satellite-derived estimates of criteria and traffic-related air pollutants ($PM_{2.5}$, NO_2, elemental carbon) that can provide baseline estimates of pollution levels at the neighborhood scale, high-resolution (1km) emissions that are consistent with the National Emissions Inventory, and high resolution (1km, 4km) chemical transport model setups. With regard to health effects data, recent epidemiological analyses are available that leverage nationwide cohorts (e.g., Medicare) to evaluate concentration-response functions for individual population subgroups, considering differential access to health care and other known discriminatory practices that influence exposure to air pollution.

The SAB recommends that EPA consider what new information could be incorporated in RIAs to make progress beyond the typical 12km modeling of $PM_{2.5}$ and ozone, which is too coarse to capture neighborhood-scale impacts and excludes other pollutants that are more inequitably distributed, such as NO_2 and black carbon. Due to these technical limitations, the current approach precludes analysis of the environmental justice (EJ) benefits of emission reductions, particularly for traffic-related air pollutants (e.g., NO_2, black carbon) that exhibit strong spatial gradients. The new information that could be considered includes satellite-derived pollution estimates, higher resolution emissions inventories and chemical transport modeling, and epidemiological concentration-response functions and disease rates for different population sub-groups.

The SAB recommends that EPA's plan for including distributional analyses in RIAs address the following considerations *that pertain to air quality regulations specifically*:

- Impact chains including emissions, concentrations, risks, and health impacts.
- Other pollutants in addition to $PM_{2.5}$ and ozone, including those that are very short-lived and exhibit stark spatial gradients at street-level and neighborhood scales, such as NO_2 and black carbon.
- A balance between (1) additional granularity needed for characterizing highly spatially heterogeneous pollutants, and (2) data and computational limitations that could hinder EPA from producing timely analyses for National Ambient Air Quality Standards (NAAQS) reviews and regulations. Where additional time and resources would be needed to appropriately address the considerations above, the plan should explicitly state these challenges and, if possible, include avenues for overcoming these limitations in the future.

In addition, the SAB recommends that EPA's plan for including distributional analyses in RIAs address the following considerations *that apply more broadly to other regulations as well as air quality regulations*:

- Pollutant mixtures and chemical and non-chemical cumulative impacts that interact to affect health, well-being, and quality of life. EPA's "Cumulative Impacts: Recommendations for ORD Research" report, for which the External Review Draft published in January 2022 was available at the time of this writing (Julius et al. 2022), provides a valuable resource for current capabilities and knowledge gaps.
- Both the *vulnerability* of the population with respect to who is disproportionately exposed and the *susceptibility* of the population that accounts for differences in disease rates, access to high-quality healthcare, and other factors that may affect the severity of health outcomes resulting from air pollution exposure. Such considerations may require the use of neighborhood-scale disease rates and concentration-response functions that are specific to different population sub-groups.
- Consistent Agency definitions and approaches for distributional analyses that reflect the current state of the science on appropriate spatial units of analysis and categorizations of race, ethnicity, and socioeconomic status.
- Meaningful public engagement, including a diverse range of interested parties, in needs assessment, planning, implementation, and evaluation.

The SAB also notes that the proposed rule's RIA lacked quantification and monetization of the climate benefits that would come from reduced CO_2 emissions. The Notice of Proposed Rulemaking (NPRM) preamble (87 FR 17606) published on March 28, 2022, noted:

"There would be climate-related benefits associated with the CO_2 emission reductions achieved by the targeted revisions, but we are not monetizing them in this proposal[888]. We request comment on how to address the climate benefits and other categories of non-monetized benefits of the proposed rule. We intend to conduct additional analysis for the final rule after reviewing public comments related to the proposed revised standards and considering any changes to the proposed advanced technology credit program."

Footnote 888 indicates that "The U.S. District Court for the Western District of Louisiana has issued an injunction concerning the monetization of the benefits of greenhouse gas emission reductions by EPA and other defendants. See Louisiana v. Biden, No. 21-cv-01074-JDC-KK (W.D. La. Feb. 11, 2022)." As the 5th Circuit Court of Appeals reinstated the social cost of greenhouse gases used to value the climate impacts of rulemaking, this metric can now be used to estimate the benefits of reduced greenhouse gas emissions for this proposed rule.

Though the U.S. government's current social cost of greenhouse gases is a limited metric—there are new studies showing that the health damages of climate change are significantly higher than estimated in earlier studies (Carleton et. al. 2022, Rennert et. al. 2022) — the SAB strongly recommends that the Agency include the valuation of climate benefits in the final rule, as the Agency stated they intended to do in the notice of proposed rulemaking. Note that the SAB did not review the EPA's "Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances" because it was released in September 2022, after an SAB workgroup had completed its review of the proposed heavy-duty vehicle emissions standards.

Preamble References:

Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R.E., McCusker, K.E., Nath, I., Rising, J., Rode, A., Seo, H.K., Vianene, A., Yuan, J., and Zhang, A.T. 2022. Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits. *The Quarterly Journal of Economics* 1–69. https://doi.org/10.1093/qje/qjac020. Advance Access publication on April 21, 2022.

Julius, S., Mazur, S., Tulve, N., Paul, S., Loschin, N., Geller, A., Shatas, A., Dionisio, K., Owens, B., Lee, S., Williams, J., Hoffman, J., Buck, K., Smith, D., Barzyk, T., Nweke, O., Lee, C., Braverman, C., and Small, M. 2022. *Cumulative Impacts: Recommendations for ORD Research.* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-22/014.

Rennert, K., Errickson, F., Prest, B.C., et al. 2022. Comprehensive evidence implies a higher social cost of CO_2. *Nature* 610, 687–692. https://doi.org/10.1038/s41586-022-05224-9

Revesz, R.L., and Yi, Samantha P. 2022. Distributional consequences and regulatory analysis. *Environmental Law* 52(1): 53-98.

1. INTRODUCTION

As part of its statutory duties, the Environmental Protection Agency (EPA) Science Advisory Board (SAB) may provide advice and comments on the scientific and technical basis of planned EPA actions pursuant to the Environmental Research, Development, and Demonstration Authorization Act of 1978 (ERDDAA). ERDDAA requires the EPA to make available to the SAB proposed criteria documents, standards, limitations, or regulations, together with the relevant scientific and technical information on which the proposed action is based. Based on this information, the SAB may provide advice and comments. Thus, the SAB has reviewed the scientific and technical basis of the proposed rule titled "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards published in the Federal Register on March 28, 2022 (87 FR 17414).

EPA proposed the rule to reduce air pollution from highway heavy-duty vehicles and engines, including ozone, particulate matter, and greenhouse gases. The proposal would change the heavy-duty emission control program—including the standards, test procedures, useful life, warranty, and other requirements— to further reduce the air quality impacts of heavy-duty engines across a range of operating conditions and over a longer period of the operational life of heavy-duty engines.

The SAB met by video conference on May 31, 2022, and June 2, 2022, and elected to review the scientific and technical basis of the proposed rule. The SAB discussed providing advice on the proposed rule and future regulatory actions the agency would consider. A workgroup of the SAB took the lead in reviewing the proposed rule and considering topics and questions of interest raised by the SAB including air quality, costs and benefits, and environmental justice (EJ) considerations. Proposed recommendations concerning the proposed rule were discussed at a November 3-4, 2022, virtual public meeting of the chartered SAB. Oral and written public comments were considered throughout the process.

