Final Regulatory Impact Analysis for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter

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In setting primary and secondary national ambient air quality standards (NAAQS), the Environmental Protection Agency's (EPA) responsibility under the law is to establish standards that protect public health and welfare. The Clean Air Act (CAA) requires the EPA, for each criteria pollutant, to set standards that protect public health with "an adequate margin of safety" and public welfare from "any known or anticipated adverse effects." As interpreted by the Agency and the courts, the CAA requires the EPA to base the decisions for primary standards on health considerations only; economic factors cannot be considered. The prohibition against considering cost in the setting of the primary air quality standards does not mean that costs, benefits, or other economic consequences are unimportant. The Agency believes that consideration of costs and benefits is an essential decision-making tool for the efficient implementation of these standards. The impacts of costs, benefits, and efficiency are considered by the States when they make decisions regarding what timelines, strategies, and policies are appropriate for their circumstances.

On June 10, 2021, the EPA announced its decision to reconsider the 2020 Particulate Matter (PM) NAAQS final action. The EPA is reconsidering the December 2020 decision because the available scientific evidence and technical information indicate that the current standards may not be adequate to protect public health and welfare, as required by the CAA. In general, the Administrator recognizes that the primary annual $PM_{2.5}$ standard is most effective at controlling exposures to "typical" daily $PM_{2.5}$ concentrations that are experienced over the year, while the primary 24-hour $PM_{2.5}$ standard, with its 98th percentile form, is most effective at limiting daily "peak" $PM_{2.5}$ concentrations. The EPA has concluded that the existing primary annual $PM_{2.5}$ standard for PM, set at a level of 12.0 $\mu g/m^3$, is not requisite to protect public health with an adequate margin of safety. The EPA Administrator is revising the existing annual standard to provide increased public health protection. Specifically, the EPA Administrator is revising the level of the annual standard to 9 $\mu g/m^3$. The EPA Administrator is retaining the primary 24-hour $PM_{2.5}$ standard at its current level of 35 $\mu g/m^3$. The Administrator is also retaining the primary 24-hour PM_{10}

standard, which provides public health protection against $PM_{10-2.5}$-related health effects, at its current level of 150 μg/m^3.

The EPA also concluded that the existing secondary PM standards are requisite to protect public welfare from known or anticipated effects and is not changing the secondary standards for PM at this time. Specifically, for the secondary annual $PM_{2.5}$ standard, the EPA Administrator is retaining the existing standard of 15.0 μg/m^3. For the secondary 24-hour $PM_{2.5}$ standard, the EPA Administrator is retaining the existing standard of 35 μg/m^3. For the secondary 24-hour PM_{10} standard, the EPA Administrator is retaining the existing standard of 150 μg/m^3.

Overview of the Regulatory Impact Analysis

Per Executive Orders 12866, 13563, and 14094 and the guidelines of the Office of Management and Budget's (OMB) Circular A-4, in this Regulatory Impact Analysis (RIA) we analyze the revised annual and current 24-hour alternative standard levels of 9/35 μg/m^3, as well as the following less and more stringent alternative standard levels: (1) a less stringent alternative annual standard level of 10 μg/m^3 in combination with the current 24-hour standard (i.e.,10/35 μg/m^3), (2) a more stringent alternative annual standard level of 8 μg/m^3 in combination with the current 24-hour standard (i.e., 8/35 μg/m^3), and (2) a more stringent alternative 24-hour standard level of 30 μg/m^3 in combination with an annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). Because the EPA is not changing the current secondary $PM_{2.5}$ standards at this time, as well as retaining the primary and secondary PM_{10} standards, we did not evaluate alternative levels of these standards. The RIA includes the following chapters: Chapter 2: Air Quality Modeling and Methods; Chapter 3: Control Strategies and $PM_{2.5}$ Emissions Reductions; Chapter 4: Engineering Cost Analysis and Qualitative Discussion of Social Costs; Chapter 5: Benefits Analysis Approach and Results; Chapter 6: Environmental Justice; Chapter 7: Labor Impacts; and Chapter 8: Comparison of Benefits and Costs.

The RIA presents estimates of the costs and benefits of applying illustrative national control strategies in 2032 after implementing existing and expected regulations and assessing emissions reductions to meet the current annual and 24-hour fine particulate matter NAAQS (12/35 μg/m³). The selection of 2032 as the analysis year in the RIA does not predict or prejudge attainment dates that will ultimately be assigned to individual areas under the CAA. The CAA contains a variety of potential attainment dates and flexibility to move to later dates, provided that the date is as expeditious as practicable. For the purposes of this analysis, the EPA assumes that it would likely finalize designations for the revised fine particulate matter NAAQS in late 2025. Furthermore, also for the purposes of this analysis and depending on the precise timing of the effective date of those designations, the EPA assumes that nonattainment areas classified as Moderate would likely have to attain in late 2032. As such, we selected 2032 as the primary year of analysis.

The analyses in this RIA rely on national-level data (emissions inventory and control measure information) for use in national-level assessments (air quality modeling, control strategies, environmental justice, and benefits estimation). However, the ambient air quality issues being analyzed are highly complex and local in nature, and the results of these national-level assessments therefore contain uncertainty. It is beyond the scope of this RIA to develop detailed local information for the areas being analyzed, including populating the local emissions inventory, obtaining local information to increase the resolution of the air quality modeling, and obtaining local information on emissions controls, all of which would reduce some of the uncertainty in these national-level assessments. For example, having more refined data would be ideal for agricultural dust and burning, prescribed burning, and non-point (area) sources due to their large contribution to primary $PM_{2.5}$ emissions and the limited availability of emissions controls.[1] In addition, for residential wood combustion emissions, people will respond differently to the various regulations and incentives offered for controlling $PM_{2.5}$ emissions from wood burning, making it important to identify the right balance of controls for each area.

ES.1 Design of the Regulatory Impact Analysis

The goal of this RIA is to provide estimates of the potential costs and benefits of the illustrative national control strategies in 2032. Because States are ultimately responsible for implementing strategies to meet alternative standard levels, this RIA provides insights

[1] Examples of area source emissions include area fugitive dust, residential wood combustion, and commercial cooking emissions.

and analysis of a limited number of illustrative control strategies that states might adopt to implement a revised standard level.

We developed our projected baselines for emissions and air quality for 2032. To estimate the costs and benefits of the illustrative national control strategies for the revised and less and more stringent annual and 24-hour $PM_{2.5}$ alternative standard levels, we first prepared an analytical baseline for 2032 that assumes full compliance with the current standards of 12/35 $\mu g/m^3$. From that analytical baseline, we estimate $PM_{2.5}$ emissions reductions needed to reach the revised and alternative annual and 24-hour $PM_{2.5}$ standard levels and then analyze illustrative control strategies that areas might employ.

Because $PM_{2.5}$ concentrations are most responsive to primary PM emissions reductions, for the illustrative control strategies we analyze direct, local $PM_{2.5}$ emissions reductions by individual counties.[2] For the eastern U.S. where counties are relatively small and terrain is relatively flat, we identified potential $PM_{2.5}$ emissions reductions within each county and in adjacent counties within the same state, where needed. As discussed in Chapter 3, Section 3.2.2, when we applied the emissions reductions from adjacent counties, we used a $\mu g/m^3$ per ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions. Because the counties in the western U.S. are generally large and the terrain is more complex, we only identified potential $PM_{2.5}$ emissions reductions within each county.

We then prepared illustrative control strategies. We apply end-of-pipe control technologies to non-electric generating unit (non-EGU) stationary sources (e.g., fabric filters, electrostatic precipitators, venturi scrubbers) and area source controls to non-point (area) sources (e.g., installing controls on charbroilers), to residential wood combustion

[2] As discussed in Chapter 2, Section 2.1.3, the spatial distributions of $PM_{2.5}$ concentrations in the U.S. are characterized by an "urban increment" of consistently higher $PM_{2.5}$ concentrations over urban areas than in surrounding areas. Monitored concentrations are highest in urban areas and relatively low in rural areas. Conceptually, $PM_{2.5}$ concentrations in urban areas can be viewed as the superposition of the urban increment and the contributions from regional and natural background sources. The decreases in anthropogenic SO_2 and NO_X emissions in recent decades have reduced regional background concentrations and increased the relative importance of the urban increment. The projections of additional large reductions in SO_2 and NO_X emissions in the 2032 case further motivate the need for control of local primary $PM_{2.5}$ sources to address the highest $PM_{2.5}$ concentrations in urban areas. The 2032 projections include wildfire emissions at their 2018 levels, but these emissions were not targeted for control.

sources (e.g., converting woodstoves to gas logs), and for area fugitive dust emissions (e.g., paving unpaved roads) in analyzing $PM_{2.5}$ emissions reductions. Below we discuss the SO_2 and NO_X emissions reductions from mobile sources and EGUs reflected in the projections between 2018 and 2032. We analyze $PM_{2.5}$ emissions reductions in and near counties with projected exceedances because this is the most efficient approach for assessing reductions in future $PM_{2.5}$ concentrations after accounting for the large projected SO_2 and NO_X emissions reductions. The estimated $PM_{2.5}$ emissions reductions from these control applications do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. In Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 μg/-m^3; the areas include counties with near-road monitors, counties in border areas, counties in small western mountain valleys, and counties in California's air basins and districts. The characteristics of the air quality challenges for these areas include features of certain near-road sites with challenging local conditions, cross-border transport, effects of complex terrain in the west, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events (U.S. EPA, 2019a). Lastly, we estimate the engineering costs and human health benefits associated with the illustrative control strategies, as well as assess environmental justice considerations.

Chapter 2, Section 2.1.3, includes discussions of historical and projected emissions trends for direct $PM_{2.5}$ and precursor emissions (i.e., SO_2, NOx, VOC, and ammonia), as well as of the "urban increment" of consistently higher $PM_{2.5}$ concentrations over urban areas. We did not apply controls to EGUs or mobile sources beyond what is reflected in the projections between 2018 and 2032. The projections reflect SO_2 and NO_X emissions decreases between 2018 and 2032 — over this period (1) NO_X emissions are projected to decrease by 3.6 million tons (41 percent), with the greatest reductions from mobile source and EGU emissions inventory sectors, and (2) SO_2 emissions are projected to decrease by

1.1 million tons (48 percent), with the greatest reductions from the EGU emissions inventory sector.

ES.1.1 Establishing the Analytical Baseline

To project air quality to the future, the Community Multiscale Air Quality Modeling System (CMAQ) model was applied to simulate air quality over the U.S. during 2018 and for a case with emissions representative of 2032. In the 2032 projections, $PM_{2.5}$ design values (DVs) exceeded the current standards for some counties in the west and California.[3] As described in Chapter 2, Section 2.3.2, we adjusted the $PM_{2.5}$ DVs for 2032 to account for emissions reductions needed to attain the current annual and 24-hour $PM_{2.5}$ standards of 12/35 μg/m^3 to form the 12/35 μg/m^3 analytical baseline; it is from this baseline that we estimate the incremental costs and benefits associated with control strategies for the revised and less and more stringent alternative standard levels relative to the current standards. For EGUs, the analytical baseline reflects, among other existing regulations, the Final Good Neighbor Plan for the 2015 Ozone NAAQS (2023), the Revised Cross-State Air Pollution Rule Update (2021), the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources (2015), and the Mercury and Air Toxics Rule (2011). The baseline also reflects provisions of tax incentives in the Inflation Reduction Act of 2022 (IRA). For mobile sources, the baseline reflects the Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (2022), the Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026 (2021), the GHG Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2 (2016), and the Tier 3 Motor Vehicle Emission and Fuel Standards (2014). For non-EGUs, the baseline reflects the Final Good Neighbor Plan for the 2015 Ozone NAAQS (2023), the New Source Performance Standards (NSPS) for oil and natural gas sources (2016), the NSPS for process heaters (2013), the NSPS for natural gas turbines and reciprocating

[3] $PM_{2.5}$ DVs were projected to 2032 using the air quality model results in a relative sense, as recommended by the EPA modeling guidance, by projecting monitoring data with relative response factors (RRFs) developed from the 2018 and 2032 CMAQ modeling.

internal combustion engines (2012), and the NSPS for residential wood combustion (2015). For a more complete list of regulations, please see Chapter 2, Section 2.2.1.

We present results throughout the RIA by northeast, southeast, west, and California, and Figure ES-1 includes a map of the U.S. with these areas identified. Table ES-1 presents a summary of the $PM_{2.5}$ emissions reductions needed by area to meet the current standards to form the 12/35 μg/m^3 analytical baseline.

Figure ES-1 Geographic Areas Used in Analysis

Table ES-1 Summary of $PM_{2.5}$ Emissions Reductions Needed by Area in 2032 to Meet Current Primary Annual and 24-hour Standards of 12/35 μg/m^3 (tons/year)

Area	12/35
Northeast	0
Southeast	0
West	1,494
CA	6,032
Total	7,526

Sixteen counties need $PM_{2.5}$ emissions reductions to meet the current standards in 2032 – 11 counties in California and five counties in the west.[4] The counties in California include several counties in the San Joaquin Valley Air Pollution Control District and the South Coast Air Quality Management District, as well as Plumas County, Colusa County, and Siskiyou County in Northern California, Mono County in Eastern California, and Imperial County in Southern California. No counties in the northeast or southeast U.S. need $PM_{2.5}$ emissions reductions to meet the current annual and 24-hour standards.

ES.1.2 Estimating $PM_{2.5}$ Emissions Reductions Needed for Annual and 24-hour Revised and Alternative Standard Levels Analyzed

We apply regional $PM_{2.5}$ air quality ratios to estimate the emissions reductions needed to reach the revised and less and more stringent annual and 24-hour alternative standard levels analyzed. To develop air quality ratios that relate the change in DV in a county to the change in primary $PM_{2.5}$ emissions in that county, we performed air quality sensitivity modeling with reductions in primary $PM_{2.5}$ emissions in selected counties. More specifically, we conducted a 2028 CMAQ sensitivity modeling simulation with 50 percent reductions in primary $PM_{2.5}$ emissions from anthropogenic sources in counties with annual 2028 DVs greater than 8 $\mu g/m^3$. We divided the change in annual and 24-hour $PM_{2.5}$ DVs in these counties by the change in emissions in the respective counties to determine the air quality ratio at individual monitors.

We developed representative air quality ratios for regions of the U.S. from the ratios at individual monitors as in the 2012 $PM_{2.5}$ NAAQS review (U.S. EPA, 2012). These regions are shown in Chapter 2, Figure 2-7, and the air quality ratios for primary $PM_{2.5}$ emissions used in estimating the emission reductions needed to just meet the revised and alternative standard levels analyzed are listed in Chapter 2, Table 2-1. We estimated the emissions reductions needed to just meet the revised and alternative standard levels analyzed using the primary $PM_{2.5}$ air quality ratios in combination with the required incremental change in concentration. Chapter 2, Section 2.3.1 includes a brief discussion of developing air quality ratios and estimated emissions reductions needed to just meet the revised and alternative

[4] The 16 counties require primary PM emissions reductions to meet the current standards of 12/35 $\mu g/m^3$ following application of the NOx emission reductions in San Joaquin Valley and the South Coast to adjust the 2032 DVs. For additional discussion, see Appendix 2A, Section 2A.3.2 and Section 2A.3.3.

standard levels analyzed, and Appendix 2A, Section 2A.3 includes more detailed discussions.

Table ES-2 presents a summary of the estimated emissions reductions needed by area to reach the annual and 24-hour revised and alternative standard levels. For each set of standard levels, Table ES-2 also includes an area's percent of the total estimated emissions reductions needed nationwide to reach those standard levels in all locations. For example, for the less stringent alternative standard levels of 10/35 μg/m^3, California's 10,753 estimated tons needed is 81 percent of the total estimated emissions reductions needed nationwide to meet 10/35 μg/m^3. See Appendix 2A, Table 2A-14 for the estimated $PM_{2.5}$ emissions reductions, from the analytical baseline, needed by county for the revised and alternative standard levels analyzed. Figure ES-2 shows the counties projected to exceed the annual and 24-hour revised and alternative standard levels of 10/35 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 in the analytical baseline. Additional information on the air quality modeling, as well as information about projected future DVs, DV targets, and air quality ratios is provided in Chapter 2 and Appendix 2A.

Table ES-2 By Area, Summary of $PM_{2.5}$ Emissions Reductions Needed, In Tons/Year and as Percent of Total Reduction Needed Nationwide, for the Revised and Alternative Primary Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 in 2032

Area	**10/35**	**10/30**	**9/35**	**8/35**
Northeast	1,032	1,073	6,974	20,620
Southeast	531	531	3,279	18,658
West	987	6,673	3,132	10,277
CA	10,753	16,660	19,402	31,518
Total	13,303	24,938	32,786	81,073

Area	**10/35**	**10/30**	**9/35**	**8/35**
Northeast	8%	4%	21%	25%
Southeast	4%	2%	10%	23%
West	7%	27%	10%	13%
CA	81%	67%	59%	39%

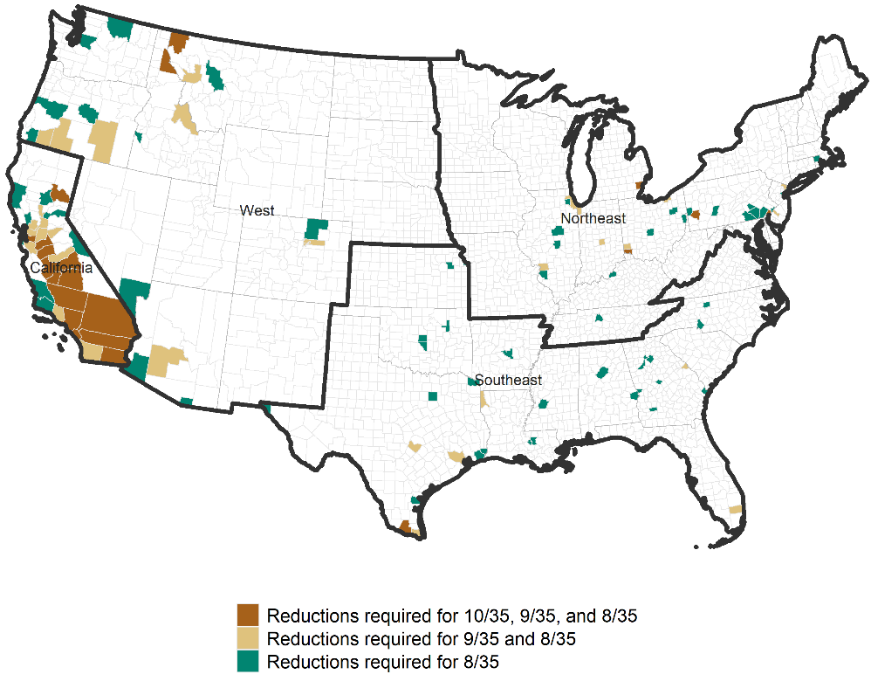

Figure ES-2 Counties Projected to Exceed in Analytical Baseline for the Revised and Alternative Standard Levels of 10/35 µg/m³, 9/35 µg/m³, and 8/35 µg/m³

For each set of alternative standard levels, Chapter 2, Section 2.3.3 includes a discussion of the number of counties that are projected to exceed in 2032, and Figure 2-9 includes maps of counties projected to exceed along with the number of counties. The following summarizes the number of counties, by revised and alternative standard levels, in each geographic area that need $PM_{2.5}$ emissions reductions from the analytical baseline.

- 10/35 µg/m³ — *20 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 1 county in the southeast, 2 counties in the west, and 13 counties in California.
- 10/30 µg/m³ — *49 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 1 county in the southeast, 19 counties in the west, and 25 counties in California.
- 9/35 µg/m³ — *52 counties* need $PM_{2.5}$ emissions reductions. This includes 12 counties in the northeast, 7 counties in the southeast, 10 counties in the west, and 23 counties in California.

- 8/35 μg/m^3 — *117 counties* need $PM_{2.5}$ emissions reductions. This includes 31 counties in the northeast, 33 counties in the southeast, 21 counties in the west, and 32 counties in California.

ES.1.3 Control Strategies and $PM_{2.5}$ Emissions Reductions

We identified controls using the EPA's Control Strategy Tool (CoST) (U.S. EPA, 2019b) and the control measures database.[5] CoST estimates emissions reductions and engineering costs associated with end-of-pipe control technologies or area source controls applied to non-electric generating unit (non-EGU) point, non-point (area), residential wood combustion, and area fugitive dust sources of air pollutant emissions by matching end-of-pipe or area source controls to emissions sources by source classification code (SCC). For these control strategy analyses, to maximize the number of emissions sources we included a lower emissions source size threshold (5 tons per year) and a higher marginal cost per ton threshold ($160,000/ton) than reflected in prior NAAQS RIAs (25-50 tpy, $15,000-$20,000/ton). In Chapter 3, Figure 3-4 shows estimated $PM_{2.5}$ emissions reductions for several emissions source sizes and cost thresholds up to the $160,000/ton marginal cost threshold. We selected the $160,000/ton marginal cost threshold because it is around that cost level that (i) road paving controls get selected and applied, and (ii) opportunities for additional emissions reductions diminish. In addition, in the northeast and southeast we applied emissions reductions from adjacent counties, using a ratio of 4:1. That is, four tons of $PM_{2.5}$ emissions reductions would be required from an adjacent county to reduce one ton of emissions reduction needed in a given county. For additional discussion, see Chapter 2, Section 2.3.1 and Chapter 3, Section 3.2.2.

By area, Table ES-3 includes a summary of the estimated emissions reductions from control applications for the revised and alternative standard levels analyzed. These emissions reductions were used to create the $PM_{2.5}$ spatial surfaces described in Appendix 2A, Section 2A.4.2 for the human health benefits assessments presented in Chapter 5. See

[5] More information about CoST and the control measures database can be found at the following link: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-analysis-modelstools-air-pollution.

Chapter 3, Table 3-5 through Table 3-7 for additional summaries of estimated $PM_{2.5}$ emissions reductions from CoST.