In conducting this review, the SAB followed the engagement process for review of science supporting EPA decisions outlined in the February 28, 2022, memorandum, signed by the Associate Administrator in the EPA Office of Policy, the Deputy Assistant Administrator for Science Policy in the EPA Office of Research and Development, and the Director of the EPA Science Advisory Board Staff Office. All materials and comments related to this document are available at: https://sab.epa.gov.

2. SAB ADVICE AND COMMENTS ON THE PROPOSED RULE

Air Quality.

2.1. Given the spatial resolution of this rule's air quality modeling and its inability to reflect the near-roadway NO_2 gradient, would NO_2 assessment be informative for this rule*?*

Assessing NO_2 concentrations for this rule would be informative, despite the relatively coarse spatial resolution of the air quality modeling performed. The Nox emission reductions are expected to decrease $PM_{2.5}$ and ozone concentrations, as discussed in the proposed rule. They are also expected to reduce NO_2 concentrations, likely a proxy for the traffic-related air pollution, which are associated with health outcomes (see question 2.3). NO_2 is also more inequitably distributed compared with $PM_{2.5}$ and ozone, so including NO_2 provides information about distributional benefits that would complement the $PM_{2.5}$ and ozone analyses. While the SAB finds that a long-term strategy for including distributional analyses in RIAs is needed, as described in the Preamble, here we suggest several ways to assess NO_2 for the heavy-duty vehicle emissions standards, which are on a faster timeline. We note that while there are currently no non-attainment areas for the NO_2 National Ambient Air Quality Standard, epidemiological studies show that there are health effects of NO_2, either on its own or as a proxy for traffic-related air pollution, at levels far below the current standard. See Question 2.3 for further SAB advice on calculating health benefits of reduced NO_2.

Recommendations:

The SAB recognizes that there is unlikely to be enough time to complete a thorough analysis with sufficient spatial resolution to capture the near-roadway and neighborhood-scale NO_2 variation before the rule is promulgated. In fact, the RIA indicates that data and methodological limitations may preclude analysis addressing actual environmental justice benefits. Therefore, we offer three recommendations to address these current limitations by acknowledging important omissions from this rule, incorporating additional existing data, and/or revising the current analysis. Recommendations for modeling future environmental justice benefits of NO_2 reductions are included in the "SAB Advice for Future Regulation Actions" section of this report.

1. At minimum, this rule would benefit from a thorough discussion of what is missing by not including an assessment of NO_2 concentrations and the implications of using a 12km x 12km grid, which cannot reflect near-road NO_2 gradients, for the conclusions that can be drawn. Discussion of the uncertainty around the projected average change in NO_2 concentrations in 2045, implications for the use of different metrics of NO_2, and potential for new NO_2 nonattainment areas due to the proposed rule would be helpful.

2. This rule should consider the use of other existing data that can be included such as the California Air Resources Board (CARB) NO_x assessment. The CARB assessment (2019) provides valuable information on state-level programs that were not finalized at the time that the air quality modeling analysis for the proposed rule was initiated (i.e., the CARB Heavy-Duty Low NO_x Omnibus rule). These data can be incorporated into reference scenarios. Additional data sources (e.g., satellite-derived data, Nox emissions, etc.) should also be assessed.

3. The proposed rule can use NO_2 data from the Agency's modeling while acknowledging limitations that come along with using the data, including a lack of spatial resolution in the data and their implications for the estimated impacts. A key limitation is the ecological fallacy from bias that occurs by inferring relationships between individual units (e.g., individuals, households) from larger, more aggregated units (e.g., states,

counties) that contain those units. (e.g., Baden, Noonan, and Turaga (2007) surveyed 110 environmental justice studies to assess the unit of analysis impact on measurement).

2.2 Would the effect of heavy-duty vehicles on local air pollution be informative for this rule? Are there concerns for equity across different communities?

The SAB finds that information on the effect of heavy-duty vehicles on local air pollution would be informative for this rule, both generally and considering concerns for equity across differentially exposed communities. Plausibly causal estimates in the economics literature show that exposure to vehicle emissions near major roadways increases premature adult mortality (Anderson 2020), infant mortality (Currie and Walker 2011, Knittel et al. 2016), childhood asthma (Marcus 2017), and other important negative outcomes such as violent crime (Herrnstadt et al. 2021). Evidence also suggests that the negative effects of vehicle emissions from roadways on infant health are greater for low-income than for high-income households (Long et al. 2021), and greater for more vulnerable (i.e., lower birthweight) infants (Knittel et al. 2016). The impacts of heavy-duty vehicle emissions, in isolation, are not as well-studied, but some evidence suggests that reducing diesel emissions from heavy trucks (even if replaced by a similar flow of light-duty gasoline vehicles) reduces cardiovascular and respiratory hospitalizations and deaths (He et al. 2018). Taken together, these papers suggest that households in close proximity to major roadways suffer differential health effects from transportation emissions and that those effects may raise significant environmental justice concerns given the typical demographic composition of neighborhoods near highways (Rowangould 2013), especially truck freight routes (U.S. EPA 2021).

The SAB applauds the EPA for discussing EJ concerns thoroughly in a qualitative manner in the RIA (U.S. EPA 2022). However, these concerns are inadequately addressed in the modeling that supports the development of the rule's health benefit estimates. For example, the MOVES modeling for the Agency's air quality analysis for this rule is done at the county level. Analyzing air pollution impacts at a finer spatial scale would likely be informative for the demographic analyses performed in the RIA. The literature shows that aggregating pollution exposure at the county or similar spatial scales masks significant local variations in exposure to pollution and other environmental hazards (Banzhaf et al. 2019, Baden et al. 2007).

Recommendations:

For the current rule, we recommend that the Agency cite the literature described above and carefully discuss the likelihood that aggregation impairs the ability to analyze the rule's local impacts, a key EJ consideration. In future analyses, the Agency should estimate impacts within a small distance of large roads/highways, perhaps doing so for the urban areas most likely to be affected by the regulation, in order to better describe the regulation's likely differential impacts by race, income, and other characteristics of exposed populations. In addition, cumulative exposure to multiple risk factors, including exposure to other air pollutants, heat, and lead, should be assessed in future analyses.

2.3. Can benefits be estimated for the reduction of NO_2 as for PM and Ozone in this rule for children's asthma or other adverse health effects?

The SAB finds that benefits can be estimated for reduction of NO_2 as for PM and ozone based on the assumption that NO_2 is causally associated with children's asthma and other adverse health effects and that causation can be reasonably apportioned among the components of the air pollution mixture. Abundant evidence points to ambient air pollution, specifically PM and ozone, as drivers of the increased prevalence of childhood asthma worldwide, contributing to exacerbation and possibly to onset.

Biological Plausibility:

With respect to NO_2 exposure, particularly with regard to beneficial consequences of mitigation, direct health benefits for pediatric asthma are plausible but there is substantial uncertainty. From a mechanistic standpoint, controversy exists as to whether NO_2 is a direct contributor to asthma morbidity, performs in the context of concurrent exposures, or is a marker of traffic-related air pollution (TRAP). Controlled exposure maneuvers in adult volunteers show that NO_2 can trigger mild inflammation even at high exposures (Goodman et al. 2009, Hesterberg et al. 2009). Similar studies have not been conducted in children.