Table ES-3 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST by Area for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

	$PM_{2.5}$ Emissions Reductions			
Area	**10/35**	**10/30**	**9/35**	**8/35**
Northeast	1,032	1,074	7,226	14,036
Northeast (Adjacent Counties)	0	0	2,599	11,911
Southeast	521	521	1,959	13,995
Southeast (Adjacent Counties)	45	45	354	3,086
West	470	2,715	1,386	5,323
CA	3,010	4,652	5,069	7,181
Total	5,078	9,006	18,592	55,532

Note: Totals may not match related tables due to independent rounding. In the northeast and southeast when we applied the emissions reductions from adjacent counties, we used a ppb/ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions.

ES.1.4 Estimates of $PM_{2.5}$ Emissions Reductions Still Needed after Applying Controls

The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. By area, Table ES-4 includes a summary of the estimated emissions reductions still needed after control applications for the revised and alternative standard levels analyzed. See Chapter 3, Table 3-9 for an additional summary of estimated emissions reductions still needed. Figure ES-3 shows the counties that still need emissions reductions after control applications for the revised standard levels of 9/35 μg/m³. Section ES.2 below includes a qualitative discussion of the remaining air quality challenges. In addition, Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5 provide more detailed discussions of these air quality challenges.

Table ES-4 Summary of $PM_{2.5}$ Emissions Reductions Still Needed by Area for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Area	10/35	10/30	9/35	8/35
Northeast	0	0	130	3,285
Southeast	0	0	1,038	3,519
West	516	3,959	1,747	4,982
CA	7,739	11,986	14,411	24,366
Total	8,255	15,945	17,327	36,152

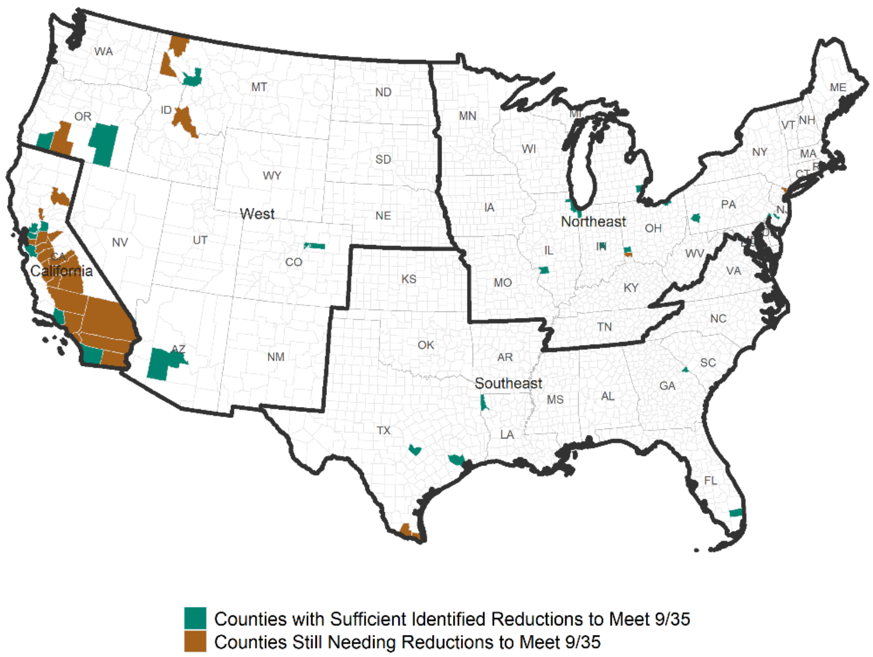

Figure ES-3 Counties that Still Need $PM_{2.5}$ Emissions Reductions for the Revised Standard Levels of 9/35 μg/m³

ES.1.5 Engineering Costs

The EPA also used CoST and the control measures database to estimate engineering control costs. We estimated costs for non-EGU point, non-point (area), residential wood combustion, and area fugitive dust sources of air pollutant emissions. CoST calculates engineering costs using one of two different methods: (1) an equation that incorporates key operating unit information, such as unit design capacity or stack flow rate, or (2) an average annualized cost-per-ton factor multiplied by the total tons of reduction of a pollutant. The engineering cost analysis uses the equivalent uniform annual costs (EUAC) method, in which annualized costs are calculated based on the equipment life for the control and the interest rate incorporated into a capital recovery factor. Annualized costs represent an equal stream of yearly costs over the period the control is expected to operate. The cost estimates reflect the engineering costs annualized using a 7 percent interest rate.

By area, Table ES-5 includes a summary of estimated control costs from control applications for the revised and alternative standard levels analyzed. See Chapter 4, Table 4-2 through Table 4-5 for additional summaries of estimated control costs associated with the control strategies.

Table ES-5 By Area, Summary of Annualized Control Costs for the Revised and Alternative Primary Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 for 2032 (millions of 2017$)

Area	10/35	10/30	9/35	8/35
Northeast	$5.3	$5.5	$203.6	$371.1
Northeast (Adjacent Counties)	$0	$0	$62.1	$364.2
Southeast	$35.8	$35.8	$60.4	$299.7
Southeast (Adjacent Counties)	$0.02	$0.02	$25.5	$69.2
West	$39.7	$112.4	$57.7	$140.6
CA	$121.8	$186.1	$184.4	$256.7
Total	$202.5	$339.8	$593.8	$1,501.5

Note: The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California.

For the alternative standard levels of 10/35 μg/m^3, the majority of the estimated costs are incurred in California because 13 of the 20 counties that need emissions reductions are located in California. Looking at the more stringent alternative standard levels of 10/30 μg/m^3, in the west an additional 17 counties need emissions reductions and estimated costs increase significantly; also, in the west estimated costs for the revised standard levels of 9/35 μg/m^3 are higher than for 10/35 μg/m^3 but lower than for 10/30 μg/m^3.

For revised and more stringent alternative standard levels of 9/35 μg/m^3 and 8/35 μg/m^3, more controls are available to apply in the northeast and the southeast as compared to California and the west. Therefore, the estimated costs for the northeast and southeast are higher for 9/35 μg/m^3 and 8/35 μg/m^3. In addition, in the northeast and southeast when we applied the emissions reductions from adjacent counties, we applied a ratio of 4:1. Application of this ratio also contributes to the higher estimated cost estimates for alternative standard levels of 9/35 µg/m^3 and 8/35 µg/m^3 in those areas.

ES.1.6 Human Health Benefits

We estimate the quantity and economic value of air pollution-related effects using a "damage-function." This approach quantifies counts of air pollution-attributable cases of adverse health outcomes and assigns dollar values to those counts, while assuming that each outcome is independent of one another. We construct this damage function by adapting primary research—specifically, air pollution epidemiology studies and economic value studies—from similar contexts. This approach is sometimes referred to as "benefits transfer."

We use the environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) software program to quantify counts of premature deaths and illnesses attributable to photochemical modeled changes in annual mean $PM_{2.5}$ for the year 2032 using health impact functions (Sacks et al., 2018). A health impact function combines information regarding: the concentration-response relationship between air quality changes and the risk of a given adverse outcome; the population exposed to the air quality change; the baseline rate of death or disease in that population; and the air pollution concentration to which the population is exposed.

After quantifying the change in adverse health impacts, the final step is to estimate the economic value of these avoided impacts. The appropriate economic value for a change in a health effect depends on whether the health effect is viewed *ex ante* (before the effect has occurred) or *ex post* (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a small amount for a large population. The appropriate economic measure is therefore *ex ante willingness-to-pay (WTP)* for changes in risk. However, epidemiological studies generally provide estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk.

Applying the impact and valuation functions to the estimated changes in $PM_{2.5}$ yields estimates of the changes in physical damages (e.g., premature mortalities, cases of hospital admissions and emergency department visits) and the associated monetary values for those changes. Table ES-6 presents the estimated avoided incidences of PM-related illnesses and premature mortality resulting from emissions reductions associated with the application of the illustrative control strategies for the revised and alternative standard levels in 2032. Table ES-7 and Table ES-8 present a summary of the monetized benefits associated with emissions reductions from the application of the illustrative control strategies for the revised and alternative standard levels, both nationally and by area, thereby allowing the comparison of cost and benefits of the application of the illustrative controls. As mentioned above and discussed in Chapter 3, Section 3.2.4, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. In Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 $\mu g/m^3$. In Appendix 5A, a set of tables summarizes the benefits associated with identifying all of the emissions reductions needed to reach the revised and less and more stringent alternative standard levels. For Table ES-7 and Table ES-8, the monetized value of unquantified effects is represented by adding an unknown "B" to the aggregate total. This B represents both uncertainty and a bias in this analysis, as it reflects health and welfare benefits that we are unable to quantify. Note that not all known PM health effects could be quantified or monetized.

Table ES-6 Estimated Avoided PM-Related Premature Mortalities and Illnesses of the Control Strategies for the Revised and Alternative Primary $PM_{2.5}$ Standard Levels for 2032 (95% Confidence Interval)

Avoided Mortality[a]	**10/35**	**10/30**	**9/35**	**8/35**
(Pope III et al., 2019) (adult mortality ages 18-99 years)	1,700 (1,200 to 2,100)	2,000 (1,400 to 2,600)	4,500 (3,200 to 5,700)	9,500 (6,800 to 12,000)
(Wu et al., 2020) (adult mortality ages 65-99 years)	810 (710 to 900)	970 (850 to 1,100)	2,100 (1,900 to 2,400)	4,500 (4,000 to 5,100)
(Woodruff et al., 2008) (infant mortality)	1.7 (-1.0 to 4.3)	2.0 (-1.2 to 5.1)	5.0 (-3.1 to 13)	11 (-7.2 to 29)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	140 (100 to 180)	160 (120 to 200)	330 (240 to 420)	690 (500 to 870)
Hospital admissions—respiratory	90 (31 to 150)	100 (35 to 170)	230 (79 to 370)	480 (170 to 780)
ED visits—cardiovascular	260 (-98 to 600)	300 (-110 to 690)	660 (-250 to 1,500)	1,400 (-550 to 3,300)
ED visits—respiratory	470 (93 to 990)	560 (110 to 1,200)	1,300 (250 to 2,700)	2,900 (570 to 6,000)
Acute Myocardial Infarction	30 (17 to 42)	35 (20 to 49)	72 (42 to 100)	150 (86 to 210)
Cardiac arrest	14 (-5.9 to 33)	17 (-6.9 to 38)	36 (-15 to 81)	75 (-31 to 170)
Hospital admissions—Alzheimer's Disease	360 (270 to 440)	400 (300 to 500)	910 (690 to 1,100)	2,000 (1,500 to 2,400)
Hospital admissions—Parkinson's Disease	47 (24 to 69)	56 (29 to 81)	130 (67 to 190)	280 (140 to 400)
Stroke	54 (14 to 93)	65 (17 to 110)	140 (35 to 230)	290 (74 to 490)
Lung cancer	65 (20 to 110)	77 (23 to 130)	160 (49 to 270)	340 (100 to 560)
Hay Fever/Rhinitis	15,000 (3,600 to 26,000)	17,000 (4,200 to 30,000)	38,000 (9,100 to 65,000)	79,000 (19,000 to 140,000)
Asthma Onset	2,300 (2,200 to 2,300)	2,600 (2,500 to 2,700)	5,700 (5,500 to 6,000)	12,000 (12,000 to 13,000)
Asthma symptoms – Albuterol use	310,000 (-150,000 to 760,000)	370,000 (-180,000 to 900,000)	800,000 (-390,000 to 1,900,000)	1,700,000 (-820,000 to 4,100,000)
Lost work days	110,000 (96,000 to 130,000)	130,000 (110,000 to 150,000)	290,000 (240,000 to 330,000)	610,000 (510,000 to 700,000)
Minor restricted-activity days	670,000 (540,000 to 790,000)	780,000 (630,000 to 920,000)	1,700,000 (1,400,000 to 2,000,000)	3,500,000 (2,900,000 to 4,200,000)

Note: Values rounded to two significant figures.
[a] Reported here are two alternative estimates of the number of premature deaths among adults due to long-term exposure to $PM_{2.5}$. These values should not be added to one another.

Table ES-7 Estimated Monetized Benefits of the Control Strategies for the Revised and Alternative Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 µg/m³ (billions of 2017$)

Benefits Estimate	10/35	10/30	9/35	8/35
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Pope III et al., 2019)				
3% discount rate	$17 + B	$21 + B	$46 + B	$99 + B
7% discount rate	$16 + B	$19 + B	$42 + B	$89 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Wu et al., 2020)				
3% discount rate	$8.5 + B	$10 + B	$22 + B	$48 + B
7% discount rate	$7.6 + B	$9.2 + B	$20 + B	$43 + B

Notes: Rounded to two significant figures.
The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California.
Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag.
It was not possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

Table ES-8 Estimated Monetized Benefits by Area of the Control Strategies for the Revised and Alternative Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 µg/m³ (billions of 2017$)

Benefits Estimate	Area	10/35	10/30	9/35	8/35
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Pope III et al., 2019)					
3% discount rate	**Northeast**	$2.4 + B	$2.5 + B	$18 + B	$37 + B
	Southeast	$0.51 + B	$0.51 + B	$5.3 + B	$25 + B
	West	$0.059 + B	$1.3 + B	$2.3 + B	$10 + B
	California	$15 + B	$17 + B	$21 + B	$27 + B
7% discount rate	**Northeast**	$2.1 + B	$2.2 + B	$16 + B	$34 + B
	Southeast	$0.46 + B	$0.46 + B	$4.8 + B	$22 + B
	West	$0.053 + B	$1.2 + B	$2.1 + B	$9.3 + B
	California	$13 + B	$15 + B	$19 + B	$24 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Wu et al., 2020)					
3% discount rate	**Northeast**	$1.2 + B	$1.2 + B	$8.7 + B	$18 + B
	Southeast	$0.24 + B	$0.24 + B	$2.5 + B	$12 + B
	West	$0.03 + B	$0.64 + B	$1.1 + B	$5.0 + B
	California	$7.0+ B	$8.1 + B	$10 + B	$13 + B
7% discount rate	**Northeast**	$1.0 + B	$1.1 + B	$7.8 + B	$16 + B
	Southeast	$0.21 + B	$0.21 + B	$2.2 + B	$10 + B
	West	$0.027 + B	$0.58 + B	$1.0 + B	$4.5 + B
	California	$6.3 + B	$7.3 + B	$9.1 + B	$12 + B

Notes: Rounded to two significant figures.
The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California.
Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag.
It was not possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

ES.1.7 Welfare Benefits of Meeting the Primary and Secondary Standards

Even though the primary standards are designed to protect against adverse effects to human health, the emissions reductions would have welfare benefits in addition to the direct health benefits. The term *welfare benefits* covers both environmental and societal benefits of reducing pollution. Welfare benefits of the primary PM standard include improved visibility, reduced climate effects, reduced materials damage, reduced vegetation effects resulting from PM exposure, and reduced ecological effects from particulate matter deposition and from nitrogen emissions. This RIA does not assess welfare effects quantitatively; this is discussed further in Chapter 5.

ES.1.8 Environmental Justice

Environmental justice (EJ) concerns for each rulemaking are unique and should be considered on a case-by-case basis, and EPA's EJ Technical Guidance (U.S. EPA, 2015) states that "[t]he analysis of potential EJ concerns for regulatory actions should address three questions:

1. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline?
2. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern for the regulatory option(s) under consideration?
3. For the regulatory option(s) under consideration, are potential EJ concerns created or mitigated compared to the baseline?"

To address these questions, EPA developed an analytical approach that considers the purpose and specifics of the rulemaking, as well as the nature of known and potential exposures and impacts. For the rule, we quantitatively evaluate the potential for disparities in $PM_{2.5}$ exposures and mortality rates across different demographic populations under illustrative control strategies associated with implementation of the current standards (12/35 $\mu g/m^3$, i.e., the baseline) and lower alternative $PM_{2.5}$ standard levels (10/35 mg/m^3, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$) at the national and regional levels. Specifically, we provide information on total burden, absolute changes, and proportional changes in 1) exposures, in terms of annual $PM_{2.5}$ concentrations and 2) premature mortality, in terms of rates per 100,000 individuals across and within various demographic populations. Each type of analysis has strengths and weaknesses, but when taken together, can respond to the above three questions from EPA's Environmental Justice (EJ) Technical Guidance.

Beginning with the first question, under the 12/35 $\mu g/m^3$ analytical baseline, some populations are predicted to experience disproportionately higher annual $PM_{2.5}$ exposures nationally than the reference (overall) population, both in terms of aggregated average exposure and across the distribution of air quality. Specifically, populations who are linguistically isolated, Hispanic, Asian, Black, less educated, unemployed, uninsured, and living below the poverty line live in areas with higher national annual $PM_{2.5}$ concentrations, on average and across the distributions, than both the overall reference population or other populations (e.g., non-Hispanic, White, and more educated) (Section 6.3.1). In addition, those living in urban areas that received Home Owners' Loan Corporation (HOLC) neighborhood quality grades for mortgage lending purposes have higher national annual $PM_{2.5}$ concentrations, both for urban areas designated as "redlined" (i.e., 'Grade D' or "hazardous") and those not redlined (i.e., Grades A, B, and C) as compared to everywhere else (identified here as 'Ungraded by HOLC') (Mitchell et al., 2018, Swope et al., 2022, Lee et al., 2022). Those living in urban areas that received a grade of D are estimated to experience the highest concentrations, both on average and across $PM_{2.5}$ concentration distributions, of all demographic groups analyzed. These disproportionalities are also observed at the regional level, to different extents.

In response to the second question, while lower standard levels would be predicted to reduce $PM_{2.5}$ exposures and mortality rates across all demographic groups, disparities seen in the baseline persist under lower alternative standard levels. However, as to the third question, for most populations assessed, $PM_{2.5}$ exposure disparities are mitigated in the illustrative air quality scenarios reflecting control strategies (10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$) as compared to the baseline (12/35 $\mu g/m^3$), and more so as the alternative standard levels become more stringent. At the national scale, populations that are linguistically isolated, Hispanic, Asian, those less educated, and unemployed populations are estimated to see greater proportional reductions in $PM_{2.5}$ concentrations than reference populations under all lower standard levels evaluated, with proportional reductions increasing as the standard levels decrease. This is also the case for urban areas that received HOLC neighborhood quality grades and for those living in areas that were historically redlined within those urban areas. In addition, exposure disparities in baseline Black and uninsured populations are estimated to be mitigated when moving to alternative standard levels of 8/35 $\mu g/m^3$. Considering the four geographic areas (northeast, southeast, west, and California), proportionally greater reductions in $PM_{2.5}$

concentrations experienced by various populations with baseline exposure disparities are most notable in California, whereas $PM_{2.5}$ concentration reductions are greatest. In Appendix Section 6.6.3 we provide insight into exposures in areas with remaining air quality challenges (i.e., without sufficient emissions control strategies to reach alternative standard levels).

In terms of health effects, some populations are also predicted to experience disproportionately higher rates of premature mortality than the reference population under the baseline scenario. Black populations over the age of 64 are predicted to experience substantially greater mortality rate burdens as compared to White populations over the age of 64. When moving to more stringent standard levels, Black and non-Hispanic Black populations are predicted to experience proportionally similar mortality rate reductions as compared to the reference populations under control strategies associated with 12/35-10/35 or 12/35-10/30, but greater reductions in mortality rates under control strategies associated with 12/35-9/35 or 12/35-8/35. Disparities in national $PM_{2.5}$ mortality rates across demographic groups are mitigated for Hispanics in all the alternative PM standard levels (10/35, 10/30, 9/35, and 8/35), as compared to the baseline.

ES.2 Qualitative Assessment of the Remaining Air Quality Challenges

For the revised standard levels of 9/35 $\mu g/m^3$, the analysis indicates that some areas in the northeast and southeast, as well as in the west and California may still need emissions reductions (Figure ES-3). As discussed in Chapters 2 and 3, the remaining air quality challenges for the revised standard levels can be grouped into the following “bins”: counties with near-road monitors, border areas, small mountain valleys, and California areas. By bin, Table ES-9 below summarizes the counties that may need additional emissions reductions for the revised standard levels.

Table ES-9 Summary of Counties by Bin that Still Need Emissions Reductions for the Revised Primary Standard Levels of 9/35 μg/m³

Bin	Area	Counties[a] for 9/35 mg/m³	$PM_{2.5}$ Emissions Reductions Still Needed
Near-Road Monitors	Northeast	Bergen County, NJ	75
		Hamilton County, OH	55
Border Areas	Southeast	Cameron County, TX	351
		Hidalgo County, TX	687
	California	Imperial County, CA	2,516
Small Mountain Valleys	West	Plumas County, CA	626
		Lemhi County, ID	235
		Shoshone County, ID	558
		Lincoln County, MT	894
		Klamath County, OR	60
California Areas		Fresno County, CA (SJVAPCD)	441
		Kern County, CA (SJVAPCD)	726
		Kings County, CA (SJVAPCD)	730
		Los Angeles County, CA (SCAQMD)	1,450
		Madera County, CA (SJVAPCD)	38
		Merced County, CA (SJVAPCD)	339
		Orange County, CA (SCAQMD)	1,179
		Riverside County, CA (SCAQMD)	2,551
		San Bernardino County, CA (SCAQMD)	2,475
		Stanislaus County, CA (SJVAPCD)	414
		Tulare County, CA (SJVAPCD)	763
		San Joaquin County, CA (SJVAPCD)	48
		Alameda County, CA (BAAQMD)	34
		Calaveras County, CA	50
		Sutter County, CA	31

Note: For California counties that are part of multi-county air districts, the relevant district is indicated in parentheses; BAAQMD = Bay Area Air Quality Management District, SCAQMD = South Coast Air Quality Management District, and SJVAPCD= San Joaquin Valley Air Pollution Control District.

[a] The following counties had no identified $PM_{2.5}$ emissions reductions because available controls were applied for the current standard of 12/35 μg/m³ and additional controls were not available to apply for analyses of the revised and alternative standards: Colusa, Mono, Plumas, and Riverside, CA, Lake, OR, and Yakima, WA.

The characteristics of the air quality challenges for these areas include features of certain near-road sites with challenging local conditions, cross-border transport, effects of complex terrain in the west and California, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events (U.S. EPA, 2019a). For bin-specific detailed discussions of these air quality challenges, see Chapter 2, Section 2.4. Further, for each bin for discussions of the estimated $PM_{2.5}$ emissions reductions needed, the control strategy analyses and controls applied, the estimated $PM_{2.5}$ emissions reductions still needed after the application of controls, and the bin-specific air quality challenges, see Chapter 3, Section 3.2.5.

For counties with near-road monitors, understanding the nature of the local contributions under complex conditions would require detailed local studies beyond the scope of the RIA. For the border areas that may be influenced by cross-border emissions, more detailed analyses of international transport emissions will be needed to assess the relevance of Section 179B of the Clean Air Act. For the small mountain valleys in the west that are influenced by the temperature inversions, residential wood combustion, and wildfire smoke additional detailed analyses that reflect local $PM_{2.5}$ response factors, emissions inventory information, and control measure information will be needed. In addition, more detailed analyses will be needed to characterize the influence of wildfires on $PM_{2.5}$ concentrations and the potential for some wildfires to qualify for exclusion as atypical, extreme, or unrepresentative events.

The air quality in the SJVAPCD and SCAQMD is influenced by complex terrain and meteorological conditions that are best characterized with a high-resolution air quality modeling platform developed for the specific conditions of the air basins. Specific, local information on area source controls to reduce emissions from agricultural dust and burning, prescribed burning, and many of the non-point (area) emissions sources (e.g., commercial and residential cooking) will be needed given the magnitude of emissions from these sources in these areas. In addition, Alameda, Calaveras, and Sutter Counties were influenced by wildfires during the monitoring period used for the air quality projections. Further, more detailed analyses will be needed to characterize the influence of wildfires on $PM_{2.5}$ concentrations and the potential for some wildfires to qualify for exclusion as atypical, extreme, or unrepresentative events.

ES.3 Changes in Data Used and Methods Between Proposal and Final RIAs

Between the proposal and final RIAs, we made some minor updates to the data used, methods applied, and results presented; overall the results of the benefit-cost analysis presented in this final rule RIA are similar to the results presented in the proposed rule RIA.

For the proposal RIA, to project air quality to the future the CMAQ model was applied to simulate air quality over the U.S. during 2016 and for a case with emissions representative of 2032. For the final RIA, the CMAQ model was used to simulate air quality over the U.S. during 2018 and for a case with emissions representative of 2032. Some of the additional policies and final rules reflected in the updated modeling include provisions of tax incentives in the Inflation Reduction Act of 2022, the 2023 Final Good Neighbor Plan for the 2015 Ozone NAAQS, the 2022 Control of Air Pollution from New Motor Vehicles, and the 2021 Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026. For additional information on the air quality modeling platform, see Chapter 2, Section 2.2.1.

In addition, for the control strategy analyses, with the exception of two area source controls, the non-point (area) source, residential wood combustion, and area source fugitive dust controls were applied at different rule penetration (RP) rates depending on the reductions needed in particular areas at different standard levels.[6] The controls were applied at between 5 percent and 35 percent RP at 5 percent increments. In the proposal RIA, these controls were applied at 10 percent and 25 percent RP.

When accounting for reductions from neighbor counties in the northeast and southeast, we identified controls and reductions from adjacent or neighboring counties in 2 rounds. Note that a county can be both a core/home county and an adjacent/neighboring county. In round 1, we identified controls and reductions in the home counties for application in the home counties. In round 2, we identified controls and reductions in neighboring counties for application in home counties that still needed reductions. If a county was both a home county and a neighboring county in round 1, in the final RIA before round 2 we adjusted any potential remaining reductions needed for a home county to account for reductions that were applied in round 1 for application in its neighboring county. In the proposal RIA, we did not make these adjustments before applying controls in round 2. For additional information on the control strategy analyses, see Chapter 3, Section 3.2.2.

Lastly, for the EJ analyses we added several population groups to the exposure EJ assessment, including employment status, health insurance status, linguistic isolation, and redlined areas and added a second epidemiologic study that stratifies $PM_{2.5}$-attributable

[6] RP is the percent of the area source inventory emissions that the control is applied to at a specified percent control efficiency.

mortality by race/ethnicity, similar to the approach used by benefits assessment. In addition, we replaced the case study of areas changing when moving to a revised standard level of 9/35 $\mu g/m^3$ with new figures showing nuanced disparities at high exposures under various standard levels. For additional information on the EJ analyses, see Chapter 6.

ES.4 Results of Benefit-Cost Analysis

As discussed above and in Chapter 3, Section 3.2.4, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. In Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 $\mu g/m^3$. The EPA calculates the monetized net benefits of the revised and alternative standard levels by subtracting the estimated monetized compliance costs from the estimated monetized benefits in 2032. The estimates of costs and benefits do not fully account for all of the emissions reductions needed to reach the revised and less and more stringent alternative standard levels. In 2032, the monetized net benefits of the revised standard levels of 9/35 $\mu g/m^3$ are approximately \$22 billion and \$46 billion using a 3 percent real discount rate for the benefits estimates (in 2017\$). The benefits are associated with two point estimates from two different epidemiologic studies discussed in more detail in Chapter 5, Section 5.2.3. Table ES-10 presents a summary of these impacts for the revised standard levels and the less and more stringent alternative standard levels for 2032.

Table ES-10 Estimated Monetized Benefits, Costs, and Net Benefits of the Control Strategies Applied Toward the Primary Revised and Alternative Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 in 2032 for the U.S. (millions of 2017$)

	10/35	10/30	9/35	8/35
Benefits[a]	$8,500 and $17,000	$10,000 and $21,000	$22,000 and $46,000	$48,000 and $99,000
Costs[b]	$200	$340	$590	$1,500
Net Benefits	$8,300 and $17,000	$9,900 and $21,000	$22,000 and $46,000	$46,000 and $97,000

Notes: Rows may not appear to add correctly due to rounding.
We focus results to provide a snapshot of costs and benefits in 2032, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.
The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California.
[a] We assume that there is a cessation lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure, which affects the valuation of mortality benefits at different discount rates. Similarly, we assume there is a cessation lag between the change in PM exposures and both the development and diagnosis of lung cancer. The benefits are associated with two point estimates from two different epidemiologic studies, and we present the benefits calculated at a real discount rate of 3 percent. The benefits exclude additional health and welfare benefits that could not be quantified (see Chapter 5, Sections 5.2.4 and 5.2.5).
[b] The costs are annualized using a 7 percent interest rate.

As part of fulfilling analytical guidance with respect to E.O. 12866, the EPA presents estimates of the present value (PV) of the monetized benefits and costs over the twenty-year period 2032 to 2051. To calculate the present value of the social net benefits of the revised standard levels, annual benefits and costs are discounted to 2023 at 3 percent and 7 percent discount rates as recommended by OMB's Circular A-4. The EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2032 to 2051, would yield a sum equivalent to the PV. The EAV represents the value of a typical cost or benefit for each year of the analysis, in contrast to the 2032-specific estimates.

For the twenty-year period of 2032 to 2051, for the revised standard levels of 9/35 μg/m^3 the PV of the net benefits, in 2017$ and discounted to 2023, is $540 billion when using a 3 percent discount rate and $280 billion when using a 7 percent discount rate. The EAV is $36 billion per year when using a 3 percent discount rate and $27 billion when using a 7 percent discount rate. The comparison of benefits and costs in PV and EAV terms for the revised standard levels can be found in Table ES-11. Estimates in the table are presented as rounded values.

Table ES-11 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs, Benefits, and Net Benefits of the Control Strategies Applied Toward the Revised Primary Standard Levels of 9/35 μg/m³ (millions of 2017$, 2032-2051, discounted to 2023 using 3 and 7 percent discount rates)

Year	Benefits[a] 3%	Benefits[a] 7%	Costs[b] 3%	Costs[b] 7%	Net Benefits 3%	Net Benefits 7%
2032	$35,000	$25,000	$460	$320	$35,000	$25,000
2033	$34,000	$24,000	$440	$300	$34,000	$23,000
2034	$33,000	$22,000	$430	$280	$33,000	$22,000
2035	$32,000	$21,000	$420	$260	$32,000	$20,000
2036	$31,000	$19,000	$400	$250	$31,000	$19,000
2037	$31,000	$18,000	$390	$230	$30,000	$18,000
2038	$30,000	$17,000	$380	$220	$29,000	$17,000
2039	$29,000	$16,000	$370	$200	$28,000	$15,000
2040	$28,000	$15,000	$360	$190	$28,000	$14,000
2041	$27,000	$14,000	$350	$180	$27,000	$14,000
2042	$26,000	$13,000	$340	$160	$26,000	$13,000
2043	$26,000	$12,000	$330	$150	$25,000	$12,000
2044	$25,000	$11,000	$320	$140	$25,000	$11,000
2045	$24,000	$10,000	$310	$130	$24,000	$10,000
2046	$23,000	$9,800	$300	$130	$23,000	$9,600
2047	$23,000	$9,100	$290	$120	$22,000	$9,000
2048	$22,000	$8,500	$280	$110	$22,000	$8,400
2049	$21,000	$8,000	$280	$100	$21,000	$7,900
2050	$21,000	$7,400	$270	$96	$21,000	$7,300
2051	$20,000	$7,000	$260	$89	$20,000	$6,900
Present Value	$540,000	$290,000	$7,000	$3,700	$540,000	$280,000
Equivalent Annualized Value	$36,000	$27,000	$470	$350	$36,000	$27,000

Notes: Rows may not appear to add correctly due to rounding. The annualized present value of costs and benefits are calculated over a 20-year period from 2032 to 2051.
[a] The benefits values use the larger of the two avoided premature deaths estimates presented in Chapter 5, Table 5-5, and are discounted at a rate of 3 percent over the SAB-recommended 20-year segmented lag. The benefits exclude additional health and welfare benefits that could not be quantified (see Chapter 5, Sections 5.2.4 and 5.2.5).
[b] The costs are annualized using a 7 percent interest rate.

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CHAPTER 1: OVERVIEW AND BACKGROUND

Overview of the Final Rule

On June 10, 2021, the EPA announced its decision to reconsider the 2020 Particulate Matter (PM) NAAQS final action. The EPA is reconsidering the December 2020 decision because the available scientific evidence and technical information indicate that the current standards may not be adequate to protect public health and welfare, as required by the CAA. In general, the Administrator recognizes that the primary annual $PM_{2.5}$ standard is most effective at controlling exposures to "typical" daily $PM_{2.5}$ concentrations that are experienced over the year, while the primary 24-hour $PM_{2.5}$ standard, with its 98th percentile form, is most effective at limiting daily "peak" $PM_{2.5}$ concentrations. The EPA has concluded that the existing primary annual $PM_{2.5}$ standard for PM, set at a level of 12.0 $\mu g/m^3$, is not requisite to protect public health with an adequate margin of safety. The EPA Administrator is revising the existing annual standard to provide increased public health protection. Specifically, the EPA Administrator is revising the level of the annual standard to 9 $\mu g/m^3$. The EPA Administrator is retaining the primary 24-hour $PM_{2.5}$ standard at its current level of 35 $\mu g/m^3$. The Administrator is also retaining the primary 24-hour PM_{10} standard, which provides public health protection against $PM_{10-2.5}$-related health effects, at its current level of 150 $\mu g/m^3$.

The EPA also concluded that the existing secondary PM standards are requisite to protect public welfare from known or anticipated effects and is not changing the secondary standards for PM at this time. Specifically, for the secondary annual $PM_{2.5}$ standard, the EPA Administrator is retaining the existing standard of 15.0 $\mu g/m^3$. For the secondary 24-hour $PM_{2.5}$ standard, the EPA Administrator is retaining the existing standard of 35 $\mu g/m^3$. For the secondary 24-hour PM_{10} standard, the EPA Administrator is retaining the existing standard of 150 $\mu g/m^3$. The docket for the rulemaking is EPA-HQ-OAR-2015-0072.

Overview of the Regulatory Impact Analysis

This chapter summarizes the purpose and background of this Regulatory Impact Analysis (RIA). In this RIA, we are analyzing the revised annual and current 24-hour alternative standard levels of 9/35 $\mu g/m^3$, as well as the following less and more stringent alternative standard levels: (1) a less stringent alternative annual standard level of 10 μg/m^3 in combination with the current 24-hour standard (i.e.,10/35 μg/m^3), (2) a more stringent alternative annual standard level of 8 μg/m^3 in combination with the current 24-hour standard (i.e., 8/35 μg/m^3), and (3) a more stringent alternative 24-hour standard level of 30 μg/m^3 in combination with the an annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). The RIA presents estimated costs and benefits of the control strategies analyzed for the revised and less and more stringent alternative standard levels. According to the Clean Air Act ("the Act"), the Environmental Protection Agency (EPA) must use health-based criteria in setting the NAAQS and cannot consider estimates of compliance cost.

The analyses in this RIA rely on national-level data (emissions inventory and control measure information) for use in national-level assessments (air quality modeling, control strategies, environmental justice, and benefits estimation). However, the ambient air quality issues being analyzed are highly complex and local in nature, and the results of these national-level assessments therefore contain uncertainty. It is beyond the scope of this RIA to develop detailed local information for the areas being analyzed, including populating the local emissions inventory, obtaining local information to increase the resolution of the air quality modeling, and obtaining local information on emissions controls, all of which would reduce some of the uncertainty in these national-level assessments. For example, having more refined data would be ideal for agricultural dust and burning, prescribed burning, and non-point (area) sources due to their large contribution to primary $PM_{2.5}$ emissions and the limited availability of emissions controls.[1] In addition, for residential wood combustion emissions, people will respond differently to the various regulations and incentives offered for controlling $PM_{2.5}$ emissions from wood burning, making it important to identify the right balance of controls for each area.

To maximize the number of emissions sources included and controls analyzed in the analyses, we included a lower emissions source size threshold (5 tons per year) and a higher marginal cost per ton threshold ($160,000/ton) than reflected in prior NAAQS RIAs (25-50 tpy, $15,000-$20,000/ton). As discussed in Chapter 2, Section 2.1.3, given historical

[1] Examples of area source emissions include area fugitive dust, residential wood combustion, and commercial cooking emissions.

and projected trends in NO_X and SO_2 emissions reductions (reducing background PM concentrations and increasing the importance of urban PM concentrations), we analyze direct PM emissions reductions because our modeling indicates that these reductions will be the most effective at reducing PM concentrations in counties projected to exceed the revised and alternative standard levels. The spatial distributions of $PM_{2.5}$ concentrations in the U.S. are characterized by an "urban increment" of consistently higher $PM_{2.5}$ concentrations over urban than surrounding areas. Monitored concentrations are highest in urban areas and relatively low in rural areas. Conceptually, $PM_{2.5}$ concentrations in urban areas can be viewed as the superposition of the urban increment and the contributions from regional and natural background sources. The decreases in anthropogenic SO_2 and NO_X emissions in recent decades have reduced regional background concentrations and increased the relative importance of the urban increment. The projections of additional large reductions in SO_2 and NO_X emissions in the 2032 case further motivate the need for control of local primary $PM_{2.5}$ sources to address the highest $PM_{2.5}$ concentrations in urban areas. Lastly, Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5 discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 $\mu g/m^3$; the areas include counties with near-road monitors, border areas, counties in small western mountain valleys, and counties in California's air basins and districts. The characteristics of the air quality challenges for these areas include features of certain near-road sites with challenging local conditions, cross-border transport, effects of complex terrain in the west, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events (U.S. EPA, 2019).

The remainder of this chapter provides a brief background on the NAAQS, the need for the NAAQS, and an overview of structure of this RIA. The EPA prepared this RIA both to provide the public with information on the benefits and costs of meeting a revised $PM_{2.5}$ NAAQS and to meet the requirements of Executive Orders 12866, 13563, and 14094.

1.1 Background

In setting primary ambient air quality standards, the EPA's responsibility under the law is to establish standards that protect public health, without consideration of the costs of implementing those standards. As interpreted by the Agency and the courts, the CAA requires the EPA to create standards based on health considerations only. The prohibition against the consideration of cost in the setting of the primary air quality standards, however, does not mean that costs or other economic consequences are unimportant or should be ignored. The Agency believes that consideration of costs and benefits is essential to making efficient, cost-effective decisions for implementing these standards. The impact of cost and efficiency is considered by states during the implementation process, as they decide what timelines, strategies, and policies are appropriate for their circumstances. This RIA is not part of the standard setting and is intended to inform the public about the potential costs and benefits that may result when new standards are implemented.

1.1.1 National Ambient Air Quality Standards

Sections 108 and 109 of the CAA govern the establishment and revision of the NAAQS. Section 108 (42 U.S.C. 7408) directs the Administrator to identify pollutants that "may reasonably be anticipated to endanger public health or welfare" and to issue air quality criteria for them. These air quality criteria are intended to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air." PM is one of six pollutants for which the EPA has developed air quality criteria.

Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants identified under section 108. Section 109(b)(1) defines a primary standard as an ambient air quality standard "the attainment and maintenance of which in the judgment of the Administrator, based on [the] criteria and allowing an adequate margin of safety, [is] requisite to protect the public health." A secondary standard, as defined in section 109(b)(2), must "specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on [the] criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air." Welfare effects as defined in section 302(h) [42 U.S.C. 7602(h)] include but are not limited to "effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

Section 109(d) of the CAA directs the Administrator to review existing criteria and standards at 5-year intervals. When warranted by such review, the Administrator is to retain or revise the NAAQS. After promulgation or revision of the NAAQS, the standards are implemented by the states.

1.1.2 Role of Executive Orders in the Regulatory Impact Analysis

While this RIA is separate from the NAAQS decision-making process, several statutes and executive orders still apply to any public documentation. The analyses required by these statutes and executive orders are presented in the final rule preamble, and below we briefly discuss requirements of Orders 12866, 13563, and 14094 and the guidelines of the Office of Management and Budget (OMB) Circular A-4 (U.S. OMB, 2003).

In accordance with Executive Orders 12866, 13563, and 14094 and the guidelines of OMB Circular A-4, the RIA presents the estimated benefits and costs associated with control strategies for a range of annual and 24-hour $PM_{2.5}$ standard levels. The estimated benefits and costs associated with emissions controls are incremental to a baseline of attaining the current standards (annual and 24-hour $PM_{2.5}$ standards of 12/35 $\mu g/m^3$ in ambient air). OMB Circular A-4 requires analysis of one potential alternative standard level more stringent than the final standard and one less stringent than the final standard. The Agency is revising the current annual $PM_{2.5}$ standard to a level of 9 $\mu g/m^3$. The Agency is also retaining the current 24-hour standard of 35 $\mu g/m^3$. In this RIA, we are analyzing the revised annual and current 24-hour alternative standard levels of 9/35 $\mu g/m^3$, as well as the following less and more stringent alternative standard levels: (1) a less stringent alternative annual standard level of 10 $\mu g/m^3$ in combination with the current 24-hour standard (i.e.,10/35 $\mu g/m^3$), (2) a more stringent alternative annual standard level of 8 $\mu g/m^3$ in combination with the current 24-hour standard (i.e., 8/35 $\mu g/m^3$), and (2) a more stringent alternative 24-hour standard level of 30 $\mu g/m^3$ in combination with an annual standard level of 10 $\mu g/m^3$ (i.e., 10/30 $\mu g/m^3$).

1.1.3 Nature of the Analysis

The control strategies presented in this RIA are an illustration of one possible set of control strategies states might choose to implement in response to the revised standards. States—not the EPA—will implement the revised NAAQS and will ultimately determine appropriate emissions control strategies and measures. State Implementation Plans (SIPs) will likely vary from the EPA's estimates provided in this analysis due to differences in the data and assumptions that states use to develop these plans. Because states are ultimately responsible for implementing strategies to meet the revised standards, the control strategies in this RIA are considered hypothetical. The hypothetical strategies were constructed with the understanding that there are inherent uncertainties in estimating and projecting emissions and applying controls to specific emissions or emissions sources. Additional important uncertainties and limitations are documented in the relevant chapters of the RIA.

The EPA's national program rules require technology application or emissions limits for a specific set of sources or source groups. In contrast, a NAAQS establishes a standard level and requires states to identify and secure emissions reductions to meet the standard level from any set of sources or source groups. To avoid double counting the impacts of NAAQS and other national program rules, the EPA includes previously promulgated federal regulations and enforcement actions in its baseline for this analysis (See Section 1.3.1 below for additional discussion of the baseline). The benefits and costs of the revised standards will not be realized until specific controls are mandated by SIPs or other federal regulations.

1.2 The Need for National Ambient Air Quality Standards

OMB Circular A-4 indicates that one of the reasons a regulation such as the NAAQS may be issued is to address a market failure. The major types of market failure include externality, market power, and inadequate or asymmetric information. Correcting market failures is one reason for regulation, but it is not the only reason. Other possible justifications include improving the function of government, removing distributional unfairness, or promoting privacy and personal freedom.

Environmental problems are classic examples of externalities -- uncompensated benefits or costs imposed on another party as a result of one's actions. For example, the smoke from a factory may adversely affect the health of local residents and soil the property in nearby neighborhoods. If bargaining was costless and all property rights were well defined, people would eliminate externalities through bargaining without the need for government regulation.

From an economics perspective, setting an air quality standard is a straightforward remedy to address an externality in which firms emit pollutants, resulting in health and environmental problems without compensation for those incurring the problems. Setting a standard with an adequate margin of safety attempts to place the cost of control on those who emit the pollutants and lessens the impact on those who suffer the health and environmental problems from higher levels of pollution. For additional discussion on the $PM_{2.5}$ air quality problem, see Chapter 2 of the Policy Assessment for the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter (U.S. EPA, 2022a).

1.3 Design of the Regulatory Impact Analysis

The RIA presents the estimates of costs and benefits of applying hypothetical national control strategies for the revised and less and more stringent alternative annual and 24-hour standard levels of 10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$, incremental to attaining the current $PM_{2.5}$ standards and implementing existing and expected regulations. We assume that potential nonattainment areas everywhere in the U.S. will be designated such that they are required to attain the revised standards by 2032.