Investigations of Childhood Asthma:

Question 2.3 refers specifically to the occurrence/diagnosis of asthma. Capturing asthma onset or incidence in epidemiological studies is challenging, in part because of the overlap of various clinical syndromes (e.g., lower respiratory infections with wheezing, seasonal allergies with wheezing, exercise-induced bronchial hyperreactivity) and asthma. Additionally, physician-diagnosed asthma, an indicator used in epidemiological research, is heterogeneous in its designation. Additionally, separate, but perhaps overlapping factors, may lead to the onset of asthma and to the diagnosis of asthma.

There is no set of universally agreed upon methods to establish the onset of incident asthma in healthy children, forcing reliance on a battery of approaches in the available studies. These include point prevalence assessments in which pollutant exposure is documented at an early stage of healthy life and disease ascertainment determined later, period prevalence studies in which a single time-period exposure in healthy children is followed by monitoring for subsequent asthma and cumulative exposures over prolonged time periods with similar disease ascertainment. The critical element to all of these strategies is the establishment of a baseline healthy state. Given the multiple extrinsic and intrinsic risk factors for asthma, a healthy baseline state is not well described. Additionally, when exposures occur during a developmentally vulnerable period of airway maturation, arguably from birth to year 4, adverse exposures can have complex effects on airway structure that can simulate conventional asthma. For these reasons, observational studies demonstrate conflicting associations of environmental NO_2 and incident pediatric asthma. Early life NO_2 exposure is only modestly associated with childhood asthma in a Latino and African American cohort (Nishimura et al. 2013). Two prospective cohort studies evaluating new-onset asthma with metrics of regional traffic emissions in young children show a significant increased risk (HR-2.17, 1.29 respectively) associated with ambient NO_2 (McConnell et al. 2010, Jerrett et al. 2008). One of these studies used personal monitors supporting the relevance of individual exposure readouts (Jerrett et al. 2008).

Baseline allergic predisposition confers greater susceptibility to asthma onset in children exposed to airborne pollutants including NO_2 (Dong et al. 2011). There are data showing that NO_2 exposure may also promote allergic features.

Estimating Independent Effects of NO_2:

Estimating "independent" causal effects of NO_2 is challenging, as NO_2 and nitrous oxide are ozone precursors and also contributors to PM mass. Additionally, in urban environments, NO_2 concentration has been considered as an index of the air pollution mixture resulting from vehicle emissions, sometimes referred to as "TRAP" or traffic-related air pollution. Any modeling of potential health benefits for childhood asthma associated with reduction of NO_2 concentration comes with the implicit assumption that lowering NO_2 concentration itself will lead to a decline in risk for childhood asthma, rather than from a general reduction in the TRAP mixture. There are substantial uncertainties around that assumption, which the draft RIA partially acknowledges (page 178) in addressing non-respiratory health outcomes. The text describes concern for "co-pollutant confounding," an overly simplistic description of the mixture problem, particularly that from the TRAP mixture.

Relevant Epidemiological Studies:

Asthma prevalence studies conducted over the last two decades consistently show an association with metrics of TRAP exposure. Moreover, observational studies similarly suggest that ambient NO_2 exposure worsens baseline asthma based on morbidity metrics of exacerbations, hospitalizations, emergency room visits, enhanced symptoms or increased medication use. (Mann et al. 2010. And Iskandar et al. 2012). Since pediatric asthma encompasses multiple subphenotypes with distinct mechanisms of development and persistence, the question of whether NO_2 exposure worsens specific types of asthma has not been resolved and merits further examination (Deliu et al. 2017). Overall, the effects are modest but consistent across diverse and regionally distinct cohorts. Multicomponent analyses have not clarified relevant interactions among conventional or nonconventional pollutants in causing the onset of childhood asthma. A further limitation is posed by exposure assessment methods. Exposure metrics currently rely on routine monitoring stations, standard land use regression models, and air pollution dispersion models, all having strengths and limitations. Spatial resolution, while improving, is not fully granular to assess differential associations across neighborhoods, economic zones, etc. Once quantified metrics of exposure can be linked to pediatric asthma subphenotypes and morbidity scores, dose responses will facilitate more targeted policies that can address aggregate burdens and disparate susceptibilities.

With regards to the exposure-response relationship for NO_2, a systematic review by Khreis et al. (2017), "Exposure to traffic-related air pollution and risk of on-set of childhood asthma: A systematic review and meta-analysis," provides relevant results. In a database of 41 studies, the authors examine associations of indicators of asthma onset with NO_2, PM, and ozone in assessing the role of TRAP. The studies identified reflect the diversity of indicators for asthma occurrence and the limitations of the data available to examine associations of TRAP and its components with asthma incidence. Overall, there was a small, statistically significant association of NO_2 but substantial heterogeneity among studies. The relative risk of pediatric asthma incidence was 1.05 (95% CI, 1.02-1.07) per 4 $\mu g/m^3$ increase in annual average NO_2. The authors interpret the results as reflecting NO_2 as a surrogate for the mixture or some other component.

Reviews in the 2016 NO_2 Integrated Science Assessment (ISA), the Health Effects Institute TRAP Report, the American Thoracic Society, and the 2021 WHO Air Quality Guidelines:

Several systematic reviews have examined the relationships between NO_2 and health outcomes. The 2016 NO_2 Integrated Science Assessment (ISA) found the evidence to be at the causal level for short-term NO_2 exposure (minutes up to 1 month) and respiratory effects and "likely to be causal" for long-term exposure (more than 1 month to years) and respiratory effects. The likely causal determination for long-term NO_2 exposure and respiratory effects was based on evidence for asthma onset, in particular among children (U.S. EPA 2016)

The 2022 review of TRAP by the Health Effects Institute found the following:

"*The Panel concluded that the overall level of confidence in the evidence for an association between exposure to TRAP and asthma onset in both children and adults and acute lower respiratory infections in children was considered moderate to high. Studies examining exposure to NO_2 have made the greatest contribution to this evaluation. The overall level of confidence in the evidence for an association between TRAP and asthma ever and active asthma in children was moderate. Asthma ever refers to lifetime asthma prevalence and active asthma refers to prevalence of asthma in the last 12 months.*" (Health Effects Institute 2022).

A 2020 report of the American Thoracic Society (ATS) workshop on outdoor air pollution and new-onset airway disease provides further review on mechanistic, epidemiological, and clinical aspects of airway disease related to air pollution (Thurston et al. 2020). The Epidemiology Group "found that long-term exposure to air pollution, especially metrics of traffic-related air pollution such as nitrogen dioxide and black carbon, is associated with onset of childhood asthma." The Mechanistic Group "concluded that air pollution exposure can cause airway remodeling, which can lead to asthma or COPD..." And, finally, the Clinical Group "concluded that air pollution is a plausible contributor to the onset of both asthma and COPD." The workshop report concluded that "The strongest epidemiological evidence for a causal relationship with new-onset childhood asthma comes from studies that used NO_2 as the TRAP metric." Thus, this ATS workshop concluded that air pollution is a cause of childhood asthma, and the strongest evidence is from studies that used NO_2 as a marker for the TRAP mixture.

The 2021 revision of the World Health Organization's Air Quality Guidelines offered comments on the strength of evidence for shorter-term and longer-term exposures to NO_2. For shorter-term exposures (i.e., 24 hours), the evidence was judged to be causal for respiratory effects, but suggestive for all-cause mortality (WHO, 2021). A 24-hour guideline value of 25 $\mu g/m^3$ was proposed. For longer-term exposure to NO_2, a guideline value of 10 $\mu g/m^3$ was proposed based on a 2020 meta-analysis of epidemiological study results on all-cause mortality by Huangfu and Atkinson (2020). The evidence was not considered as reaching the causal level.