The selection of 2032 as the analysis year in the RIA does not predict or prejudge attainment dates that will ultimately be assigned to individual areas under the CAA. The CAA contains a variety of potential attainment dates and flexibility to move to later dates, provided that the date is as expeditious as practicable. For the purposes of this analysis, the EPA assumes that it would likely finalize designations for the revised particulate matter NAAQS in late 2025. Furthermore, also for the purposes of this analysis and depending on the precise timing of the effective date of those designations, the EPA assumes that nonattainment areas classified as Moderate would likely have to attain in late 2032. As such, we selected 2032 as the primary year of analysis. States with areas classified as

Moderate and higher are required to develop attainment demonstration plans for those nonattainment areas.

The EPA recognizes that areas designated nonattainment for the final $PM_{2.5}$ NAAQS and classified as Moderate will likely incur some costs prior to the 2032 analysis year. States with nonattainment areas designated as Moderate are required by the CAA to develop SIPs demonstrating attainment by no later than the assigned attainment date. The CAA also requires these states to address Reasonably Available Control Technologies (RACT) for sources in the Moderate nonattainment area, which would lead to additional point source controls in an area beyond existing federal emissions control requirements. Additionally, the CAA requires some Moderate areas with larger populations to implement basic vehicle inspection and maintenance in the area. Should these federal programs and CAA required programs prove inadequate for the area to attain the revised standards by the attainment date, the state would need to identify additional emissions controls in its SIP to meet attainment requirements.

1.3.1 Establishing the Baseline for Evaluating Revised and Alternative Standard Levels

To develop and evaluate control strategies, it is important to estimate $PM_{2.5}$ levels in the future after attaining the current standards of 12/35 $\mu g/m^3$, taking into account projections of future air quality reflecting on-the-books Federal regulations, enforcement actions, state regulations, population and where possible, economic growth. Establishing this baseline for the analysis then allows us to estimate the incremental costs and benefits associated with the revised and alternative standard levels. For the purposes of this analysis and depending on the precise timing of the effective date of designations, the EPA assumes that areas will be designated such that they are required to reach attainment by 2032, and we developed our projected baselines for emissions and air quality for 2032.[2]

Attaining the current standards of 12/35 $\mu g/m^3$ reflects emissions reductions (i) already achieved as a result of national regulations, (ii) expected prior to 2032 from

[2] Because of the complex nature of air quality in California, we adjusted baseline air quality in 2032 to reflect mobile source NOx emissions reductions for California that would occur between 2032 and 2035. These emissions reductions are the result of mobile source regulations expected to be fully implemented by 2035. California provided the mobile source inventory data for 2035.

recently promulgated national regulations (i.e., reductions that were not realized before promulgation of the previous standard but are expected prior to attainment of the current $PM_{2.5}$ standards), and (iii) from additional controls that the EPA estimates need to be included to reach the current standards. Additional emissions reductions achieved as a result of state and local agency regulations and voluntary programs are reflected to the extent that they are represented in emissions inventory information submitted to the EPA by state and local agencies.

We took two steps to develop the baseline for this analysis. First, national $PM_{2.5}$ concentrations were projected to the analysis year (2032) based on forecasts of population and where possible, economic growth and the application of emissions controls resulting from national rules promulgated prior to this analysis, as well as state programs and enforcement actions. Second, we estimated additional emissions reductions needed to meet the current standards of 12/35 $\mu g/m^3$. Below is a list of some of the national rules reflected in the baseline. For a more complete list, please see Chapter 2, Section 2.2.1 (Air Quality Modeling Platform) and the technical support document (TSD) for the 2018v2 emissions modeling platform titled *Preparation of Emissions Inventories for the 2018v2 North American Emissions Modeling Platform* (U.S. EPA, 2023a). If the national rules reflected in the baseline result in changes in $PM_{2.5}$ concentrations or actual emissions reductions that are lower or higher than those estimated, the costs and benefits estimated in this RIA would be higher or lower, respectively.

For EGUs, rules in the baseline include:

- Final Good Neighbor Plan for the 2015 Ozone NAAQS (2023),
- Revised Cross-State Air Pollution Rule Update (2021),
- Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources (2015),
- Mercury and Air Toxics Rule (2011), and
- Provisions of tax incentives in the Inflation Reduction Act of 2022 (IRA).

For mobile sources, rules in the baseline include:

- Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (2022),

- Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026 (2021),
- GHG Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2 (2016), and
- Tier 3 Motor Vehicle Emission and Fuel Standards (2014).

For non-EGUs, rules in the baseline include:

- Final Good Neighbor Plan for the 2015 Ozone NAAQS (2023),
- New Source Performance Standards (NSPS) for oil and natural gas sources (2016),
- NSPS for process heaters (2013),
- NSPS for natural gas turbines and reciprocating internal combustion engines (2012), and
- NSPS for residential wood combustion (2015).

We did not conduct this analysis incremental to controls applied as part of previous NAAQS analyses because the data and modeling on which these previous analyses were based are now considered outdated and are not compatible with this $PM_{2.5}$ NAAQS analysis.

1.3.2 Cost Analysis Approach

The EPA estimated the costs of applying hypothetical national control strategies. Where available, we apply end-of-pipe and area source controls to achieve emissions reductions and present the costs associated with these $PM_{2.5}$ emissions reductions. These cost estimates reflect only engineering costs, which generally include the costs of purchasing, installing, and operating the referenced controls. The end-of-pipe and area source control strategies selected for analysis illustrate one way in which nonattainment areas could reduce emissions. As mentioned above, the air quality issues being analyzed are highly complex and local in nature, and the results of these national-level assessments contain uncertainty. The EPA anticipates that state and local governments will consider programs that are best suited for local conditions.

1.3.3 Benefits Analysis Approach

The EPA estimated the number and economic value of the avoided $PM_{2.5}$-attributable premature deaths and illnesses associated with the control strategies analyzed for the revised alternative standard levels. We quantified an array of mortality and morbidity effects using the BenMAP-CE tool (U.S. EPA 2023b), which has been used in recent RIAs. As compared to the 2012 PM NAAQS RIA (U.S. EPA, 2012), the Agency applied concentration-response relationships from newer epidemiologic studies, assessed a wider array of human health endpoints and updated other economic and demographic input parameters. Each of these updates is fully described in Chapter 5, the benefits analysis approach and results chapter. Unquantified health benefits, welfare benefits, and climate benefits are also discussed in Chapter 5.

1.3.4 Welfare Benefits of Meeting the Primary and Secondary Standards

Even though the primary standards are designed to protect against adverse effects to human health, the emissions reductions would have welfare benefits in addition to the direct health benefits. The term *welfare benefits* covers both environmental and societal benefits of reducing pollution. Welfare benefits of the primary PM standard include reduced vegetation effects resulting from PM exposure, reduced ecological effects from particulate matter deposition and from nitrogen emissions, reduced climate effects, and changes in visibility. This RIA does not assess welfare effects quantitatively; this is discussed further in Chapter 5.

1.4 Organization of the Regulatory Impact Analysis

This RIA is organized into the following remaining chapters:

- *Chapter 2*: *Air Quality Modeling and Methods*. The data, tools, and methods used for the air quality modeling are described in this chapter, as well as the post-processing techniques used to produce a number of air quality metrics for input into the analysis of benefits and costs.

- *Chapter 3: Control Strategies and $PM_{2.5}$ Emissions Reductions*. The chapter presents the hypothetical control strategies and estimated emissions reductions in 2032 after applying the control strategies.

- *Chapter 4: Engineering Cost Analysis and Qualitative Discussion of Social Costs.* The chapter summarizes the methods, tools, and data used to estimate the engineering costs of the revised and alternative standard levels analyzed. The chapter also provides a qualitative discussion of social costs.

- *Chapter 5: Benefits Analysis Approach and Results*. The chapter quantifies the estimated health-related benefits of the PM-related air quality improvements associated with the control strategies for the revised and alternative standard levels analyzed. The chapter also presents qualitative discussions of welfare benefits and climate benefits.
- *Chapter 6: Environmental Justice*. This chapter includes an assessment of environmental justice impacts associated with the control strategies for the revised and alternative standard levels analyzed.
- *Chapter 7: Labor Impacts*. This chapter provides a qualitative discussion of potential labor impacts.
- *Chapter 8: Comparison of Benefits and Costs*. The chapter compares estimates of the benefits with costs and summarizes the net benefits of the revised and alternative standard levels analyzed.

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CHAPTER 2: AIR QUALITY MODELING AND METHODS

Overview

To evaluate the incremental costs and benefits of meeting the revised and alternative $PM_{2.5}$ standard levels relative to meeting the existing standards, models were used to predict $PM_{2.5}$ concentrations and emissions associated with the standard levels. Air quality was simulated using a 2018-based modeling platform with the Community Multiscale Air Quality (CMAQ) model. The modeling platform paired a 2018 CMAQ simulation with a corresponding CMAQ simulation with emissions representative of 2032 that reflects effects of finalized rules and other factors.

Air quality ratios, which relate a change in $PM_{2.5}$ design values (DVs) to a change in emissions, were used to estimate the emission reductions needed to meet the existing, revised, and alternative NAAQS in areas projected to exceed the standards in 2032. These emission estimates are used in identifying controls and associated costs of meeting the revised and alternative standard levels relative to meeting the existing standards. A $PM_{2.5}$ concentration field was developed using the 2032 CMAQ modeling and was adjusted according to the required change in $PM_{2.5}$ concentrations to create $PM_{2.5}$ fields associated with meeting standard levels. These $PM_{2.5}$ concentration fields are used in calculating the health benefits associated with meeting the standard levels.

The overall steps in the process are as follows:

Step 1. Project annual and 24-hour $PM_{2.5}$ DVs to 2032 using a CMAQ simulation for 2018 and a corresponding CMAQ simulation with emissions representative of 2032 that reflects effects of finalized rules and other factors.

Step 2. Develop air quality ratios that relate a change in $PM_{2.5}$ DV to a change in emissions for use in estimating the emissions reductions needed to just meet the existing, revised, and alternative NAAQS. The air quality ratios are developed using CMAQ sensitivity modeling with reductions in anthropogenic emissions in select counties.

Step 3. Using the air quality ratios from Step 2, estimate the emission reductions beyond the 2032 modeling case that are needed to meet the existing standards and adjust $PM_{2.5}$ DVs accordingly. The resulting $PM_{2.5}$ DVs define the *12/35 analytical baseline* that is used as the reference case in estimating the incremental costs and benefits of meeting revised and alternative standard levels relative to existing standards. Note that emission reductions applied to meet the existing standards do not contribute to incremental costs and benefits in the Regulatory Impact Analysis (RIA).

Step 4. Using the air quality ratios from Step 2, estimate the primary $PM_{2.5}$ emission reductions needed to meet the alternative standard levels beyond the 12/35 analytical baseline. These emission reduction estimates are used in developing controls to meet the alternative standard levels.

Step 5. Develop a gridded national $PM_{2.5}$ concentration field associated with the 2032 case by fusing the 2032 CMAQ modeling with projected monitor concentrations. Adjust the 2032 concentration field according to the changes in $PM_{2.5}$ DVs needed to meet standard levels to create $PM_{2.5}$ fields associated with each standard level. These $PM_{2.5}$ concentration fields are used in calculating the health benefits associated with meeting revised and alternative standard levels.

In the remainder of this chapter, contextual information on $PM_{2.5}$ and its characteristics in the U.S. is first provided in Section 2.1. The projection of air quality from 2018 to 2032 is then described in Section 2.2. In Section 2.3, the development of air quality ratios and their application to estimating emission reductions is described. In Section 2.4, the air quality challenges in select areas are described in terms of highly local influences on $PM_{2.5}$ concentrations. Finally, the development of the $PM_{2.5}$ concentration fields associated with meeting the existing, revised, and alternative standards is described in Section 2.5.

2.1 $PM_{2.5}$ Characteristics

2.1.1 $PM_{2.5}$ Size and Composition

As described in the Integrated Science Assessment (US EPA, 2019a) and Policy Assessment (US EPA, 2022a), PM (particulate matter) refers to the mass concentration of suspended particles in the atmosphere. Atmospheric particles range in size from less than 1 nanometer (10^{-9} meter) to over 100 micrometers (μm, or 10^{-6} meter) in diameter. For reference, a typical strand of human hair is 70 μm in diameter and a grain of salt is about

100 μm. Atmospheric particles are often classified into size ranges associated with the three distinct modes evident in measured ambient particle size distributions. The size ranges include ultrafine particles (<0.1 μm), accumulation mode or fine particles (0.1 to ~3 μm), and coarse particles (>1 μm). For regulatory purposes, fine particles are measured as $PM_{2.5}$, which refers to the total mass concentration of particles with aerodynamic diameter less than 2.5 μm.

PM is made up of many different chemical components. The major components include carbonaceous matter (elemental and organic carbon) and inorganic species such as sulfate, nitrate, ammonium, and crustal species. PM includes solid and liquid particles as well as multiphase particles (e.g., particles with a solid core surrounded by an inorganic aqueous solution with an organic coating). The phase state and composition of an atmospheric particle can vary with atmospheric conditions. For example, the aqueous phase of a particle may effloresce (i.e., crystallize) when the atmospheric relative humidity falls below a threshold. Similarly, as gas-phase concentrations and meteorological conditions (e.g., temperature and relative humidity) change, chemical species can condense and evaporate from particles to maintain or approach equilibrium with their gas-phase counterparts (Seinfeld and Pandis, 2016).

PM can be directly emitted into the atmosphere or formed in the atmosphere through chemical and physical processes. PM that is directly emitted into the atmosphere by sources is referred to as *primary PM*. Elemental carbon and crustal species are examples of primary PM components. PM that is formed *in situ* through atmospheric processes is referred to as *secondary PM*. Secondary PM is formed through pathways including new particle nucleation, condensation and reactive uptake of gas-phase species, and cloud and fog evaporation (Seinfeld and Pandis, 2016). Nucleation of new particles occurs when molecular clusters formed from gas-phase species grow into stable particles. Condensation of atmospheric gases onto preexisting particles occurs when gas-phase concentrations exceed the equilibrium vapor concentrations of the particle constituents. PM formation from cloud and fog processes occurs when semi- and non-volatile chemical species formed via aqueous chemistry in cloud and fog remain suspended in ambient particles following cloud/fog evaporation.

Gaseous SO_2 emissions lead to $PM_{2.5}$ formation following SO_2 oxidation to sulfuric acid in the gas and aqueous phases (Seinfeld and Pandis, 2016). Sulfuric acid is essentially non-volatile under atmospheric conditions and leads to $PM_{2.5}$ sulfate formation by contributing to new particle formation, condensation onto preexisting particles, and remaining in particles following cloud/fog evaporation. Enhanced particle acidity due to $PM_{2.5}$ sulfate formation reduces the equilibrium vapor concentration of ammonia (the primary atmospheric base) and promotes condensation of ammonia onto particles, thereby forming $PM_{2.5}$ ammonium. $PM_{2.5}$ sulfate and associated water and acidity also influence chemical pathways for the formation of secondary organic aerosol (SOA).

Gaseous NOx emissions lead to $PM_{2.5}$ formation following NOx oxidation to nitric acid, which is semi-volatile under atmospheric conditions (Seinfeld and Pandis, 2016). Condensation of nitric acid onto particles tends to be favorable under cool, humid conditions with abundant ammonia, and results in $PM_{2.5}$ nitrate formation. Due to effects of nitric acid on particle acidity, ammonia often co-condenses with nitric acid to yield $PM_{2.5}$ ammonium. NOx emissions also influence secondary PM concentrations by modulating many atmospheric oxidation processes and by contributing to the production of organic nitrates. Monoterpene nitrates and isoprene nitrates are examples of $PM_{2.5}$ species that can be formed from products of anthropogenic NOx emissions and biogenic volatile organic compound (VOC) emissions. SOA formation occurs following the oxidation of VOC emissions in the atmosphere. SOA formation is an active area of research and involves myriad species and reactions occurring in the gas, particle, and aqueous phases. Gaseous ammonia emissions can influence PM concentrations by affecting cloud and aerosol acidity in addition to condensing on particles to form $PM_{2.5}$ ammonium.

The emission sources of primary $PM_{2.5}$ and the gaseous precursors of $PM_{2.5}$ have recently been summarized in the PM NAAQS Policy Assessment (USEPA, 2022a). EGUs make up the largest emissions source sector for SO_2. The largest NOx emissions sectors include mobile sources (on-road and non-road) and EGUs. Ammonia emissions are greatest from the agricultural sector (fertilizer and livestock waste) and from fires. VOC emissions are largest from mobile sources, industrial processes, fires, and biogenic sources. Primary $PM_{2.5}$ emissions are largest from fires, fugitive dust (paved/unpaved road dust and construction dust), and area sources (e.g., residential wood combustion). Fires are an important source of particulate organic matter. Note that some $PM_{2.5}$ components (e.g., elemental carbon and crustal species) occur due to direct emissions alone while other $PM_{2.5}$ components (e.g., organic carbon and sulfate) occur due to a combination of direct emissions and secondary formation in the atmosphere.

2.1.2 $PM_{2.5}$ Regional Characteristics

$PM_{2.5}$ concentrations vary in magnitude and composition over the U.S. with distinct regional and seasonal features. The characteristics of $PM_{2.5}$ concentrations in the U.S. have recently been summarized in the Integrated Science Assessment (USEPA, 2019a), and the spatial distribution of $PM_{2.5}$ over the U.S. is shown in Figure 2-1 based on a hybrid satellite modeling method (van Donkelaar et al., 2021). In the Eastern U.S., organic carbon and sulfate have the highest contribution to total $PM_{2.5}$ concentrations in most locations. In the Upper Midwest and Ohio Valley, nitrate can also be an important contributor to $PM_{2.5}$, due to the cool, humid conditions in winter and influence of ammonia that promotes ammonium nitrate formation. In the Southeastern U.S., organic carbon concentrations are relatively high due to the abundance of biogenic VOC emissions that contribute to SOA formation following oxidation in the presence of anthropogenic emissions. Areas of relatively high $PM_{2.5}$ concentrations within the Eastern U.S. are associated with urban centers.

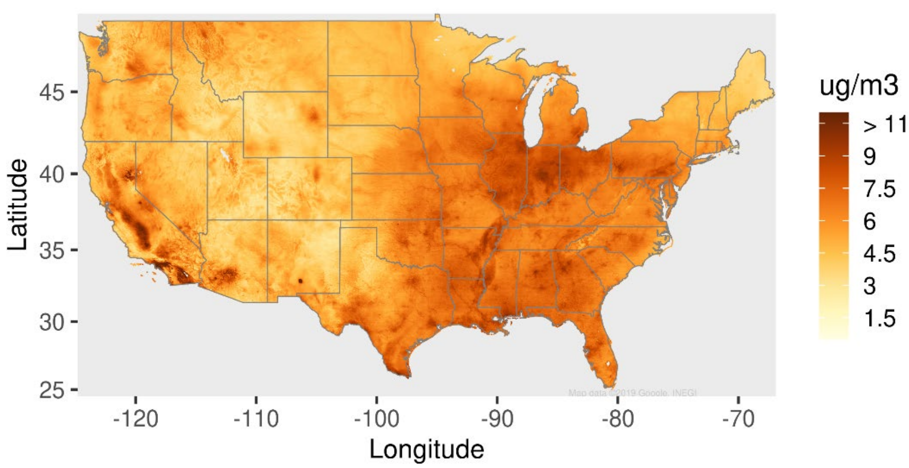

Figure 2-1 Annual Average $PM_{2.5}$ Concentrations over the U.S. in 2019 Based on the Hybrid Satellite Modeling Approach of van Donkelaar et al. (2021)

The Western U.S. is characterized by some of the lowest and highest $PM_{2.5}$ concentrations in the country, with relatively sharp spatial gradients in $PM_{2.5}$ compared to the east. The complex terrain of the Western U.S. has an important influence on air pollution processes as does the relative abundance of wildfires (and prescribed burning). In the Northwest, meteorological temperature inversions often occur in small mountain valleys in winter and trap pollution emissions in a shallow atmospheric layer at the surface. Emissions from home heating with residential wood combustion can build up in the surface layer and produce episodically high $PM_{2.5}$ concentrations in winter. Elevated wintertime $PM_{2.5}$ in these mountain valleys can approach or sometimes exceed the 24-hour $PM_{2.5}$ standard, which is based on a 98^{th} percentile form.

In large western air basins (e.g., San Joaquin Valley, CA; South Coast Air Basin, CA; and Salt Lake Valley, UT), emission sources are more diverse than in the small mountain valleys and include NOx emissions from urban centers and ammonia from agriculture. Meteorological conditions are also more complex than in the smaller valleys and can include a persistent aloft temperature inversion from high-pressure-driven air subsidence in addition to a near-surface temperature inversion from nighttime radiative cooling. The near-surface inversion has the effect of concentrating primary $PM_{2.5}$ emissions near the ground, whereas the aloft inversion caps the nighttime residual air layer, in which NOx is converted to nitrate through heterogeneous aerosol chemistry. In the morning, when the near-surface inversion breaks and the surface mixed layer grows due to surface heating, the $PM_{2.5}$ nitrate and ammonium formed overnight in the residual layer are entrained to the surface. This entrainment has the effect of diluting primary $PM_{2.5}$ concentrations near the surface and enhancing surface concentrations of secondary $PM_{2.5}$. $PM_{2.5}$ concentrations in the South Coast Air Basin are also affected by the land-sea breeze circulation and a semi-permanent high-pressure cell. Due to the large populations, diverse emission sources, and terrain-driven meteorological features, the San Joaquin Valley and South Coast Air Basin experience elevated annual-average $PM_{2.5}$ concentrations as well as short-term $PM_{2.5}$ enhancements. These characteristics can create challenges for meeting both the annual and 24-hour $PM_{2.5}$ standards.

$PM_{2.5}$ concentrations in the Western U.S. are also strongly influenced by emissions from wildfires, which are relatively common in summer but increasingly occur year-round. In the Southwest, dust emission sources are prevalent, and windblown dust makes substantial contributions to $PM_{2.5}$ concentrations under dry, windy conditions. Organic carbon is often the largest $PM_{2.5}$ contributor in the west due to the influence of combustion sources such as wildfire and residential wood combustion. Crustal species are also important contributors in dust-prone areas, and ammonium nitrate is a major $PM_{2.5}$ component in large air basins during meteorological stagnation periods in fall and winter. Along the border with Mexico, western areas also experience important cross-border transport contributions to $PM_{2.5}$ (e.g., Calexico, CA experiences contributions from the much the larger city of Mexicali, MX, which is in the same airshed just across the border).

2.1.3 $PM_{2.5}$ Trends

Over the last several decades, $PM_{2.5}$ concentrations have decreased on average over the U.S. (Figure 2-2). As described in the recent PM NAAQS Policy Assessment (USEPA, 2022a), the reductions in $PM_{2.5}$ concentrations correspond to the reductions in $PM_{2.5}$ precursor emissions illustrated in Figure 2-3. Among the $PM_{2.5}$ precursors (i.e., SO_2, NOx, VOC, and ammonia), the largest emission reductions occurred for SO_2 and NOx. SO_2 emissions decreased by 84% between 2002 and 2017, and NOx emissions decreased by 60%. Reductions in SO_2 emissions were relatively large from stationary sources such as EGUs in the Eastern U.S. NOx emission reductions were driven by reduced emissions from mobile sources and EGUs. Compared with SO_2 and NOx, emissions of primary $PM_{2.5}$ and ammonia have been relatively flat in recent decades. The small changes in primary $PM_{2.5}$ emissions in Figure 2-3 are likely due to changes in emission estimation methods for source sectors over time. Wildfire emissions are not included in the data for Figure 2-3, but an upward trend in $PM_{2.5}$ emissions is evident in estimates generated for National Emission Inventory years (i.e., 2005, 2008, 2011, 2014, and 2017).[1] Studies have also predicted that climate change presents increased potential for very large fires in the contiguous U.S. in the future (e.g., Barbero et al., 2015).

[1] https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

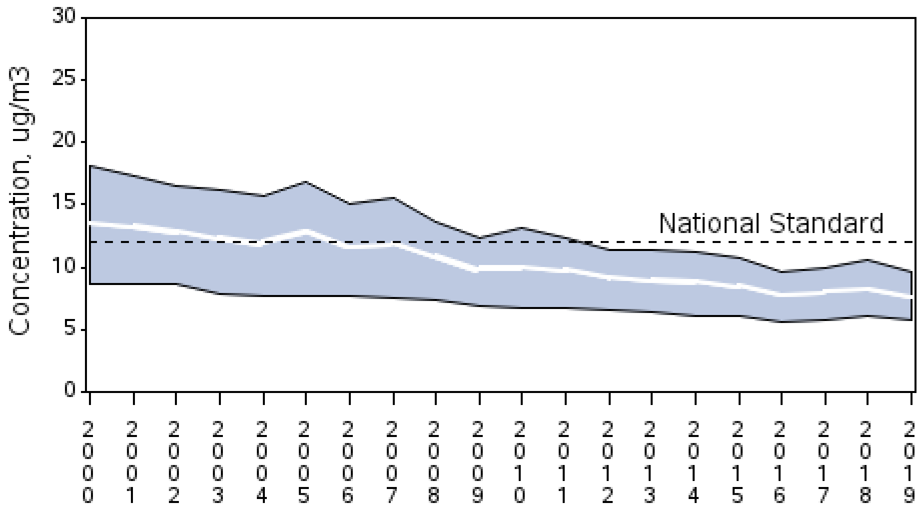

Figure 2-2 Seasonally Weighted Annual Average $PM_{2.5}$ Concentrations in the U.S. from 2000 to 2019 (406 sites)

Note: The white line indicates the mean concentration while the gray shading denotes the 10th and 90th percentile concentrations.

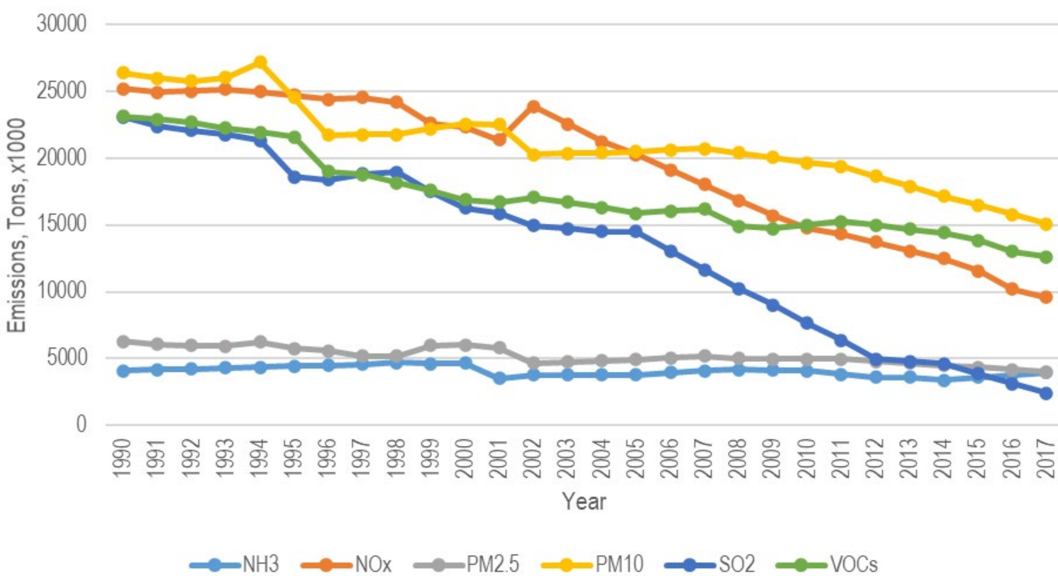

Figure 2-3 National Emission Trends of $PM_{2.5}$, PM_{10}, and Precursor Gases from 1990 to 2017

Note: Data do not include wildfire emissions.

As described in the PM NAAQS Policy Assessment (USEPA, 2022a), $PM_{2.5}$ precursor emission reductions have altered the seasonal variation in $PM_{2.5}$ concentrations over the

U.S. Through 2008, the peak in the national average $PM_{2.5}$ concentration occurred during summer, largely due to sulfate formation from summertime increases in EGU SO_2 emissions in the Eastern U.S. and wildfires in the West. However, starting in 2009, the summertime peaks in $PM_{2.5}$ concentrations have been smaller than those in winter as $PM_{2.5}$ sulfate concentrations have decreased (Chan et al., 2018). The decrease in sulfate in the Eastern U.S. has increased the relative contribution of organic carbon and sources of primary $PM_{2.5}$, whose emissions have remained flat as SO_2 emissions have decreased. Primary $PM_{2.5}$ sources in urban centers contribute to the "urban increment" of consistently higher $PM_{2.5}$ concentrations in urban than surrounding areas (Chan et al., 2018).

To explore how emission trends may persist into the future, models are applied to project emission inventories accounting for expected future emission changes from finalized rules and other factors. Air quality models are then used to simulate pollutant concentrations under conditions of the projected future emissions. For the purposes of the RIA, model projections from 2018 to 2032 were developed for air quality analyses as described in Section 2.2. As shown in Figure 2-4, the trends in NOx, SO_2, and primary $PM_{2.5}$ emissions from the recent past (Figure 2-3) are projected to continue into the near future. From 2018 to 2032, anthropogenic NOx emissions are projected to decrease by 3.6 million tons (41%), with the greatest reductions from mobile-source sectors (nonroad and onroad) and EGUs. SO_2 emissions are projected to decrease by 1.1 million tons (48%), with the greatest reductions from the EGU sector. For primary $PM_{2.5}$, emissions are relatively flat from 2018 to 2032, with a decrease of 116k tons (4%) mainly due to reductions from mobile sources and EGUs. Primary $PM_{2.5}$ emissions from the largest emitting sectors (e.g., dust, agricultural and prescribed fires, residential wood combustion, and areas sources) are essentially constant or slightly increasing (e.g., dust) (Figure 2-4).[2] This projected behavior is consistent with past trends, in which NOx and SO_2 emissions declined steadily while primary $PM_{2.5}$ emissions were relatively constant (Figure 2-3).

[2] Prescribed burning emissions were held constant at 2018 levels in the model projections, although these emissions could potentially change in the future. Available evidence indicates that wildfire acres burned have increased over time, which, in turn, has drawn attention to prescribed fires as an important tool for reducing wildfire risk and the severity of wildfires and wildfire smoke (88 FR, 54118, 54126, August 9, 2023). A few agencies have efforts in place to increase fuel load minimization efforts in areas at high risk of wildfire (as noted in the PM NAAQS proposal 88 FR 5570, January 27, 2023).

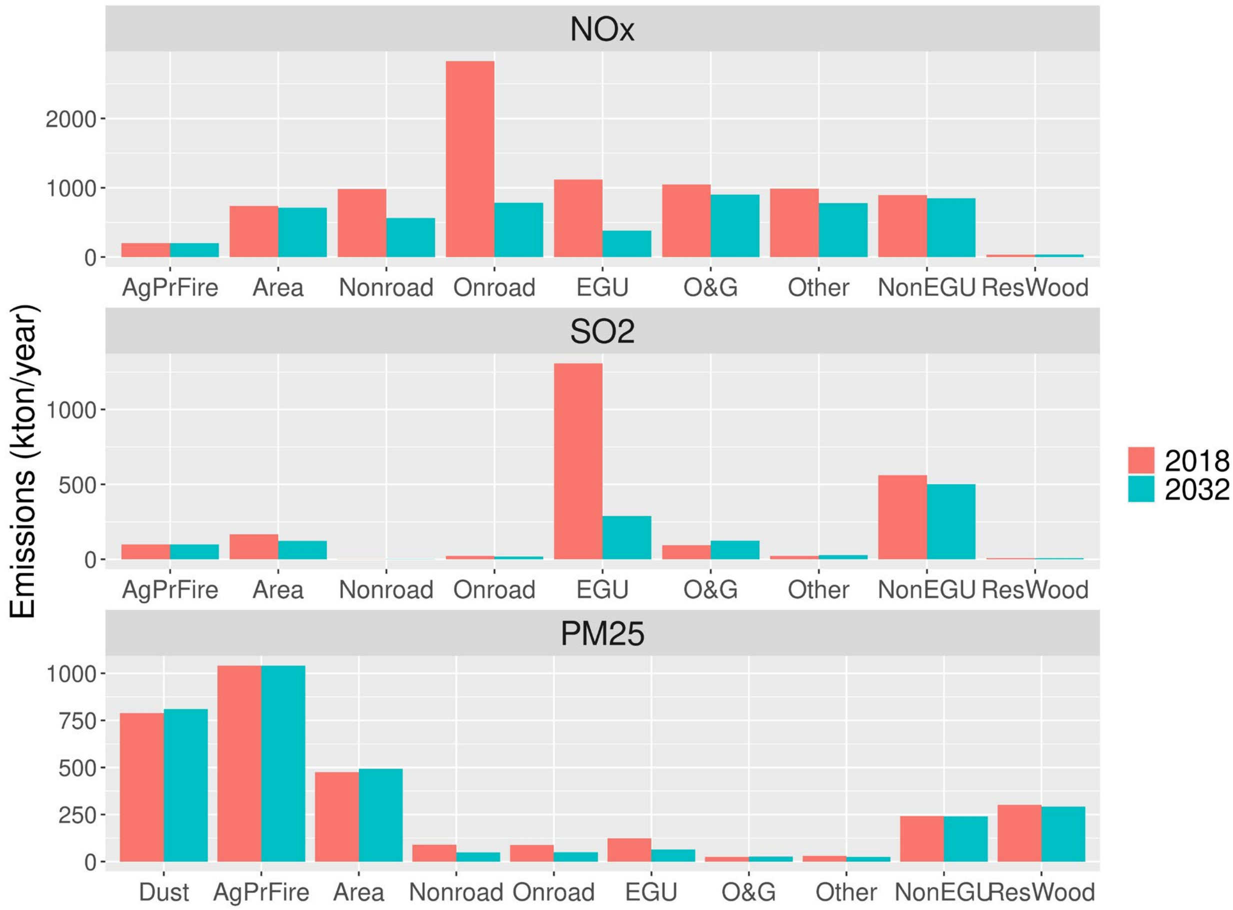

Figure 2-4 Annual Anthropogenic Source Sector Emission Totals (1000 tons per year) for NOx, SO_2, and $PM_{2.5}$ for 2018 and 2032

Note that AgPrFire: agricultural and prescribed fire; Area: non-point area sources; O&G: oil and gas; Other: airports, commercial marine vehicles, rail, and solvents; NonEGU: remaining non-EGU point sources; RWC: residential wood combustion.

As mentioned above, spatial distributions of $PM_{2.5}$ concentrations in the U.S. are characterized by an "urban increment" of consistently higher $PM_{2.5}$ concentrations over urban than surrounding areas. Monitored concentrations are highest in urban areas and relatively low in rural areas. Conceptually, $PM_{2.5}$ concentrations in urban areas can be viewed as the superposition of the urban increment and the contributions from regional and natural background sources. The decreases in anthropogenic SO_2 and NOx emissions in recent decades have reduced regional background concentrations and increased the relative importance of the urban increment. The projections of additional large reductions in SO_2 and NOx emissions in the 2032 case further motivates the need for control of local primary $PM_{2.5}$ sources to address the highest $PM_{2.5}$ concentrations in urban areas.

In Figure 2-5, $PM_{2.5}$ concentrations are shown over four urban areas in the Eastern U.S. based on the 2032 modeling case described in Section 2.2. A common feature of these diverse locations is the relatively high $PM_{2.5}$ concentrations over the urban area and lower concentrations just outside of the urban core. $PM_{2.5}$ concentrations in the urban core of these Eastern U.S. areas exceed revised and alternative standards levels considered in the RIA, whereas concentrations surrounding the urban core are below the revised and alternative standard levels. In the illustrative control strategy analysis of the RIA, the urban exceedances are addressed by focusing on primary $PM_{2.5}$ emission controls in the local county. This approach is consistent with the exceedances being driven by the urban $PM_{2.5}$ increment, the relatively high responsiveness of $PM_{2.5}$ concentrations to primary $PM_{2.5}$ emission reductions, and the reductions in regional $PM_{2.5}$ concentrations from the large SO_2 and NOx emission reductions in recent decades and in the 2032 projection. Patterns may vary in the Western U.S. where the spatial extent of the $PM_{2.5}$ increment may be influenced by complex terrain that defines distinct air basins.

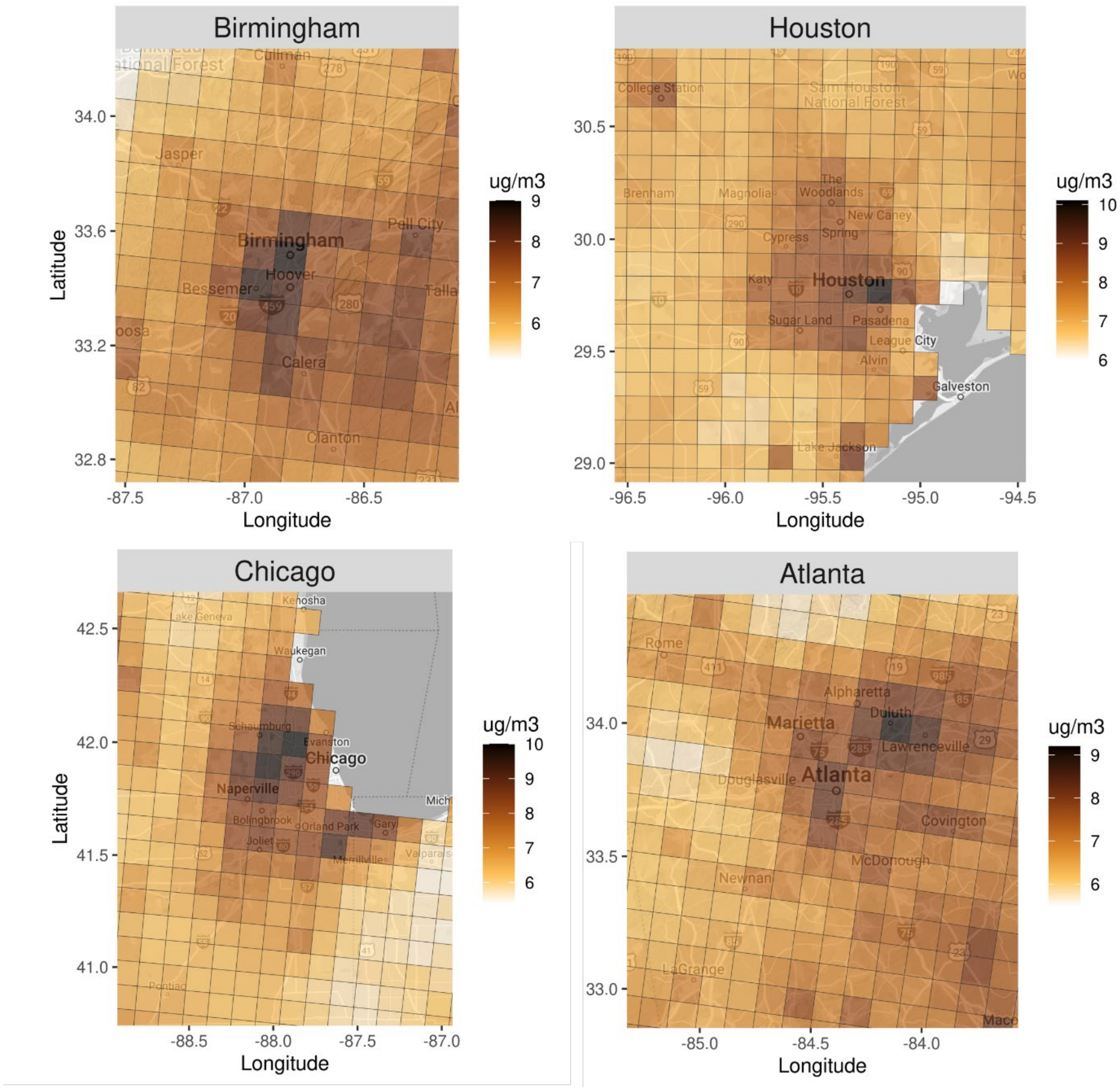

Figure 2-5 Gridded $PM_{2.5}$ Concentrations over Selected Urban Areas Based on the 2032 Modeling Case Described Below with the Enhanced Voronoi Neighbor Averaging Approach

2.2 Modeling $PM_{2.5}$ in the Future

To evaluate the incremental costs and benefits of meeting the revised and alternative $PM_{2.5}$ standard levels in this RIA relative to meeting the existing standards, models were used to predict $PM_{2.5}$ concentrations associated with emissions representative of a 2032 future year to inform subsequent analyses. The projections were performed using a 2018-based modeling platform with the Community Multiscale Air

Quality (CMAQ) model (www.epa.gov/cmaq). The modeling platform paired a 2018 CMAQ simulation with a corresponding CMAQ simulation based on emissions representative of 2032. The 2032 emission projections account for numerous factors including the effects of finalized rules. This modeling platform was chosen because it represents the most recent, complete set of emissions information currently available for national-scale modeling. The approach used for projecting future-year air quality with the platform is described in this section.

2.2.1 Air Quality Modeling Platform

To project air quality to the future, the CMAQ model was applied to simulate air quality over the U.S. during 2018 and for a case with emissions representative of 2032. Other than the differences in emissions inventories for the 2018 and 2032 CMAQ simulations, all other model inputs specified for the 2018 base year remained unchanged in the 2032 modeling case. Inputs for CMAQ simulations include files with emissions, meteorology, and initial and boundary condition data.

2.2.1.1 Model Configuration

CMAQ is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary $PM_{2.5}$ concentrations, and deposition over regional spatial scales (e.g., over the contiguous U.S.) (Appel et al., 2021; Appel et al., 2018; Appel et al., 2017). CMAQ simulates the key processes (e.g., emissions, transport, chemistry, and deposition) that affect primary (directly emitted) and secondary (formed by atmospheric processes) $PM_{2.5}$ using state-of-the-science process parameterizations and input data for emissions, meteorology, and initial and boundary conditions. CMAQ's representation of the chemical and physical mechanisms that govern the formation and fate of air pollution enable simulations of the impacts of emission controls on $PM_{2.5}$ concentrations.

CMAQ version 5.3.2 (www.epa.gov/cmaq) was used to simulate air quality for 2018 to provide a reference simulation for the 2032 air quality projection. The geographic extent of the air quality modeling domain is shown in in Figure 2-6. The modeling domain covers the 48 contiguous states along with parts of Canada and Mexico with a horizontal resolution of 12 x 12 km. Air quality modeling for a larger 12-km domain (USEPA, 2021) was used to provide chemical boundary conditions for the 12US2 domain simulation used in air quality analyses in the RIA.

Gas-phase chemistry in the CMAQ simulations was based on the Carbon Bond 2006 mechanism (CB6r3) (Emery et al., 2015), and deposition was modeled with the M3DRY parameterization. Aerosol processes were parameterized with the AERO7 module using ISORROPIA II for inorganic aerosol thermodynamics (Fountoukis and Nenes, 2007) and the non-volatile treatment for primary organic aerosol (Appel et al., 2017; Simon and Bhave, 2012). Emissions of biogenic compounds were modeled with the Biogenic Emission Inventory System (BEIS) (Bash et al., 2016). Anthropogenic emissions were based on 2018 version 2 emissions modeling platform (USEPA, 2023a), which included emissions for 2018 and the projected 2032 case. Meteorological data were based on a 2018 simulation with version 3.8 of the Weather Research Forecasting (WRF) model (Skamarock et al., 2008). The meteorological fields include hourly-varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer. Additional details on the model configuration are available in section 2A.1.1 of Appendix 2A.