Recommendations:

Benefits can be estimated for NO_2 using existing epidemiological data, but the estimates would be subject to substantial uncertainty if interpreted as reflecting an independent effect of NO_2

versus as a marker for the TRAP mixture. There is some plausibility for the hypothesis that NO_2 causes the onset of childhood asthma, but any estimated effect of NO_2 cannot be interpreted as independent of the broad and complex TRAP mixture. Common EPA practice is to estimate benefits for health outcomes that are considered to be "causally" or "likely to be causally" associated with the pollutant in the ISA. The 2016 NO_2 ISA determined that short-term NO_2 is causally associated with respiratory effects and long-term NO_2 is likely to be causally associated with respiratory effects, based on evidence for asthma onset, particularly among children. The ISA determination for long-term exposure to NO_2 and respiratory effects is the same causality level as for long-term $PM_{2.5}$ and respiratory effects in the 2019 $PM_{2.5}$ ISA, and RIAs currently include respiratory effects (including asthma development) associated with $PM_{2.5}$ in benefits assessments. The epidemiological literature finding associations between NO_2 and asthma development has continued to grow since the 2016 NO2 ISA. There is evidence for NO_2 as an independent trigger of pediatric asthma, but further research drawing on the better characterization of exposure and asthma phenotype is needed to achieve the level of certainty needed to quantify benefits for policy purposes.

Given the mounting evidence linking NO_2 (as a marker for the TRAP mixture) and pediatric asthma development, the SAB recommends that the Agency include benefits for pediatric asthma onset from reduced NO_2 in RIAs as a supplemental analysis that is described as having more uncertainty compared with, for example, $PM_{2.5}$ mortality. Since independent effects of NO_2 and $PM_{2.5}$ on asthma onset are uncertain, estimated benefits for both $PM_{2.5}$ and NO_2 and asthma onset may not be additive. From an environmental justice standpoint, including benefits for reduced NO_2 (again, as a proxy for the TRAP mixture) and asthma onset may provide additional valuable information beyond benefits from reduced $PM_{2.5}$, considering the more inequitable distribution of NO_2 and TRAP compared with general $PM_{2.5}$ mass (Kerr et al. 2022) and the larger contribution of transportation emissions to NO_2 compared with $PM_{2.5}$ (e.g. Nawaz et al. 2021). Since the epidemiological studies largely treat NO_2 as a marker for the TRAP mixture, it would be more appropriate to estimate the health benefits of reduced NO_2 for rules that reduce the entire TRAP mixture, as opposed to NO_2 alone. A systematic review and meta-analysis by Khries et al. (2017) provides estimates for the association of incident asthma with several indicators of TRAP, including NO_2, which might be useful for a benefits analysis. When estimating the benefits of reduced NO_2, EPA should be very clear about how to interpret results.

In the future, the next NO_2 ISA should provide an updated systematic review of the evidence and causal determination as the SAB anticipates that further relevant evidence could support better estimates of benefits related to NO_2 and childhood asthma. Such analyses would require a finer spatial scale for NO_2 estimates that captures gradients of NO_2 exposure within urban environments. Such detail is needed to describe changes in spatial gradients that would follow the proposed control measures for heavy-duty vehicles. The SAB also anticipates that the evidence around NO_2 and childhood asthma will become more informative and that uncertainties will be reduced. The dilemma around separating a possible "independent" effect of NO_2 from the traffic mixture more broadly will likely persist and continue to complicate benefits assessment for NO_2. This issue is important in considering whether planned emissions reduction and control strategies addressing NO_2 may also reduce key mixture components that might also be linked to asthma.

Costs and Benefits.

2.4 What is the cost of health care associated with air emissions and pollution overall and particularly in disadvantaged communities as it relates to this rule?

The supporting documents of the current rule focus on estimating the benefits from reducing $PM_{2.5}$ and ozone-related human health costs rather than health care costs. The EPA's *Guidelines for Preparing Economic Analyses* provide a breakdown of various types of health costs of air pollution (U. S. EPA 2010). Health care costs can be considered one of several types of defensive expenditures or, more broadly, avoidance behaviors to mitigate the impacts of pollution exposure (Bartik 1988). If costs are incurred to mitigate the health effects of pollution, then the monetized health impacts that ignore such mitigation costs will be underestimated. The defensive expenditures approach can therefore be used to partially quantify the benefits of pollution reduction (e.g., Moretti and Neidell 2011, Neidell 2009, Deschênes et al. 2017). In some cases, these costs can represent a non-trivial share of the benefits: Deschênes et al. (2017) find that the Nox Budget Program yielded reductions in annual pharmaceutical expenditures of $800 million and annual mortality reductions of $1.3 billion. Recent evidence using nationwide data in China finds a similar health care to mortality cost ratio (Barwick et al. 2021).

While there may be reductions in health care costs associated with the current regulatory action, it is unclear what portion of these costs are already included in the health effects estimates currently in the analysis. In the current analysis, the EPA selects a set of health endpoints and then takes either a Value of Statistical Life (VSL) approach or a Cost-of-Illness (COI) approach to value the benefits of risk reductions among affected populations. The VSL approach is based on the willingness-to-pay (WTP) for a marginal reduction in the risk of death, whereas the COI approach calculates benefits using direct expenditures on treatment or mitigation associated with health endpoints for which WTP estimates are not available. Unit values used in the benefits analysis of the current proposal (Table 21 of the Estimating $PM_{2.5}$- and ozone-Attributable Health Benefits Technical Support Document) include medical costs from the Healthcare Cost and Utilization Project database, which are applied to value hospitalization in the draft RIA, (page 387) (U.S. EPA, 2022). Any additional discussion of health care costs should be clear about the distinction between health effects and health care expenditure effects.

With respect to the benefit values used in the analysis, there have been new studies in the economics literature that estimate air pollution impacts (e.g., $PM_{2.5}$, Nox) on mortality and medical costs (Deschênes et al. 2017, Deryugina et al. 2019, Barwick et al. 2021). For example, Deryugina et al. (2019) estimate the causal impacts of $PM_{2.5}$ on elderly mortality, health care use, and medical costs in the U.S. using Medicare data. Deschênes et al. (2017) estimate changes in mortality and annual pharmaceutical expenditures due to the Nox Budget Program. We encourage the EPA to use the most cutting-edge information for valuation if it is seeking new estimates of the healthcare costs of air pollution. Given that exposure and vulnerability to climate risks vary, the benefits of reducing emissions vary as well. The differential benefits of reduced greenhouse gas emissions are not captured by the average social cost of carbon value and therefore additional consideration of the distributional effects of reducing greenhouse gas emissions is warranted.

With respect to the cost of health care for disadvantaged communities, disadvantaged communities may benefit more from reductions in health care costs from the current regulation since these groups are more likely to be exposed to the pollutants in the affected areas under this rule. Differential health insurance coverage or access to health care (U.S. EPA 2019) may also generate savings in out-of-pocket health care costs, which are likely to represent a larger share of income for members of disadvantaged groups. The U.S. Global Change Research Program report (Gamble et al. 2016) and EPA Climate Change Impacts and Risk Analysis (CIRA, https://www.epa.gov/cira) program may be a useful reference for understanding the disproportionate health impacts of climate change.