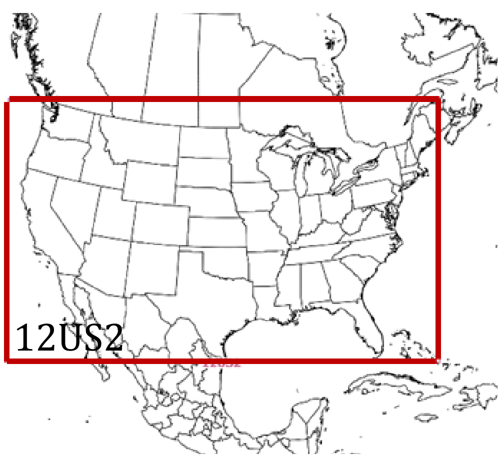

Figure 2-6 Map of the 12US2 (12 x 12 km Horizontal Resolution) Modeling Domain

2.2.1.2 Emissions Inventory

The future-year emissions inventory is projected from the 2018 version 2 emissions modeling platform. The projected emission case is labeled 2032, although the emission projections are based on a combination of projection years, with some sources held constant at base year levels.[3] The development of the 2018 base-year inventory, the projection methodology, and the controls applied to create the projected inventory are described in detail in the emissions *Technical Support Document (TSD): Preparation of Emissions Inventories for the 2018v2 North American Emissions Modeling Platform* (USEPA, 2023a). The types of sources included in the emission inventory include stationary point sources such as EGUs and non-EGUs; non-point emissions sources including those from oil and gas production and distribution, agriculture, residential wood combustion, fugitive dust, and residential and commercial heating and cooking; mobile source emissions from onroad and nonroad vehicles, aircraft, commercial marine vessels, and locomotives; wild, prescribed, and agricultural fires; and biogenic emissions from vegetation and soils.[4]

The EGU emissions were developed using the Post-IRA 2022 Reference Case of the EPA's Power Sector Platform v6 using Integrated Planning Model (IPM), (USEPA, 2023b) where the 2023 Federal Good Neighbor Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standards (Final GNP) was also reflected. The IPM is a multiregional, dynamic, deterministic linear programming model of the U.S. electric power sector. The EGU projected inventory represents demand growth, fuel resource availability, generating technology cost and performance, and other economic factors affecting power sector behavior. It also reflects environmental rules and regulations, consent decrees and settlements, plant closures, and newly built units for the calendar year 2030. In this analysis, the projected EGU emissions include provisions of tax

[3] 2032: nonroad, onroad, airports, non-EGU point (except for biorefineries / ethanol plants), paved-road dust, oil and gas (except in WRAP states), residential wood combustion (except held constant from base year in CA, OR, and WA), locomotives, livestock, solvents, other U.S. nonpoint sources, Canadian onroad and nonroad emissions, Mexico onroad emissions; 2030: US EGUs and commercial marine vessels; 2028: Canada and Mexico nonpoint and point emissions; 2018: fertilizer, fires, biogenic, and US fugitive dust (other than paved road) emissions

[4] Emissions reductions from the Federal Implementation Plan for Managing Emissions from Oil and Natural Gas Sources on Indian Country Lands within the Uintah and Ouray Indian Reservation in Utah (2022) are not reflected in the baseline for this analysis. Given the focus of this rule, any potential impacts are likely to be small. Also, the impacts of any proposed rules, such as those for onroad mobile sources, are not reflected.

incentives impacting electricity supply in the Inflation Reduction Act of 2022 (IRA), Final GNP, 2021 Revised Cross-State Air Pollution Rule Update (RCU), the 2016 Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources, the Mercury and Air Toxics Rule (MATS) finalized in 2011, and other finalized rules. Documentation and results of the Post-IRA 2022 Reference Case, where the Final GNP was also included for EGUs, are available at (https://www.epa.gov/power-sector-modeling/final-pm-naaqs).

Regulations for non-EGU point sources and non-point sources reflected in the inventories include:

- Good Neighbor Plan for the 2015 ozone NAAQS;
- New Source Performance Standards (NSPS) for oil and natural gas sources (2016), process heaters (2013), natural gas turbines (2012), and reciprocating internal combustion engines;
- NSPS for residential wood combustion (2015);
- Fuel sulfur rules in mid-Atlantic and northeast states (current through 2019);
- NSPS and Emission Guidelines for Commercial and Industrial Solid Waste Incineration (CISWI) from March 2011;
- NSPS Subpart JA for Standards of Performance for Petroleum Refineries from June 2008;
- Specific consent decrees; and
- Ozone Transport Commission controls for Portable Fuel Containers, consumer products, architectural and industrial maintenance coatings, and various other solvents.

Known closures are also implemented for non-EGU point sources.

Onroad and nonroad mobile source emissions were developed using the Motor Vehicle Emission Simulator version 3 (MOVES3). The SMOKE-MOVES emissions modeling framework was used that leverages MOVES-generated emission factors, county and SCC-specific activity data, and hourly meteorological data. MOVES3 was run in emission rate mode to create emission factor tables for the 2032 future modeling year for all representative counties and fuel months. These emissions represent the effects the Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards (2022); the Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks Through Model Year 2026 (2021); the Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026 (2020); the Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 (2016); the Tier 3 Vehicle Emission and Fuel Standards Program (2014); and other finalized rules. A full discussion of the future year base inventory is provided in USEPA (2023a). Nonroad emissions rules related to nonroad spark-ignition engines, equipment, and vessels from October 2008 are reflected.

Emissions for commercial marine vessels and locomotive engines reflect the rules finalized in 2010 and 2008:

- Growth and control from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder: March 2008
- Category 3 marine diesel engines Clean Air Act and International Maritime Organization standards: April 2010
- Growth and control from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder: March 2008

2.2.1.3 Model Evaluation

An operational model performance evaluation for $PM_{2.5}$ and its speciated components (e.g., sulfate, nitrate, elemental carbon, and organic carbon) was performed to estimate the ability of the CMAQ modeling system to replicate the 2018 base year concentrations. This evaluation includes statistical assessments of model predictions versus observations from national monitoring networks paired in time and space. Details on the evaluation methodology and the calculation of performance statistics are provided in section 2A.1.2 of Appendix 2A. Overall, the performance statistics for $PM_{2.5}$ and its components from the CMAQ 2018 simulation are within or close to the ranges found in other recent applications. These model performance results provide confidence that our use of the 2018 modeling platform is a scientifically credible approach for assessing $PM_{2.5}$ concentrations for the purposes of the RIA.

2.2.2 Future-Year $PM_{2.5}$ Design Values

To evaluate the incremental costs and benefits associated with meeting revised and alternative standard levels relative to the existing standard, $PM_{2.5}$ DVs were first projected to 2032 accounting for emission reductions expected from finalized rules. The air quality and emission changes associated with meeting the existing, revised, and alternative standard levels were then estimated as described below in Section 2.3. $PM_{2.5}$ DVs were projected to 2032 using the air quality model results in a relative sense, as recommended by the EPA modeling guidance (USEPA, 2018), by projecting monitoring data with relative response factors (RRFs) developed from the 2018 and 2032 CMAQ modeling.

$PM_{2.5}$ RRFs were calculated as the ratios of modeled $PM_{2.5}$ species concentrations in the future year (2032) to the base year (2018) for each $PM_{2.5}$ component (i.e., sulfate, nitrate, organic carbon, elemental carbon, crustal material, and ammonium). The 2032 $PM_{2.5}$ DVs were calculated by applying the species-specific RRFs to ambient $PM_{2.5}$ species concentrations from the $PM_{2.5}$ monitoring network. Observed $PM_{2.5}$ concentrations were disaggregated into species concentrations by applying the SANDWICH method (Frank, 2006) and through interpolation of $PM_{2.5}$ species data from the Chemical Speciation Network (CSN) and the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring network. The RRF method for projecting $PM_{2.5}$ DVs was implemented using EPA's Software for Modeled Attainment Test-Community Edition (SMAT-CE) (USEPA, 2018; Wang et al., 2015). More details on the $PM_{2.5}$ projection method using RRFs are provided in the user's guide for the predecessor to the SMAT-CE software (Abt, 2014).

Ambient $PM_{2.5}$ measurements from the 2016-2020 period centered on the 2018 CMAQ modeling period were used in projecting $PM_{2.5}$ DVs. $PM_{2.5}$ species measurements from the IMPROVE and CSN networks during 2017–2019 were used to disaggregate the measured total $PM_{2.5}$ concentrations into components. In addition to exclusion of EPA-concurred exceptional events, limited exclusion of wildfire and fireworks influence on $PM_{2.5}$ concentrations was applied to the 2016-2020 $PM_{2.5}$ monitoring data. Monitoring data were evaluated (i.e., screened) for potential wildfire and fireworks influence because $PM_{2.5}$ concentrations may be influenced by atypical, extreme, or unrepresentative events such as wildfires or fireworks that may be appropriate for exclusion as described in EPA's memorandum *Additional Methods, Determinations, and Analyses to Modify Air Quality Data Beyond Exceptional Events* (USEPA, 2019b). The steps in implementing the limited screening of major wildfire and fireworks influence on $PM_{2.5}$ concentrations are as follows.

Step 1. An extreme value cutoff of 64 $\mu g\ m^{-3}$ was identified based the 99.9th percentile value from all daily $PM_{2.5}$ concentrations across all sites in the U.S. EPA's Air Quality System database of observations (2002-2020).

Step 2. Specific months were evaluated for instances of monitors exceeding the extreme value cutoff. Months included were June-October (although November can be a high fire month for parts of the western U.S., it becomes more difficult to distinguish wildfire $PM_{2.5}$ from residential wood smoke and other anthropogenic sources during the late fall).

Step 3. The presence of visible wildfire smoke was corroborated using satellite imagery from NASA's Worldview platform (https://worldview.earthdata.nasa.gov) for the time periods and geographic locations identified through Steps 1 and 2. Timeseries for individual sites were also examined to confirm $PM_{2.5}$ enhancements temporally consistent with the wildfire events identified.

Step 4. For extreme wildfire smoke periods identified through Steps 1-3 above, all concentrations above the extreme value cutoff of 64 $\mu g\ m^{-3}$ at impacted sites were excluded.

Step 5. In addition to the evaluation criteria above, data corresponding to the Creek Fire (eastern CA during September-November 2020), the Camp Fire (northern CA during November 2018), and the Appalachian Fires (NC, TN, GA during November 2016) were evaluated for exclusion if concentrations exceeded the extreme value threshold of 64 $\mu g\ m^{-3}$. These large fire episodes show obvious impacts across multiple monitors and were clearly documented with satellite imagery.

Step 6. In addition to the limited exclusion of major wildfire influence, data were evaluated to identify days for potential exclusion due to the influence of isolated fireworks events on $PM_{2.5}$ concentrations. The 99.9th percentile value of 64 μg m^{-3} was applied as the cutoff across all sites for New Year's Eve and the Fourth of July.

The percentage of days excluded from the 2016-2020 dataset was 0.9% at affected sites; the total percentage of days excluded overall from the dataset was 0.09%. Since the cutoff value (64 μg m^{-3}) is much greater than the 24-hour and annual standard levels, wildfire contributions to $PM_{2.5}$ concentrations above the standard levels likely persists in the data following screening. Comprehensive identification and exclusion of such wildfire impacts would require detailed analyses that are beyond the scope of this national assessment. More information on the wildfire and fireworks screening are provided in section 2A.2.1 of Appendix 2A.

2.3 Calculating Emission Reductions for Meeting the Existing, Revised, and Alternative Standard Levels

To estimate the tons of emissions reductions needed to reach attainment of the existing, revised, and alternative standard levels, we calculated air quality ratios based on how modeled concentrations changed with changes in emissions in CMAQ sensitivity modeling. Air quality ratios represent an estimate of how the DVs at a monitor would change in response to emissions reductions and have been used in prior PM NAAQS RIAs (USEPA, 2012a, 2012b). Air quality ratios have units of μg m^{-3} per 1000 tons of emissions. The remainder of this section describes the development of air quality ratios and their application to estimating emission reductions for meeting the existing, revised, and alternative standards.

2.3.1 Developing Air Quality Ratios

In the illustrative control strategy analysis in the RIA, the revised and alternative standard level exceedances are addressed by focusing on primary $PM_{2.5}$ emission controls in the local county. This approach is consistent with the exceedances generally being driven by the urban $PM_{2.5}$ increment, the relatively high responsiveness of $PM_{2.5}$ concentrations to primary $PM_{2.5}$ emission reductions, and the reductions in regional $PM_{2.5}$ concentrations from the large SO_2 and NOx emission reductions in recent decades and in the 2032 projection (Section 2.1.3). To develop air quality ratios that relate the change in DV in a county to the change in primary $PM_{2.5}$ emissions in that county, CMAQ sensitivity modeling was performed with reductions in primary $PM_{2.5}$ emissions in selected counties. The modeling was conducted using CMAQ version 5.2.1 for a 2028 modeling case similar to that of recent regional haze modeling (USEPA, 2019c) due to the availability of the 2028 (but not 2032) modeling at the time of the work. Since air quality ratios reflect the sensitivity of air quality to emission changes (rather than absolute concentrations), the air quality ratios based on the 2028 modeling are suitable for application to our 2032 modeling case.

To develop air quality ratios for primary $PM_{2.5}$ emissions, we used the following method:

Step 1. A CMAQ sensitivity simulation was conducted with 50% reductions in primary $PM_{2.5}$ emissions from anthropogenic sources in counties with annual 2028 DVs greater than 8 $\mu g\ m^{-3}$.

Step 2. The change in annual and 24-hour $PM_{2.5}$ DVs at monitors in counties where emission reductions were applied was calculated using projected DVs from the 2028 modeling with the SMAT-CE software.

Step 3. The change in DVs at individual monitors was divided by the change in emissions in the respective county to determine the air quality ratio ($\mu g\ m^{-3}$ per 1000 tons) for the individual monitors.

Step 4. The responsiveness of air quality at a specific monitor location to primary $PM_{2.5}$ emission reductions depends on several factors including the specific meteorology and topography in an area and the nearness of the emissions source to the monitor. As described in a previous PM NAAQS RIA (USEPA, 2012a), the strong local influence of changes in directly emitted $PM_{2.5}$ on air quality produces large variability in air quality ratios that can result in non-representative values for general application. To address this issue, representative air quality ratios for regions of the U.S. were developed from the ratios at individual monitors. The five regions are illustrated in Figure 2-7. The Northeast region was defined by combining the Upper Midwest, Ohio Valley, and Northeast U.S. climate regions (Karl and Koss, 1984); the Southeast region was defined by combining the Southeast and South U.S. climate regions (Karl and Koss, 1984); and California was separated into southern and northern regions as done previously (USEPA, 2012a) due to differences in $PM_{2.5}$ responsiveness in those areas. For each region, representative air quality ratios were calculated as the 75th percentile of air quality ratios for individual monitors within the region. The 75th percentile was selected to avoid use of extreme values while accounting for the relatively high responsiveness of the highest-DV monitors that are most relevant to our application.

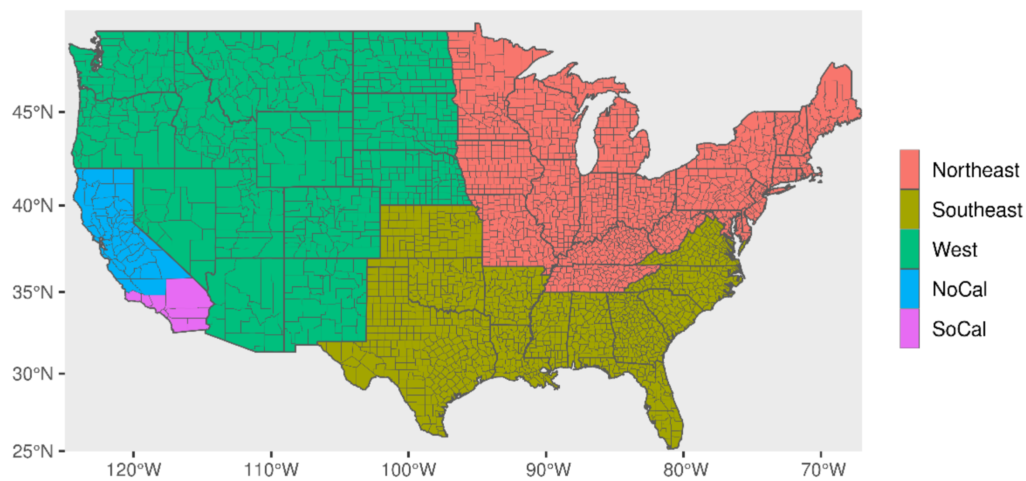

Figure 2-7 Regional Groupings for Calculating Air Quality Ratios

The air quality ratios for primary $PM_{2.5}$ emissions used in estimating the emission reductions needed to meet standard levels at monitors in the five regions are shown in Table 2-1. These data give an estimate of how $PM_{2.5}$ DVs at a monitor would change if 1000 tons of primary $PM_{2.5}$ emissions were reduced in the county in which the monitor is located. Additional details on the development of the air quality ratios are available in section 2A.3.1 of Appendix 2A.

Table 2-1 Annual and 24-Hour Air Quality Ratios for Primary $PM_{2.5}$ Emissions

Region	Annual Air Quality Ratio ($\mu g\ m^{-3}$ per kton)	24-hour Air Quality Ratio ($\mu g\ m^{-3}$ per kton)
Northeast	1.37	4.33
Southeast	1.22	3.51
West	2.14	8.70
Northern California	3.15	9.97
Southern California	1.18	2.56

The air quality ratios in Table 2-1 relate the change in DV in a county to a change in emissions in that county. The ratios are developed for county-level spatial scales because concentrations are most responsive to changes in local emissions. However, emission controls may not always be identified in the local county, and emission reductions in neighboring counties may sometimes be appropriate, such as in the Eastern U.S. where counties are relatively small and terrain is relatively flat. To apply emission reductions in the neighboring counties in the Eastern U.S., the responsiveness of annual $PM_{2.5}$ DVs for emission reductions within the county was compared to the responsiveness of DVs in the neighboring counties using the 2028 sensitivity modeling. Annual DVs were estimated to be 4 times more responsive on average for emission reductions in the county containing the monitor than for emission reductions in a neighboring county in the Eastern U.S. Primary $PM_{2.5}$ emission reductions were not applied in neighboring counties in the Western U.S. (including California) due to the large size of the counties and the complex terrain that often isolates the influence of primary $PM_{2.5}$ emissions to the local air basin. Additional information related to air quality ratios for neighboring counties is available in section 2A.3.1 of Appendix 2A.

At monitors in the South Coast Air Basin and San Joaquin Valley (SJV) of California, $PM_{2.5}$ DVs exceeded the existing standards in the 2032 modeling case. Air quality management plans apply reductions in NOx emissions in addition to reductions in primary $PM_{2.5}$ emissions to meet the existing NAAQS in these air basins (SCAQMD, 2017; SJVAPCD, 2018). The NOx emission reductions help in meeting the existing standards by reducing concentrations of $PM_{2.5}$ ammonium nitrate in the air basins as described in Section 2.1.2. In creating the 12/35 analytical baseline of DVs associated with meeting existing standards, we applied 75% reductions in NOx emissions in SJV and South Coast in addition to primary $PM_{2.5}$ emission reductions. To apply the NOx emission reductions, air quality ratios for NOx emissions were developed for South Coast and SJV monitors. Air quality ratios for South Coast were developed using 2028 sensitivity modeling for NOx emissions similar to the approach described above for the primary $PM_{2.5}$ air quality ratios. For SJV, air quality ratios were developed from sensitivity modeling results presented in the SJV air quality management plan (SJVAPCD, 2018), which was based on a fine-scale CMAQ modeling platform. Additional details on the South Coast and SJV air quality ratios for NOx are available in section 2A.3.2 and 2A.3.3 of Appendix 2A. Note that the NOx emission reductions were applied in attaining the existing standards and therefore do not contribute to the incremental costs and benefits of meeting revised and alternative standard levels relative to meeting the existing standards.

2.3.2 Emission Reductions to Meet 12/35

$PM_{2.5}$ DVs from the 2032 projection were adjusted using air quality ratios to correspond with just meeting the existing standard level to create the 12/35 analytical baseline. The 12/35 analytical baseline is used as the reference case for estimating the incremental costs and benefits of meeting the revised and alternative standard levels relative to the existing 12/35 standard combination.

The counties with projected 2032 $PM_{2.5}$ DVs that exceed the existing standard levels and require air quality adjustments to meet 12/35 are shown in Figure 2-8. Counties that exceed only the 24-hour standard are in northern California, Oregon, Washington, Idaho, and Montana. Elevated $PM_{2.5}$ episodically occurs in winter in these areas due to meteorological temperature inversions that concentrate $PM_{2.5}$ in shallow layers near the ground in complex terrain. In California, multiple counties exceed both the annual and 24-hour standards, and two counties (San Bernardino and Imperial) exceed only the annual standard.