The EPA acknowledges the unquantified health benefits of the current regulation through climate impacts (U.S. EPA 2022 page 388). Similarly, climate impacts that are long-term and global (e.g., increased frequencies of hurricanes, wildfires, etc.) could also affect the health care costs of the current regulation. Generally, the SAB suggests that attention is needed on the greenhouse gas implications of the proposed rule in addition to the effects of toxic air pollutants such as PM and ozone.

Recommendations:

The SAB encourages the EPA to use the most cutting-edge information for valuation if it is seeking new estimates of the healthcare costs of air pollution. The EPA should utilize Gamble et al. 2016 and the EPA CIRA program for information on the disproportionate health impacts of climate change and consider greenhouse gas implications from the proposed rule.

<u>Environmental Justice.</u>

2.5 Given the known data and methodological limitations, how could the EPA consider the environmental justice impacts of this rule using the available data from the Heavy-Duty Engine and Vehicle Standards 2027 proposal?

While data and methodological limitations may preclude analysis addressing actual environmental justice benefits of the rule, an acknowledgment of the evidence base or the unjust distribution of traffic related air pollution across populations is recommended. This can be addressed through a deeper qualitative characterization of the current state of the literature and should include (though not be limited to) studies that examine the associations between the government-sanctioned policies and practices of redlining (i.e., discriminatory practices in which services are withheld from neighborhoods classified as hazardous to investment)/residential segregation (Rothstein 2017) and concentrations of traffic-related air pollution (Jones 2014, Lane 2022, Woo 2019). Federal policies such as the Highway Act of 1956 which used highways to reinforce redlining and racial residential segregation (Ware 2021), should also be highlighted as this federal regulation has the potential to begin to redress such policies by reducing pollutant concentrations in these neighborhoods. Further environmental justice impacts can underscore studies concerning traffic-related air pollution and health disparities, which may include physical health, mental health, and overall well-being.

Language used in the RIA document (U.S. EPA. 2022) also needs a greater degree of specificity to address proposed environmental justice benefits of this rule. EJ language and terminology should be contextually appropriate, clearly defined, and consistent throughout the document, for example distinguishing between inequities and disparities. Appropriate use of language is critical as these terms can impact the analysis and interpretation of results. Of note is Section 6.3.9, Demographic Analysis of Air Quality, of the draft RIA (U.S. EPA. 2022, page 305) which states "This approach can then answer two principal questions to determine disparity of air quality on the basis of race and ethnicity." The analysis is completed for all "people of color." While this term is defined, there seems to be no clear rationale as to why this approach is used. Combining these racial and ethnic groups for analysis is inappropriate for addressing EJ considerations, as present and historical air pollutant exposures vary considerably among these populations and will likely distort the EJ impacts. These racial and ethnic groups should be examined separately.

With regard to this RIA, a critical limitation is the geospatial scale of the pollutant modeling, done in 12 by 12 km grid squares. This grid size does not offer sufficient resolution to capture population disparities from critical sources (i.e., warehouses and other facilities and heavily trafficked highways) known to be sited in historically poorer and minoritized neighborhoods. This scale obscures the impact of heavy-duty vehicles in introducing disparities in air pollution exposure and in characterizing the benefits of emissions reductions. Arguably, a smaller scale grid introduces further uncertainty from model error, but perhaps there could be some case studies in areas with sufficiently dense monitoring networks for model checking. The SAB is inclined to ask whether EPA has modeling tools that could be used to estimate near-roadway concentrations. One dataset that could be useful in this regard is U.S. Census Grids (https://sedac.ciesin.columbia.edu/data/collection/usgrid), which avoid mismatches between pollutant grids and administrative boundaries of demographic data. Other datasets EPA may wish to use for improving distributional analyses include daytime population versus residential population and other types of vulnerable populations (daycare centers, prisons, healthcare facilities, etc.).

The EPA's analytical approach to describing the anticipated benefits involves stratifying the approximately 48,000 grid cells into two groups: in the highest 5 percent of estimates or in the remaining 95 percent based on 2045 estimates for either PM or ozone. Demographic characteristics were assigned to the population in each grid square as percentages of "people of color" or "non-Hispanic White." County-level poverty status (i.e. above and below 200% of the poverty level) was assigned to the grid cells. Two sets of analyses are presented for both PM and ozone: demographic characteristics for the two strata—the highest 5% and the remainder—and the reduction in concentration to 2045 for the two strata. The analytical approach taken in the current RIA draft is expedient but limited by relying only on the dichotomous stratification and the assumption that county-level poverty status is applicable to all grid cells within a county. Further analyses could be undertaken within the timeframe available to enhance this effort to estimate benefits around pollution reduction. The number of grid cells is large and would allow for further stratification to descriptively explore how exposure varies with demographics. The descriptive analysis of changes from baseline to 2045 could be supplemented by regression modeling of the changes to 2045, using demographic characteristics as independent variables to estimate their associations with the magnitude of change.

Recommendations:

The SAB recommends that the RIA include acknowledgment of the evidence base of the unjust distribution of traffic related air pollution across populations. EPA should revise its EJ language and terminology to be contextually appropriate, clearly defined, and consistent throughout the RIA document. EPA should determine whether additional modeling tools could be used to estimate near-roadway concentrations and whether additional datasets like gridded census data and inclusion of additional vulnerable populations can improve the distributional analyses in RIAs. Finally, the descriptive analysis of changes from baseline to 2045 could be supplemented by regression modeling of the changes to 2045, using demographic characteristics as independent variables to estimate their associations with the magnitude of change.

3. SAB ADVICE FOR FUTURE REGULATORY ACTIONS

Emission Reductions.

3.1. How will $PM_{2.5}$, Ozone, and NO_2 concentration disparities change if EPA achieves maximum emission reductions?

Irrespective of socioeconomic status, communities of color are exposed to higher levels of outdoor air pollution (Bell and Ebisu 2012, Clark et al. 2014). Health outcomes associated with $PM_{2.5}$, ozone, and NO_2, such as respiratory illness (including asthma), cardiovascular disease, and increased mortality disproportionately impact Black, Latino, and low-income populations. The basis for these inequities is complex, reflecting historic redlining, land use practices, the need for public transportation, prioritization of diverse environments, and time-activity patterns (O'Neill et al. 2003). The differences represent regional, city-level, and neighborhood level exposures. Traffic-related sources (e.g., heavy-duty diesel vehicles) are among the top four source sectors contributing to these disparities. Thus, despite overall reductions in emissions by all source types, reflecting achievement of prior standards, disparities persist in vulnerable communities (Colmer et al. 2020).

Do these pollutants perform differently as metrics of disparate exposure? Urban environments show sharp spatial variations in NO_2 levels on a neighborhood scale reflecting the pollutant's short half-life and its existence as the major component of traffic emissions (Apte et al. 2017). By contrast, $PM_{2.5}$ and ozone, with their longer half-lives and more varied provenance, manifest air levels that vary by region and not neighborhood. A recent study showed that historic redlining in cities was associated with aggregate disparities in both NO_2 and $PM_{2.5}$ (Lane et al. 2022). In urban areas, after controlling for income, Clark (2014) found that nonwhites are exposed to higher outdoor NO_2 concentrations than whites; and, after controlling for race, lower-income populations are exposed to higher outdoor NO_2 concentrations than higher-income populations (Clark et al. 2014).