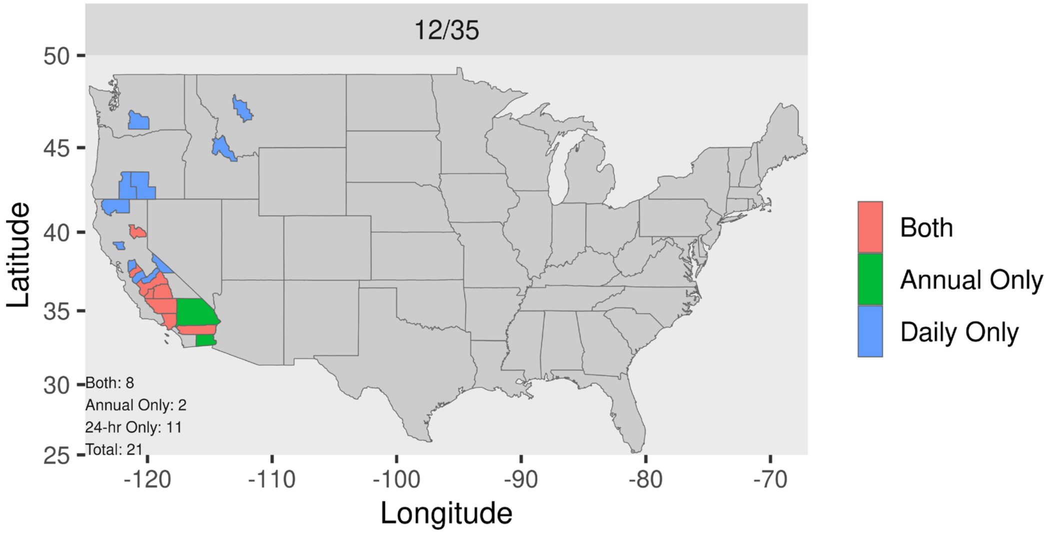

Figure 2-8 Counties with Projected 2032 $PM_{2.5}$ DVs that Exceed the 24-Hour (Daily Only), Annual (Annual Only) or Both (Both) Existing Standards (12/35 µg m^{-3})

To create the $PM_{2.5}$ DVs for the 12/35 analytical baseline, the reductions in primary $PM_{2.5}$ emissions needed to just meet 12/35 at the highest DV monitor by county were calculated using the air quality ratios in Table 2-1. The emission reductions were calculated as follows:

$$\Delta Emission_{std} = \frac{DV_{Model,std} - DV_{Target,std}}{AQratio_{std}} \times 1000 \qquad (2\text{-}1)$$

where $\Delta Emission_{std}$ is the emission reduction required to meet the annual or 24-hour standard; $DV_{Target,std}$ is the level of the annual or 24-hour standard to be met; $DV_{Model,std}$ is the modeled $PM_{2.5}$ design value for the annual or 24-hour standard at the county highest monitor; $Aqratio_{std}$ is the air quality ratio for that standard; and the factor of 1000 converts units from kton to ton.

For example, the highest 2032 annual $PM_{2.5}$ DV in Kern County is 13.70 µg m^{-3} at site 06-029-0016 after applying the 75% NOx emission reduction to the 2032 DVs. The annual air quality ratio for primary $PM_{2.5}$ emissions in Northern California is 3.15 µg m^{-3} per kton. Therefore, to meet an annual standard of 12 µg m^{-3}, a total of 527 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (13.70-12.04)/3.15 x 1000). The highest 2032 24-hour $PM_{2.5}$ DV in Kern County is 36.4 µg m^{-3} at site 06-029-0016 after applying the 75% NOx emission reduction to the 2032 DVs. The 24-hour air quality ratio for primary $PM_{2.5}$ emissions in Northern California is 9.97 μg m^{-3} per kton. Therefore, to meet a 24-hour standard of 35 μg m^{-3}, a total of 100 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (36.4-35.4)/9.97 x 1000). To determine the overall emission reductions needed to meet the combination of annual and 24-hour standards, the maximum needed reduction across standards is calculated. For the Kern County example, a total 527 tons of primary $PM_{2.5}$ emission reductions are needed to meet the 12/35 standard combination (i.e., the maximum of 527 tons and 100 tons).

After the emission reductions needed to meet a standard combination are identified, the $PM_{2.5}$ DVs are adjusted to correspond with the emission reductions. The $PM_{2.5}$ DVs associated with meeting a standard combination at the highest monitor in a county are calculated as follows:

$$DV_{std.combo} = DV_{initial} - \Delta Emission_{std.combo} \times AQratio/1000 \qquad (2\text{-}2)$$

In the Kern County example, the adjusted annual DV for the 12/35 case is 12.04 μg m^{-3} (13.70-527*3.15/1000) and the adjusted 24-hour DV is 31.1 μg m^{-3} (36.4-527*9.97/1000).

2.3.3 Emission Reductions to Meet Revised and Alternative Standards

$PM_{2.5}$ DVs in the 12/35 analytical baseline exceed the levels of the revised and alternative standards in some areas of the country. The emission reductions needed to resolve these exceedances and the associated air quality improvements contribute to the incremental costs and benefits of the revised and alternative standard levels.

Exceedances of the revised and alternative standard levels in the 12/35 analytical baseline are shown by county in Figure 2-9. Since the $PM_{2.5}$ DVs have been adjusted to meet the 24-hour standard level of 35 μg m^{-3} in the analytical baseline, there are no exceedances of the 24-hour standard for the cases of 10/35, 9/35, and 8/35. For the 10/35 case, five counties in the east, two in the northwest, and thirteen in California have annual $PM_{2.5}$ DVs greater than 10 μg m^{-3} in the 12/35 analytical baseline. For the 10/30 case, twenty-nine counties have 24-hr DVs greater than 30 μg m^{-3} with annual DVs less than 10 μg m^{-3}, and nine counties exceed both the 24-hr and annual standards. For the 9/35 case, nineteen counties exceed the annual standard in the Eastern U.S., compared with five for the 10/35 and 10/30 cases. The total number of counties exceeding the standards increases from 52 to 117 when moving from 9/35 to 8/35. Additional information on $PM_{2.5}$ DVs for the 2032 projection and 12/35 analytical baseline are available in section 2A.2.2 of Appendix 2A.

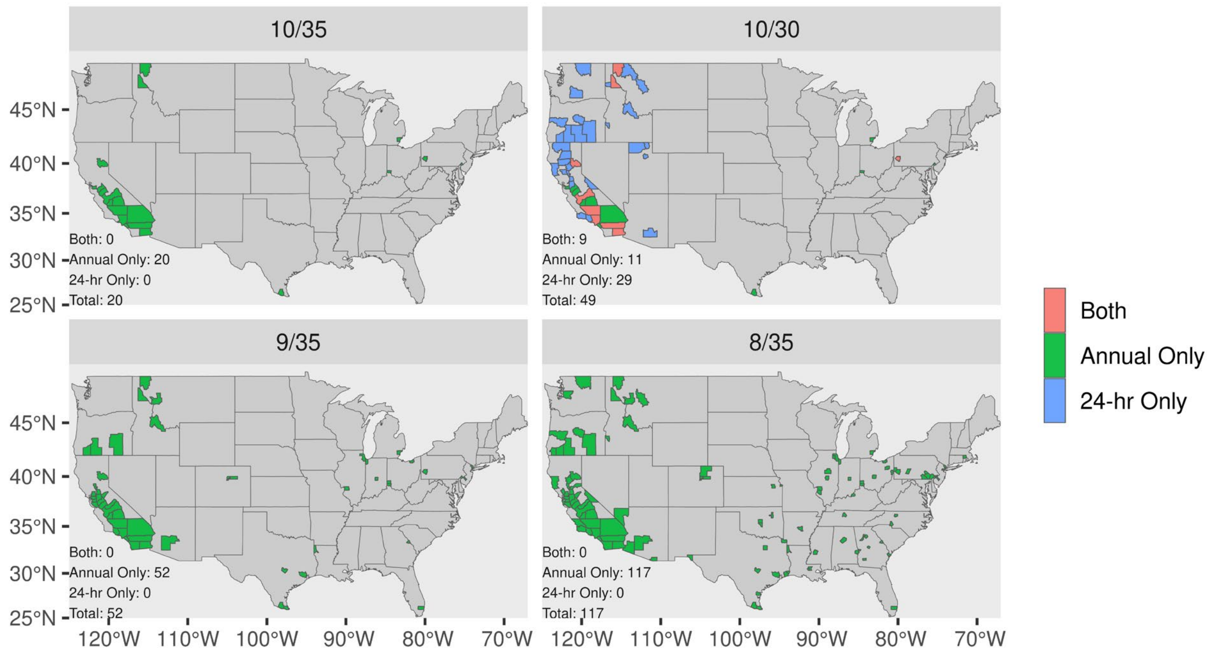

Figure 2-9 Counties with $PM_{2.5}$ DVs that Exceed Alternative Annual (Annual Only), 24-Hour (Daily Only), or Both (Both) Standards in the 12/35 Analytical Baseline

The primary $PM_{2.5}$ emission reductions needed to meet the revised and alternative standard levels of 10/35, 10/30, 9/35, and 8/35 relative to the 12/35 analytical baseline were calculated using Equation 2-1 and the air quality ratios in the Table 2-1. The emission reductions needed to meet the standard levels in the Eastern and Western U.S. are shown in Figure 2-10. These emission estimates are used to inform identification of emission controls for meeting the standard levels analyzed. Additional information on estimating the emission reductions needed to meet revised and alternative standards is available in section 2A.3.4.2 of Appendix 2A.

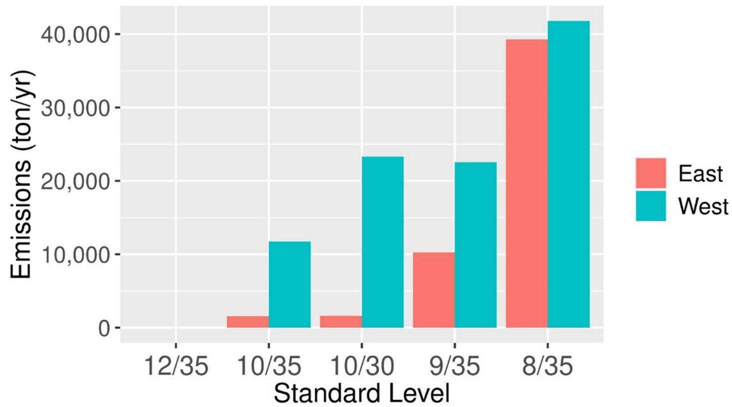

Figure 2-10 Total Primary $PM_{2.5}$ Emission Reductions Needed to Meet the Revised and Alternative Standard Levels of 10/35, 10/30, 9/35, and 8/35 Relative to the 12/35 Analytical Baseline in the Eastern and Western U.S.

2.3.4 Limitations of Using Air Quality Ratios

There are important limitations to the methodology of calculating and using air quality ratios to predict the response of air quality to emissions changes. The air quality ratios are calculated with results from only two CMAQ model runs and assume that the monitor DVs would decrease with additional reductions in the future similar to how the CMAQ model runs predicted changes in air quality concentrations. In addition, the model response to emissions changes is analyzed at the county-level and air quality concentrations at a monitor are assumed to decrease linearly with emission reductions in a county. Due to the strong local influence of changes in primary $PM_{2.5}$ emissions on air quality, the generalized air quality ratio approach may not capture the specific features of how the DV at a monitor in a county would respond to changes in specific primary $PM_{2.5}$ emissions in the county. Ideally, direct modeling would be applied to account for the location of the source relative to the location of the monitor using a model configuration designed to capture the local features near the source. Such source-specific, high-resolution modeling is beyond the scope of this national assessment.

The exact impact of using the air quality ratio methodology to estimate the emission reductions needed for attainment and the associated effect on the cost and benefits is uncertain and may vary from monitor-to-monitor. We do not believe that this methodology tends towards any general trend or results systematically in either an underestimation or overestimation of the costs and benefits of attaining the revised and alternative standard levels.

2.4 Description of Air Quality Challenges in Select Areas

Several groups of areas have air quality characteristics that limit our ability to characterize how standard levels might be met given highly local influences that require more specific information beyond what is available for this type of national analysis. The challenging air quality characteristics include features of certain near-road sites, cross-border transport, effects of complex terrain in the west, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events (USEPA, 2019b). In particular, we note that our analysis is limited in its ability to evaluate potential air quality improvements in border counties, major California air basins, small western mountain valleys, and two near-road sites with challenging local features. As a result, we have treated these areas differently in the control strategy analysis as described in Chapter 3. In this section, we describe the nature of the air quality conditions in these areas and the challenges they present for our national assessment.

2.4.1 Cincinnati, OH and Fort Lee, NJ Near-Road Sites

Of the 47 near-road sites included in the model projections, two (Cincinnati, OH, 39-061-0048 and Fort Lee, NJ, 34-003-0010) were challenging for identifying sufficient emission controls to meet the revised and alternative standard levels. The challenges in Cincinnati (Hamilton County) appear to be related to construction of a storage facility near the site during the 2016-2020 monitoring period used in our projections. In Figure 2-11, the near-road monitor and neighboring storage facility are shown on the left, and images from before, during, and after construction are shown on the right. The RIA modeling projected a 2016-2020 DV of 11.65 $\mu g/m^3$ to decrease by 1.21 $\mu g/m^3$ to 10.44 $\mu g/m^3$ in 2032. The most recent ambient $PM_{2.5}$ DV at this site is 10.3 $\mu g/m^3$ for the 2020-2022 period, which is less influenced by construction than the prior years used in model projections. The construction activity near the Cincinnati site may have contributed to the high base-period DV of 11.65 $\mu g/m^3$ that led to the high projected DV, which resulted in the challenges for meeting the revised standard at the site. However, a detailed local analysis beyond the scope of the national RIA would be needed to determine the full contribution of the construction and other local influences on the $PM_{2.5}$ DV at this site.

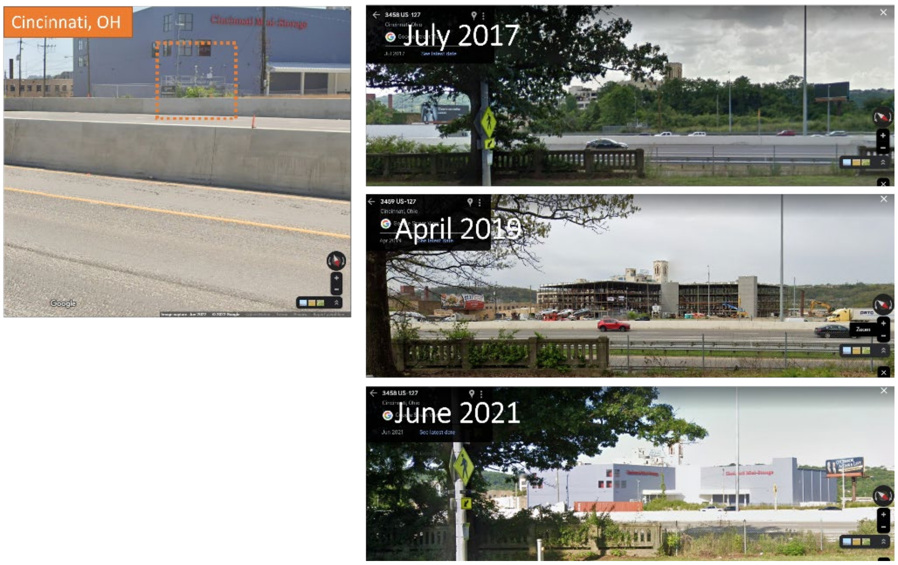

Figure 2-11 Cincinnati Near-Road Site (Left) and Storage Building Construction Near the Site (Right)

Source: Map Data ©2023 Google.

The Fort Lee, NJ near-road site also presents challenges for identifying sufficient emission controls to meet revised and alternative standard levels in the RIA. The Fort Lee site (Bergen County) is close to the roadway interchange that leads to the George Washington Bridge (Figure 2-12). Six major highways converge in the area leading to the bridge, and the location has been reported to be the most congested freight-significant highway location in the nation (ARTI, 2023). Additionally, the site is located near the urban activity of downtown Fort Lee (Figure 2-12). The projected 2032 DV at the site is 9.78 $\mu g/m^3$. This value is higher than the other Bergen County site (6.90 $\mu g/m^3$) and monitors in Manhattan (maximum: 8.94 $\mu g/m^3$) demonstrating the importance of local contributions to the concentrations. However, understanding the nature of the local contributions and developing an approach for meeting the standard under the complex conditions at this site would require a detailed study that goes beyond the scope of the RIA.

Figure 2-12 Fort Lee, NJ Near-Road Site (Red Balloon) and Roadway Exchange Leading to George Washington Bridge.

Source: Map Data ©2023 Google.

2.4.2 Border Areas

2.4.2.1 Imperial County, CA

As described in the Clean Air Act Section 179B[5] Technical Demonstration by the California Air Resources Board (CARB, 2018b), the Imperial County $PM_{2.5}$ nonattainment area is an agricultural community located in the southeast corner of California that shares a southern border with Mexicali, Mexico. Imperial County includes three $PM_{2.5}$ monitoring sites, located in the cities of Calexico (site ID: 06-025-0005), El Centro (site ID: 06-025-1003), and Brawley (site ID: 06-025-0007) (Figure 2-13). Although these three cities are of similar size and have similar emission sources, the $PM_{2.5}$ DV at the Calexico monitor closest to the U.S.-Mexico border is much greater than the other two monitors. The projected 2032 annual $PM_{2.5}$ DV is 12.36 μg m^{-3} in Calexico, 9.70 μg m^{-3} in Brawley, and 8.69 μg m^{-3} in El Centro. The Calexico monitor is in an airshed that includes both Calexico and Mexicali and is less than one mile from the international border. Previous analysis has demonstrated that Mexicali emissions have a daily influence on $PM_{2.5}$ concentrations in Calexico and can contribute to $PM_{2.5}$ NAAQS exceedances there (CARB, 2018a, 2018b).

[5] 179B refers the section of the Clean Air Act that addresses situations where a nonattainment area would be able to attain and maintain, or would have attained, the NAAQS but for emissions emanating from outside of the U.S.

The city of Mexicali has a population of about 700,000 (CARB, 2018a) and Calexico has a population of 38,633 (2020 U.S. Census). The nighttime aerial view of Calexico and Mexicali in Figure 2-14 illustrates the much larger scale of urban activity in Mexicali than Calexico. Substantially greater emissions have been estimated for Mexicali than Calexico (i.e., 3.4x greater for NOx, 13.7x greater for combined SO_2 and sulfate, and 57% greater for primary $PM_{2.5}$, (CARB, 2018b). $PM_{2.5}$ emissions in Imperial County are dominated by dust with limited contribution from other controllable sectors (Figure 2-15). Considering the influence of Mexicali emissions on $PM_{2.5}$ concentrations in Calexico, the limited emissions available for control in Imperial County, and the relatively lower concentrations predicted at the two Imperial County monitors away from the border, EPA believes it is reasonable to assume that a significant portion of the emissions affecting this area cannot be controlled in California. However, a detailed local analysis beyond the scope of the RIA would be needed to evaluate this possibility.

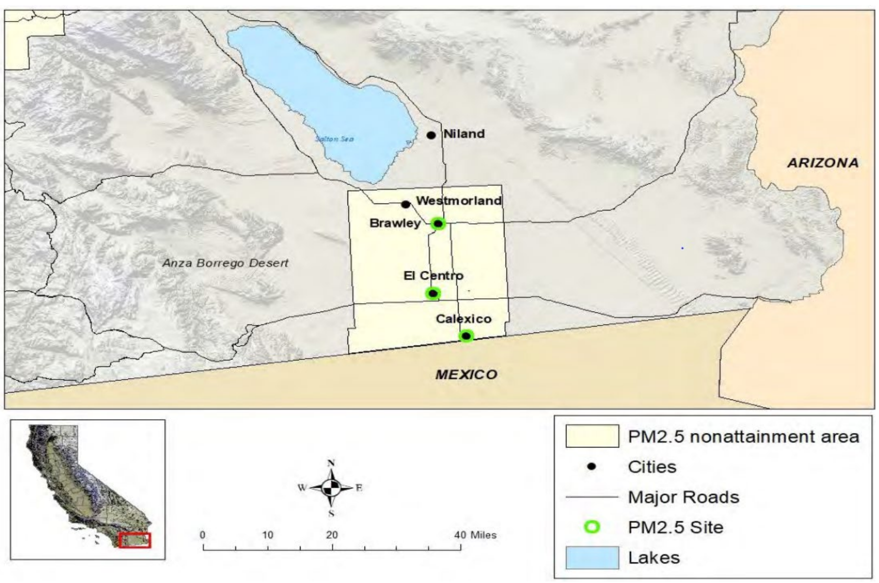

Figure 2-13 Imperial County and the Nonattainment Area

Source: (CARB, 2018a)

Figure 2-14 Nighttime Aerial View of Calexico, CA and Mexicali, MX

Source: (CARB, 2018b)

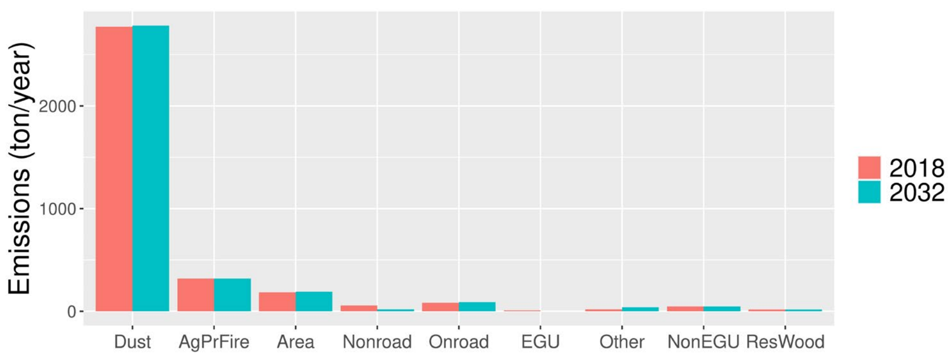

Figure 2-15 Annual Source Sector Emission Totals for $PM_{2.5}$ for 2018 and 2032 in Imperial County

Note: Sector names defined in Figure 2-4

2.4.2.2 Cameron and Hidalgo County, TX

The Brownsville monitor in Cameron County, TX (site ID: 48-061-0006) and the Mission monitor in Hidalgo County, TX (site ID: 48-215-0043) are in the Lower Rio Grande Valley, which includes the northern portion of the state of Tamaulipas, Mexico. Addressing the exceedances of the 9/35 standard level at the monitors in Cameron (2032 annual DV: 9.90 μg m^{-3}) and Hidalgo (2032 annual DV: 10.69 μg m^{-3}) is challenging due to the location of these areas along the U.S.-Mexico border. The Brownsville monitor is within one mile of the Mexican metropolitan area of Matamoros (population: 540,000; datamexico.org) and the Mission monitor is about nine miles from the Mexican metropolitan area of Reynosa (population: 700,000; datamexico.org). Due to the southeast to northwest wind pattern (Figure 2-16), emissions from these local metropolitan areas in Mexico might influence $PM_{2.5}$ concentrations at the Brownsville and Mission monitors. Studies have also identified long-range transport of emissions from agricultural burning and wildfire in the southwestern states of Mexico and Central America as major regional sources that influence air quality along the U.S.-Mexico border (Karnae and John, 2019; TCEQ, 2015). Long-range transport of Saharan dust also episodically influences concentrations in this area based on speciation data, satellite imagery, and wind-flow back trajectories (TCEQ, 2015).