A combination of personal, local, and regional assessments will best determine disparities-relevant responses to emissions regulation. Exposure measurements need a higher sensitivity and finer scale to gauge both levels of exposure and effects of mitigation. Direct comparisons of ground level measurements of $PM_{2.5}$, ozone and NO_2 as indices of disparate exposures in informative communities are not currently available but should be prioritized. Time-activity patterns which integrate commute time, indoor time and work exposures would provide more personalized and health-relevant exposure metrics. Effectiveness of regulations may depend on how they are enforced. For example, enforcement on the basis of peak exposure versus average exposure may lead to different levels of effectiveness which should be taken into consideration.

Regarding TRAP regulation and exposure mitigation, the achievement of the emissions standards attached to the proposed EPA rule will require ongoing evolution in aftertreatment technologies. Historically, success of prior emissions standards has been measured with aggregate surveillance instruments allowing suboptimal discrimination among sectors with disparate burdens of TRAP associated health and quality of life impacts.

The reductions in vehicular emissions that comply with prior EPA targets are not equally shared across communities and reinforce the components of disparities that attach to multiple adverse exposures. To sufficiently address these disparities mandated by an EJ posture, metrics to establish areas of high versus low attainment of recent TRAP mitigation targets are necessary with optimization of policy goals to address contributing factors. A careful surveillance of *ex post* traffic emissions to $PM_{2.5}$ disparities in California showed that the largest contribution to this persistent disparity were disproportionately higher road density, especially for limited access roads such as Interstate highways (Lee and Park 2020). Currently, there is no standard distributional analysis for EPA benefits assessments.

A finer scale resolution for measurements of NO_2, ozone and $PM_{2.5}$ is needed to evaluate the success of TRAP mitigation in the context of known disparities in exposure. These disparities operate on a neighborhood scale with likely temporal components which can be obscured with aggregate measures.

Strategies to estimate the impact of emission standards *ex ante* and *ex post* have shown variable utility and granularity. Using EPA's CO-Benefits Risk Assessment screening tool, Mailloux (2022) recently quantified probable benefits of recent clean energy proposals tasked to broadly reduce emissions and found large-scale public health benefits (Mailloux et al. 2022).

Emission source partitioned data for vulnerable communities would provide the best predictive framework for the specific consequences of TRAP policies on disparities, but these are not routinely obtained (Tessum et al. 2021). Another consideration is that if people move in response to air quality changes (or in response to associated housing price changes or other quality of life factors), then it is unclear how disparities in air pollutants will affect health impacts since the direction of the effect depends on how the environmental quality of the destination location compares to that of the origin location. In the absence of the relocation consideration, one could assume that reductions in these TRAP emissions might reduce the overall exposure of these populations and subsequent health disparities. This rule can also reduce pollutant exposures among vulnerable populations such as children, particularly low-income children who are more likely to live and go to school near major roadways. Other impacted populations such as outdoor workers, older adults, and individuals with preexisting conditions could also potentially experience health disparities.

In the future, the EPA should also account for future conditions in assessing the future costs and benefits of the rule. For example, given rising temperatures due to climate change, there is an additional "climate penalty" associated with the costs of attaining future air quality targets, given projections that some air pollutants (e.g., ozone) will worsen with rising temperatures. This implies greater benefits to any induced technological change that may result from the rule. As another example, the transition to electrification, investments in electric vehicles (EV) and EV infrastructure, and alternative transportation fuels such as hydrogen will alter future exposures to air pollutants from vehicles, including heavy-duty vehicles. These future changes are uncertain, but nonetheless important to consider. This aligns well with the work that EPA scientists are already doing through the Climate Change Impacts and Risk Analysis (CIRA) project, which uses detailed models of sectoral impacts (e.g., human health, infrastructure, and water resources) to quantify and monetize how risks, impacts, and damages may change in response to greenhouse gas mitigation and adaptation actions.

In summary, if one assumes that people do not respond to air quality changes associated with emissions reductions (by moving to other locations), then maximum emissions reductions will likely reduce disparities in $PM_{2.5}$, ozone, and NO_2, given the current spatial distribution of air pollution with respect to disadvantaged populations.

Recommendations:

The SAB recommends that the RIA include acknowledgment of disparities and the issue of fine scale resolution in EPA's regulations and how critical it is to understand these factors. Emission source partitioned data coupled to contemporary multi-exposure assessments would provide the best framework to link TRAP to exposure disparities and associated outcomes. Future RIAs should also account for future conditions, as climate change and other broader transitions (e.g. vehicle electrification) will alter future exposure to air pollution.

Pollutant Mixtures.

3.2. How can EPA consider multiple pollutants (i.e., combined effects of pollutant mixture) simultaneously, including the potential reduction for several pollutants at the same time through proposed regulation?

This question refers to the long-standing problem of handling mixtures and characterizing the contributions of individual components versus the effect of the mixture per se, which reflects potential interactions among components. Such interactions depend on how agents act on the pathways of injury leading to adverse outcomes, i.e., the same or different pathways. There have been countless workshops and publications on the topic of mixtures. EPA should review this literature for the current state-of-practice and any useful methods. As a further complication and challenge, mixture effects and the interactions of mixture components are likely to vary by health outcome (e.g., carcinogenicity and lung cancer versus exacerbation or causation of asthma). As a starting point, for considering the potential benefits of reducing multiple pollutant concentrations, there should be an effort to characterize the underlying causal pathways to assure that the benefits of pollutant reduction can be separated, one from the other. NO_2 serves as a useful example with the possibility that it causes an effect by itself, but also additional adverse effects by being an ozone precursor and contributing to PM mass. A directed acyclic graph would be useful for this purpose.

One challenge lies in identifying data sets relevant to multiple pollutants that have been analyzed in a way that considers underlying causal structures so that component effects have been appropriately estimated. Typically, multipollutant models use some form of regression with inclusion of terms for main effects of pollutants and perhaps interaction terms to assess departures from additivity. Epidemiological data sets that may be relevant are typically analyzed in multiple ways with combinations of pollutants and findings of all models may not be available in manuscripts so that the findings of various multipollutant models can be compared. EPA should consider working with investigators to obtain regression estimates related to multipollutant benefit analyses. A further potential challenge is differing levels of measurement error across pollutants, which complicates interpretation of multipollutant models. Analyses that would address EJ need to further consider the populations exposed, reflecting EPA's plan to incorporate cumulative risk into its EJ framework.

This topic appears to have been under-researched by the epidemiology community. Because of EPA's focus on single pollutants, there is a perception that multi-pollutant models are of little interest to EPA. Dominici et al. (2010) previously advocated that EPA should shift to a multi-pollutant viewpoint but there does not seem to have been much shift in that direction as far as the regulatory agenda is concerned, perhaps because of the single pollutant focus of the Clean Air Act (2008). As a result, the scientific community has lagged as well.

A traditional approach to modeling health effects from multiple pollutants is to build a regression model including all the pollutants of interest as covariates, as well as other variables that may act as confounders or effect modifiers. Traditional approaches based on variable selection, may not be efficient at identifying health effects that arise from combinations of pollutants. Coker et al. (2018) reviewed approaches using Bayesian profile regression (Molitor et al. 2010). This is a Bayesian methodology for identifying "profiles" of covariates that are clustered into groups and associated with relevant outcomes for the response of interest. The method can also be applied spatially, to identify locations with the most health-relevant exposure-mixture profiles. The approach is potentially useful in identifying subpopulations with increased susceptibility to complex non-linear interactions among pollutants.

An alternative approach to essentially the same class of problems is Bayesian Kernel Machine Regression. This is an approach that uses kernels to represent multi-variable effects, including variable selection in a hierarchical Bayesian context. Bobb et al. (2015) described the methodology and discussed an application based on multi-pollutant mixtures in a toxicology study of air pollution and hemodynamics. Liu et al. (2018) presented an extension that they called lagged kernel machine regression. This is useful in situations where there is doubt about the timescale of the air pollution effects, so the model effectively allows for a combination of effects at different time lags.

A different approach to multipollutant modeling is to focus on the sources of pollution rather than the pollutants themselves. Source apportionment refers to a very general class of methods for taking monitoring data on multiple pollutants at multiple sites and representing them as mixtures of contributions from different sources. The most challenging problems arise when the number and locations of the sources are themselves unknown. Park et al. (2014) presented a Bayesian approach for attributing health effects to an unknown number of sources that consider model uncertainty as well as parameter uncertainty, in the case where the response of interest may be assumed to be normally distributed. Park and Oh (2018) extended the approach to over Poisson regression, which is the most common type of model when the response of interest is mortality. Other papers that have presented multivariate source receptor modeling from a Bayesian viewpoint are Park, Hopke et al. (2018) and Park, Lee and Oh (2021).

With reference, specifically, to the proposed Heavy-Duty Vehicles rule, it seems that it should be possible to calculate the combined effect of reductions across all three pollutants, $PM_{2.5}$, ozone and NO_2, using these methods or some variants on them. However, the SAB is not aware of papers offering specific methodologies. Cumulative impacts from simultaneous exposure to multiple risk factors could contribute to even larger disparities than those calculated for each pollutant alone.

The topic is important and needs consideration, particularly regarding the disparate exposures of populations who live in urban environments where they face pollution with complex mixtures, such as traffic-related air pollution. Most of the studies showing disparate air pollution exposures in under-resourced communities or communities of color have used single pollutant metrics with limited spatial resolution. Such studies do not provide information that is useful for understanding the benefits of reductions of mixture components. Recently, a dense grid of traffic density throughout Minnesota conflated with exposure estimates of 235 pollutants generated an informative assessment of multi-component exposure with spatial detail (Pratt et al. 2011). Recent approaches to mobile monitoring with the use of low-cost sensors facilitate reliable measurement of multipollutant gradients (Fujita et al. 2012, Chambliss et al. 2021). There is also a need to understand the form of interactions between mixture components, whether additive or synergistic with respect to health outcomes. In addition, community-based participatory research (CBPR) approaches can provide valuable information, particularly for communities who don't have regulatory monitors nearby.

Modeling for EJ considerations.

3.3. What technical tools and approaches are necessary for EPA to model population disparities in air quality and health benefits of regulations?

As noted in the Preamble of this report, the SAB strongly recommends that EPA develop a strategy for systematic, quantitative measurement of the EJ impacts of air pollution regulations. One framework that EPA should consider adapting is the source-to-outcome continuum-based framework for addressing human variability in next-generation human health risk assessments described by Zeise et al. (2013). Zeise et al. (2013) reasoned that, in the context of human variability, this framework enables systematic identification of biological susceptibility indicators at each point along the source-to-outcome continuum that modulate the ultimate outcomes on health and well-being. An analogous framework for EJ would enable EPA to transparently articulate, in any particular case, (i) where regulatory interventions are intended to mitigate sources or exposures, (ii) where there are disparities in baseline conditions, and (iii) how disparities may impact implementation of regulatory interventions. With this information, such a framework for EJ could thereby enable EPA to systematically identify EJ indicators at each point along the source-to-outcome continuum that modulate the implementation and impact of a particular regulatory action on health, well-being, and their corresponding disparities. Acquiring the right set of technical tools and approaches to support assessments of population disparities in air quality and the health benefits of regulations will be an important part of this process. Recommended data and modeling inclusions relevant to the current rule are noted below. Note that this list is not exhaustive, either for the current rule or future air quality regulations.

1. The literature shows that aggregating pollution exposure at the county or other level masks significant local variation in exposure to pollution that is a central EJ concern (Banzhaf et al. 2019, Baden et al. 2007). The SAB recommends that the EPA develop the capacity to model EJ impacts of air quality regulation via nationwide analysis. Potentially less computationally demanding approaches would either screen a small number of cities in which a regulation is expected to have significant impacts at a higher spatial resolution, or screen areas with large numbers of affected facilities or other entities at a higher spatial resolution. An example of the latter approach relevant to the current Heavy-Duty Vehicles

rule would be to develop fine-scale estimates of impacts within the cities likely to be most affected (such as those identified in Tables 6-2, 6-4, and 6-6 of the RIA), or even just within a standard distance of major roadways in such cities.

2. Ground-based monitoring data, estimates from remote-sensing, land use variables and, for NO_2, deterministic gradients relative to road traffic sources, which are conventional approaches to measure traffic emissions associated pollutants, are currently available tools for the EPA's use. Mobile monitoring options with vehicle mounted instruments could be more broadly utilized to detail local variation in pollutant levels.

3. To model health benefits, the EPA should develop models that integrate surrogate endpoints, pragmatic designs, and machine learning strategies when applicable. The EPA should also intensify its focus on health outcomes with strong historical relationships to conventional outdoor pollutants (i.e., TRAP) such as premature birth, low birth weight, cancer, and asthma (Steib et al. 2016, Cohen et al. 2015) that may also be differentially present in EJ communities.

4. A better understanding of prior community exposure and the relationship between pollution exposure, morbidity, and mortality as it varies with prior cumulative exposure, income and other community characteristics would also be helpful in assessing the differential impacts of air quality regulation.

Infrastructure Investments.

3.4. How can changing infrastructure investments impact air quality?

With the passage of the Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Bill of 2022, significant federal investment in transportation and energy is on the horizon (Chi 2022). The Infrastructure Bill allocates federal funds to the United States Department of Transportation ($274 billion), the Environmental Protection Agency ($67 billion), and the Department of Energy ($63 billion). Federal legislation has carved out investments in EVs and infrastructure that include $7.7 billion dedicated to the deployment of EVs and related infrastructure only and $12.7 billion dedicated to the deployment of all types of clean vehicles and fueling infrastructure (which includes EVs and charging infrastructure and $10.3 billion for grid and battery-related investments) (Tigue 2022). The impact of infrastructure investments on air quality will vary from community to community. People living in neighborhoods that are disproportionately burdened by air pollution may continue to be at risk with changing infrastructure investments. Transportation and electric power generation account for over 50% of the nation's annual emissions (U.S. EPA 2022a). Carbon dioxide (CO_2) makes up the vast majority of greenhouse gas emissions from both the transportation and energy sectors, but smaller amounts of methane and nitrous oxide are also emitted. Emission sources include the combustion of petroleum-based products, like gasoline and diesel fuel, in internal combustion engines. The largest sources of transportation-related greenhouse gas emissions include passenger cars, medium- and heavy-duty trucks, and light-duty trucks, including sport utility vehicles, pickup trucks, and minivans. In addition, small amounts of hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF_6) are produced (U.S. EPA. 2022a). Ground level ozone forms when nitrogen oxides from sources like vehicle exhaust and industrial emissions react with organic compounds in the presence of heat and sunlight. (U.S. Department of Commerce 2017).

Clean Energy tax credits promote the general development of alternative energy particularly wind and solar technology. The Department of Energy plans to invest significant funds in updating current energy production or in some cases completely replacing plants.

Through infrastructure investments the proliferation of EVs could impact air quality by reducing fossil fuel consumption. EVs produce significantly less pollution than traditional vehicles by eliminating almost all emissions from engines and tailpipes. Like traditional gas vehicles, tire wear and brake pad pollution will continue to impact communities near traffic corridors. The wear of the tires and brakes on asphalt produces fine particles that increase pulmonary health risks for local residents. Investments in the electrification of school buses as well as public mass transit can improve air quality. Investments in transportation infrastructure such as road widening projects may have the reverse effect on air quality by allowing additional vehicles to be on the road at once.

Revamping the transportation infrastructure will affect air quality by reducing greenhouse gas emissions and co-pollutants, but the effect will vary depending on implementation strategy and the community. In areas disproportionately burdened by fossil fuel infrastructure and emissions, substantive investments in clean energy infrastructure (i.e., solar, wind, geothermal) could improve community health. In communities near large ports or freight hubs, infrastructure investments such as clean power investments could also positively impact air quality (Eilperin and Fears 2021). Reducing fuel consumption through the expansion of public transportation infrastructure, light rail infrastructure, and clean energy infrastructure can improve air quality. As policy turns to reducing the effect of climate change, it is clear that not only stopping emissions of CO_2 and methane is necessary, but actually removing CO_2 and methane is vital to communities that are experiencing environmental, climate and energy injustice (Brady 2021).

Changing infrastructure may still overlook some EJ concerns (Daly 2022). Communities overburdened by environmental hazards rarely have the capacity to manage the influx of potential funds (U.S. EPA 2022b). Additional capacity is necessary at a grassroots level in frontline communities; the EPA has developed a community technical assistance program to address this gap (De La Torre 2021). Without an equitable energy transition, environmental inequalities could be exacerbated. Some political leaders prevent funding from reaching targets and often political compromises put communities at risk. For example, an amendment to the IRA invests in fossil fuels, subsidizes the building of new pipelines, guarantees new leasing of oil and gas drilling, incentivizes investment in still-nascent carbon capture technology, attempts to roll back the National Environmental Policy Act, and would entrench dirty fossil fuel infrastructure for decades to come. Populations overburdened by dirty fossil fuel infrastructure and related emissions will see their burden, exposure, and health risks increased, while emissions decrease nationwide. People of color are more likely to breathe polluted air and face health risks like asthma, diabetes, and heart disease (Vazin 2020). Concentrating pollution in already overburdened communities of color and low-income communities would create more sacrifice zones, lead to climate redlining, and drive health inequities.

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APPENDIX A: Additional Considerations for Incorporating Justice into EPA Activities

The EPA should consider environmental justice benefits (social, economic, health, ecologic, and infrastructure) in regard to the heavy-duty truck rule, particularly the reduction of greenhouse gas emissions and co-pollutants (e.g., $PM_{2.5}$, NO_x, and black carbon). By categorizing benefits into these five domains, the EPA can develop strategies to reach communities experiencing environmental, climate, and energy injustices. The EPA should consider an analysis of EJ benefits that evaluates cumulative as well as direct benefits (Morello-Frosch et al. 2011). Cumulative impacts are part of the EPA EJ analysis, but an additional analysis of cumulative benefits would guide effective investment (Sheats 2013). A rule that provides more than one type of benefit whether social, health, economic, infrastructure, or ecologic requires an analysis of the cumulative benefits in addition to impacts.

It is known that communities near high traffic corridors disproportionately carry the burden of air pollution from vehicle emissions, but limiting the environmental justice analysis to exposure prevents the agency from taking a comprehensive look at issues facing communities with EJ issues. Exposure to high concentrations of ambient air pollution (e.g., $PM_{2.5}$ and NO_2) has been shown to cause cancer through gene mutation, using improved estimation methods to assess air pollution (Letellier et al. 2022, Environmental Defense Fund. N.d.). Throughout the pandemic the compounding effect of Coronavirus Disease 2019 and poor air quality were experienced in communities like St. James Parish, Louisiana. St. James Parish, which belongs to an area known to locals as "cancer alley," has one of the highest rates of cancer-causing pollution in the nation, making its residents especially vulnerable to Coronavirus Disease 2019 (Kristoffer 2022). A recent report found that higher historical $PM_{2.5}$ exposures are positively associated with higher county-level Coronavirus Disease 2019mortality rates after accounting for area-level confounders (Wu et al. 2020).

Distributive justice focuses on the "fair allocation of" burdens and responsibility following an injustice. Procedural justice focuses on the process available to individuals to bring forward their claims. Retributive justices focus on the punishments for perpetrating or allowing injustice. Restorative justice focuses on improving the relationship between the wrongdoer and harmed party.

- In limiting the justice analysis to exposure and punishment, the EPA restricts its strategy for justice to a retributive strategy. The EPA restricts its strategy for justice implementation to punishing wrong doers via "fines "and "revoked permits" rather than spreading benefits to harmed parties. The exposure framing of injustice does not account for pre-existing health conditions, cumulative impact of environmental hazards including air pollution, poverty, health care access, indoor air quality, historic racism, segregation, redlining, social mobility and other indicators that affect environmental quality and public health.

- The EPA must integrate distributional justice analysis into its consideration of EJ benefits (i.e., determining who gets what). Screening tools have increased the EPA's ability to identify communities burdened by EJ issues through mapping "disadvantaged" indicators using geospatial software (i.e., EPA EJSCREEN 2.0). Environmental justice screening and mapping (EJSM) tools were created to identify EJ communities but fail to identify the potential for distributing benefits. By identifying burdens, these tools can identify potential EJ areas and identify areas with higher exposure and health risks. Identifying current and projected co-benefits and areas where we see inequities in benefits, including the ratio of benefits vs need, provides an opportunity to identify and target communities with EJ investments.

- The EPA must integrate procedural justice analysis into its consideration of EJ benefits (i.e., determining how fairly people are treated). The EPA must conduct an additional analysis of the barriers to procedural justice that prevent communities from realizing benefits from strategic investments. The traditional notice and comment procedure creates significant barriers to participation for members of EJ communities. Social, political, and economic barriers prevent communities with EJ issues from realizing benefits. A critical analysis of EPA programs, with focus on procedural justice will reveal the specific challenges that face EJ communities. Political barriers may be the clearest to identify but social and economic barriers to access investments and co-benefits should not be overlooked in the agency's procedural justice analysis.

- The EPA must integrate a restorative justice analysis into its consideration of EJ benefits (i.e., restore relationships to "rightness."). Communities with EJ issues should receive environmental benefits proportional to their environmental burden. When communities are overburdened by environmental health stressors and then miss out on environmental benefits the initial injustice is compounded. The agency would be well served by a comprehensive restorative justice analysis of EJ benefits. A restorative justice analysis would allow the realization of EJ benefits in communities that have suffered from environmental injustice particularly the cumulative impacts of air pollution associated with transportation corridors and movement of goods. Preventing future harms is central to restorative justice. A restorative justice analysis would highlight ways to spread EJ benefits in ways that would prevent injustice from occurring in the future. By evaluating past crises, the agency could identify policies that prevent communities from realizing EJ benefits as well as anticipate where future needs can be met.

By integrating alternative framing of justice into the EJ benefits analysis, including distributive justice, restorative justice, and procedural justice in addition to retributive justice, the EPA can better implement policy and direct investments. There are different approaches to achieving justice after a harm by developing a cumulative benefits analysis.

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