Dust makes up the largest fraction of primary $PM_{2.5}$ emissions in Hidalgo and Cameron County in the 2018 and 2032 modeling cases (Figure 2-17). Paved-road dust emissions are projected to increase in these counties between 2018 and 2032 due to projected increases in the vehicle miles travelled. Area source emissions are also projected to increase due to population-based emission projection factors. Increases in dust and area source emissions from 2018 to 2032 offset the decreases in primary $PM_{2.5}$ emissions projected for EGUs and mobile (onroad/nonroad) sources in Cameron and Hidalgo County (Figure 2-17). A local area analysis would be better suited than the national RIA to understand the potential growth in dust and area source emissions as well as the potential contributions of cross-border transport to projected exceedances in this area.

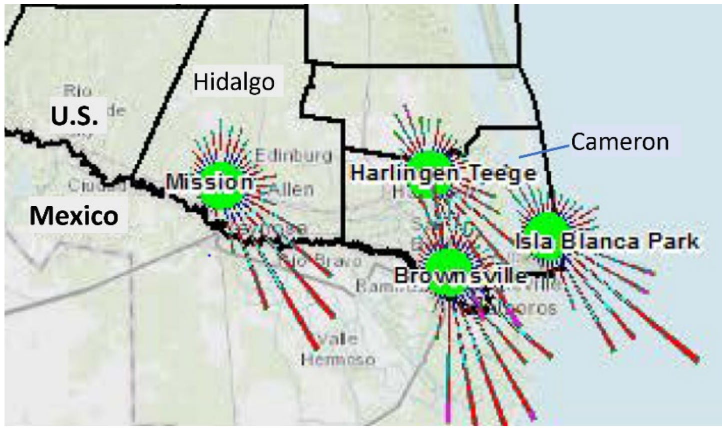

Figure 2-16 Location of Mission and Brownsville Monitors in Hidalgo and Cameron County, respectively, with Annual Wind Patterns from Meteorological Measurements

Source: (TCEQ, 2015)

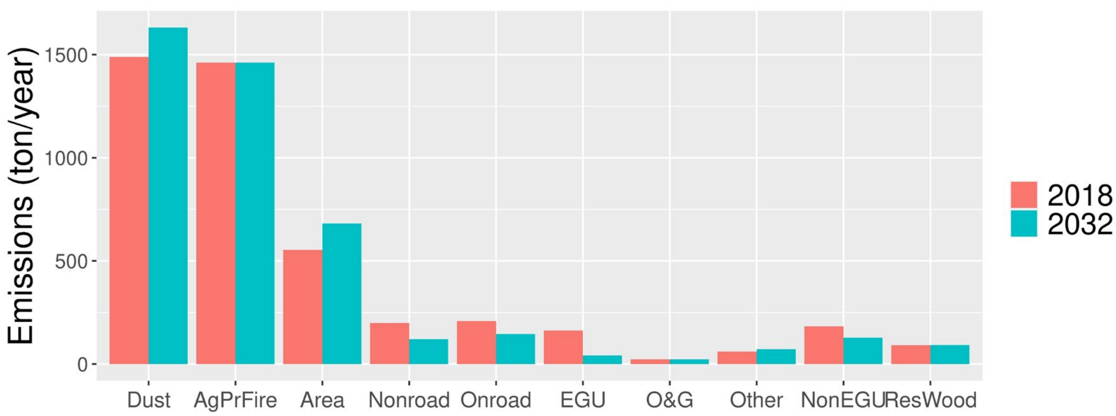

Figure 2-17 Annual Source Sector Emission Totals for $PM_{2.5}$ for 2018 and 2032 in Cameron and Hidalgo County Combined

Note: Sector names defined in Figure 2-4

2.4.3 Small Mountain Valleys in the West

As described in Section 2.1.2, meteorological temperature inversions often occur in small northwestern mountain valleys in winter and trap pollution emissions in a shallow atmospheric layer at the surface. Primary $PM_{2.5}$ emissions, particularly from home heating with residential wood combustion, can build up in the surface layer and produce high $PM_{2.5}$ concentrations in winter (e.g., Figure 2-18). The mountain valleys are often very small in size relative to the area of the surrounding county and the scales resolved by photochemical air quality models. For instance, the Portola nonattainment area for the 2012 $PM_{2.5}$ NAAQS and the city of Portola are shown within Plumas County, CA in Figure 2-19. The Libby nonattainment area for the 1997 $PM_{2.5}$ NAAQS and the city of Libby are shown within Lincoln County, MT in Figure 2-20.

Figure 2-18 Air Pollution Layer Associated with a Temperature Inversion in Missoula, MT in November 2018

Source: Tommy Martino, Missoulian[6]

[6] Missoula health official: Air quality likely to worsen over next few days. David Erickson *Missoulian,* updated Jan. 14, 2019. Available at -- https://missoulian.com/news/local/missoula-health-official-air-quality-likely-to-worsen-over-next-few-days/article_c1f00499-8a10-5625-8af8-043d7ba02a4d.amp.html.

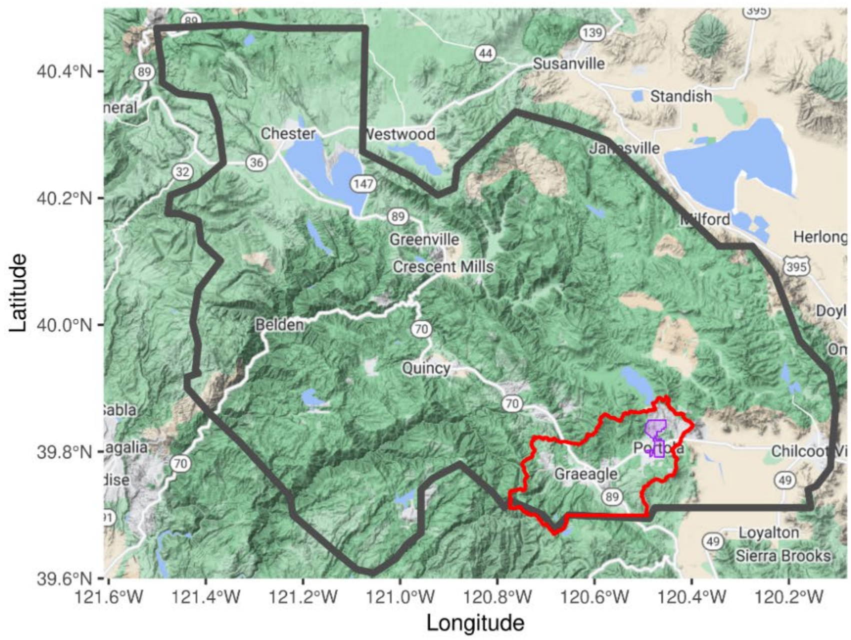

Figure 2-19 Plumas County, CA (Grey), Portola Nonattainment Area (Red), and City of Portola (Purple)

Source: Map Data ©2022 Google.

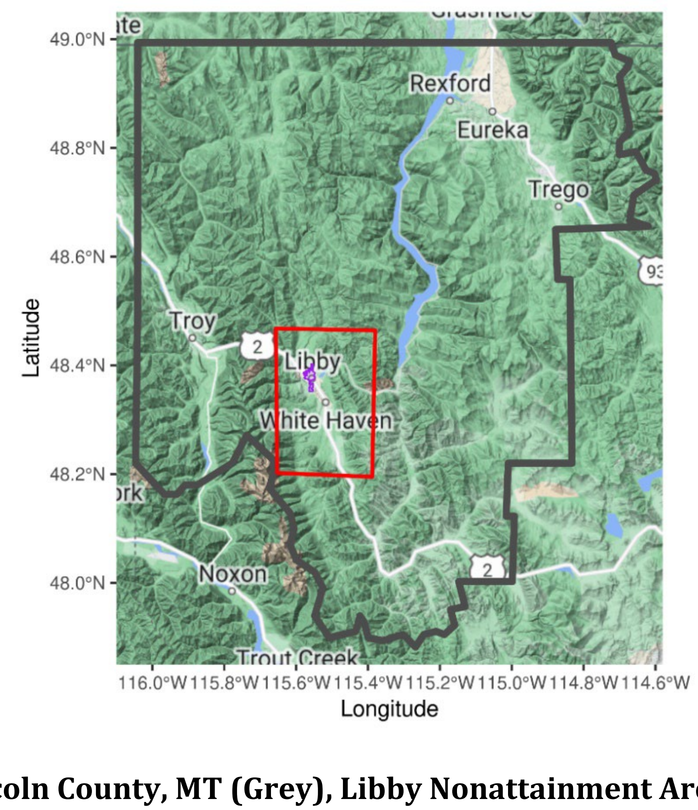

Figure 2-20 Lincoln County, MT (Grey), Libby Nonattainment Area (Red), and City of Libby (Purple)

Source: Map Data ©2022 Google.

Due to the small size of the urban areas within the western mountain valleys, air quality planning is commonly based on linear rollback methods (rather than air quality process modeling) for these areas (e.g., LRAPA, 2012; NSAQMD, 2017). The linear rollback approach relates wood-smoke contribution estimates at the exceeding monitor to the local (sub-county) wood combustion emission totals to estimate the tons of emission reductions needed to meet the standard. Due to the high effectiveness of reducing $PM_{2.5}$ emissions near monitors under stagnant meteorological conditions, the $PM_{2.5}$ response factors from linear rollback methods estimate that relatively small emission reductions can greatly influence $PM_{2.5}$ concentrations in the mountain valleys. For instance, based on the linear rollback analysis in the Portola, CA state implementation plan (NSAQMD, 2017), a reduction of 100 tons of primary $PM_{2.5}$ emissions would reduce the annual DV by about 6.6 $\mu g\ m^{-3}$. This responsiveness is about 30x more efficient than photochemical modeling estimates of $PM_{2.5}$ responsiveness for county-wide emission reductions under typical meteorological conditions (i.e., outside of mountain valley stagnation conditions). Our national RIA analysis did not apply linear rollback-based response factors for the mountain valleys because emission and control information are available only at the county level, and therefore controls cannot be targeted to the local communities in our analysis. To address standard exceedances in the small mountain valleys, a detailed analysis would be necessary that considers local $PM_{2.5}$ response factors and applies controls in the local community.

Challenges due to the wood-smoke issues just described occur in five western counties including Plumas, CA; Lincoln, MT; Shoshone, ID; Lemhi, ID; and Klamath, OR. The populations of the relevant cities within these counties are less than 3,200, except for Klamath Falls (22,000) (Table 2-2). In addition to challenges related to residential wood combustion and meteorological temperature inversions, $PM_{2.5}$ concentrations in these areas may also be influenced by wildfire smoke that could potentially qualify as atypical, extreme, or unrepresentative events. Some wildfire influence likely persists in the projected 2032 $PM_{2.5}$ DVs despite the removal of EPA-concurred exceptional events and the wildfire screening described in Section 2.2.2. Sensitivity projections using an extreme value cutoff concentration of 34 $\mu g\ m^{-3}$ (99.0^{th} percentile) rather than the default 64 $\mu g\ m^{-3}$ (99.9^{th} percentile) were performed to explore the potential for wildfire impacts to affect attainment of the standards. The alternative cutoff value led to DV projections (Table 2-2) that are 0.27 to 1.08 μg m^{-3} lower than the default approach at the five sites. Therefore, projections for these sites may include an important contribution from wildfire. However, a detailed local analysis would be needed to fully characterize the wildfire influence on attainment in these areas as well as the wood-smoke issues discussed above.

Table 2-2 Information on Areas with Challenging Residential Wood Combustion Issues

County, State	City (Population[a])	Annual 2032 DV (μg m^{-3})	Annual 2032 DV Alternative Fire Screening[b] (μg m^{-3})
Plumas, CA	Portola (1,913)	14.02	13.75
Lincoln, MT	Libby (2,845)	11.63	11.16
Shoshone, ID	Pinehurst (1,620)	10.56	10.08
Lemhi, ID	Salmon (3,182)	9.85	9.44
Klamath, OR	Klamath Falls (22,002)	10.69	9.61

[a] Population from Census.gov (https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-cities-and-towns-total.html)
[b] Screening based on a 99.0 percentile cutoff concentration of 34 μg m^{-3} (rather than the default 99.9 percentile value of 64 μg m^{-3})

2.4.4 California Areas

Several areas in California present challenges in the RIA analysis in addition to the Imperial and Plumas County areas discussed above. The additional areas, described in this section, are SJV, South Coast Air Basin, and three relatively isolated counties.

2.4.4.1 San Joaquin Valley, CA

SJV is a large inter-mountain air basin covering approximately 25,000 square miles (SJVAPCD, 2018) that makes up the southern portion of California's Central Valley. SJV is formed by the Sierra Nevada mountains in the east, the coastal mountain ranges in the west, and the convergence of mountain ranges at the Tehachapi mountains in the south. The SJV nonattainment area (Figure 2-21) includes eight counties with a combined population of about 4.3 million. Due to the typical north to south wind pattern (Ying and Kleeman, 2009) and wintertime meteorological inversions, $PM_{2.5}$ concentrations tend to be highest in the south near Bakersfield and the convergence of the mountain ranges.

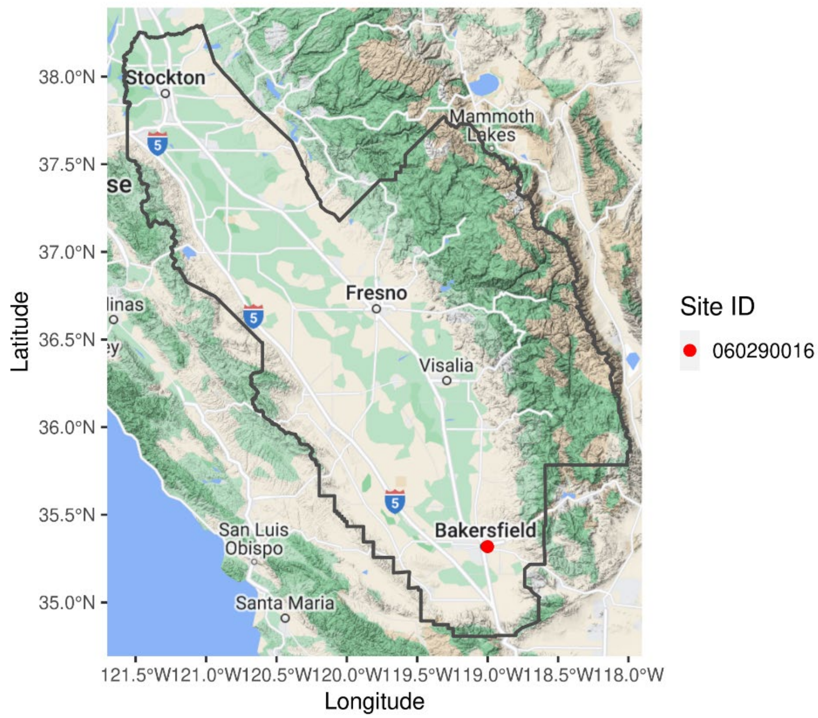

Figure 2-21 San Joaquin Valley Nonattainment Area and Location of Highest $PM_{2.5}$ Monitor in Bakersfield (06-029-0016)

Source: Map Data ©2022 Google.

SJV is currently in nonattainment of the 1997 and 2012 annual $PM_{2.5}$ NAAQS and the 2006 24-hr $PM_{2.5}$ NAAQS. The ambient DVs at the highest SJV monitor for the 2009-2011 to 2019-2021 DV periods are shown in Figure 2-22. Discerning progress from the SJV DVs over this period is complicated by the year-to-year variability in wildfire activity and meteorological conditions that strongly influence $PM_{2.5}$ concentrations. However, the effectiveness of SJV control strategies has previously been demonstrated in terms of reductions in the annual number of days that exceed the 24-hr standard level of 35 $\mu g\ m^{-3}$ (Figure 2-23; (SJVAPCD, 2018)). SJV control strategies focus on reducing NOx emissions to lower ammonium nitrate concentrations and reducing primary $PM_{2.5}$ emissions to lower carbonaceous and crustal $PM_{2.5}$ concentrations (SJVAPCD, 2018). These strategies are based on decades of modeling research and multiple intensive field measurement campaigns such as the 1995 Integrated Monitoring Study (IMS), the 2000/2001 California Regional PM_{10}/$PM_{2.5}$ Air Quality Study (CRPAQS), the 2010 California Research at the

Nexus of Air Quality and Climate Change (CalNex) study, and the 2013 Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) study. The effectiveness of NOx reduction for control of ammonium nitrate in SJV has also been demonstrated using data from the long-term ambient monitoring record (Pusede et al., 2016).

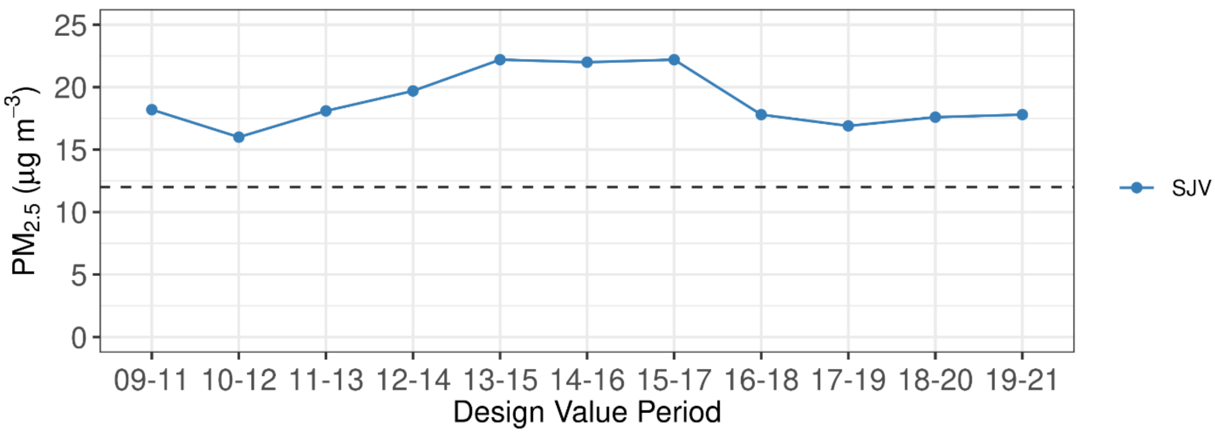

Figure 2-22 Recent Annual $PM_{2.5}$ DVs at the Highest SJV Monitor for Design Value Periods (e.g., 11-13: 2011-2013). Dashed line is the 2012 Annual $PM_{2.5}$ NAAQS Level (12 $\mu g\ m^{-3}$)

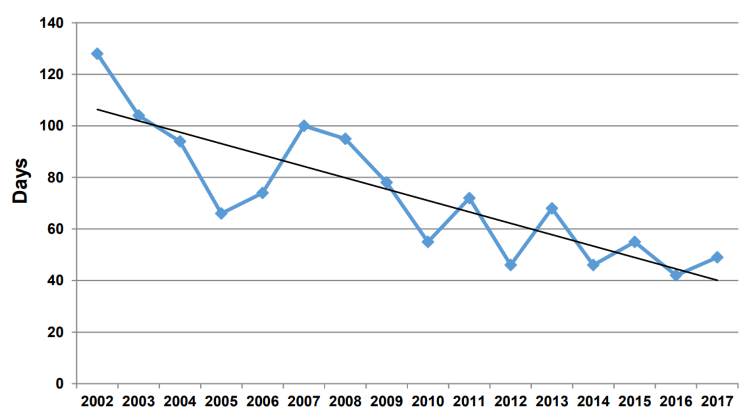

Figure 2-23 Decrease in the Number of Days SJV Exceeded the 24-hr NAAQS Level (35 $\mu g\ m^{-3}$)

Source: (SJVAPCD, 2018)

SJV air quality is influenced by emissions from large cities such as Bakersfield (population: 400,000) and Fresno (population: 540,000), an extremely productive agricultural region, dust exacerbated by drought, major goods transport corridors (i.e., Interstate-5 and Highway 99), and wildfire. Primary $PM_{2.5}$ emission totals are shown for SJV in our 2032 modeling case in Figure 2-24. $PM_{2.5}$ emissions are largest from agricultural dust from the production of crops and livestock, paved and unpaved road dust, prescribed burning, and cooking. Wildfire also contributed 13,100 tons of $PM_{2.5}$ emissions to SJV based on 2018 levels.

The highest projected 2032 annual DV in SJV Is 15.34 $\mu g\ m^{-3}$ in Bakersfield (site ID: 06-029-0016). To address standard exceedances in SJV in the RIA, we applied 75% NOx emissions reductions beyond the 2032 modeling case and pursued emission reductions of primary $PM_{2.5}$. However, the RIA is not well suited to identifying the specific measures needed to meet standards in SJV given the nature and magnitude of the air quality challenges. Challenges include air quality influenced by complex terrain and meteorological conditions that would be best characterized with a high-resolution modeling platform developed for the specific conditions of the valley. Also, specific local information on measures for reducing emissions from agricultural dust and burning and prescribed burning would be valuable given the magnitude of those emissions in SJV. Characterizing the influence of wildfire on $PM_{2.5}$ concentrations and potential atypical, extreme, or unrepresentative events in SJV would also benefit from a local analysis. Wildfire screening is particularly complex in California because different parts of the state have different wildfire seasonality (e.g., Barbero et al., 2014), and severe wildfire episodes can occur during periods where anthropogenic $PM_{2.5}$ concentrations may also be high. Progress toward meeting the alternative standards in SJV will likely occur as an outgrowth of existing efforts to meet the 1997, 2006, and 2012 $PM_{2.5}$ NAAQS.

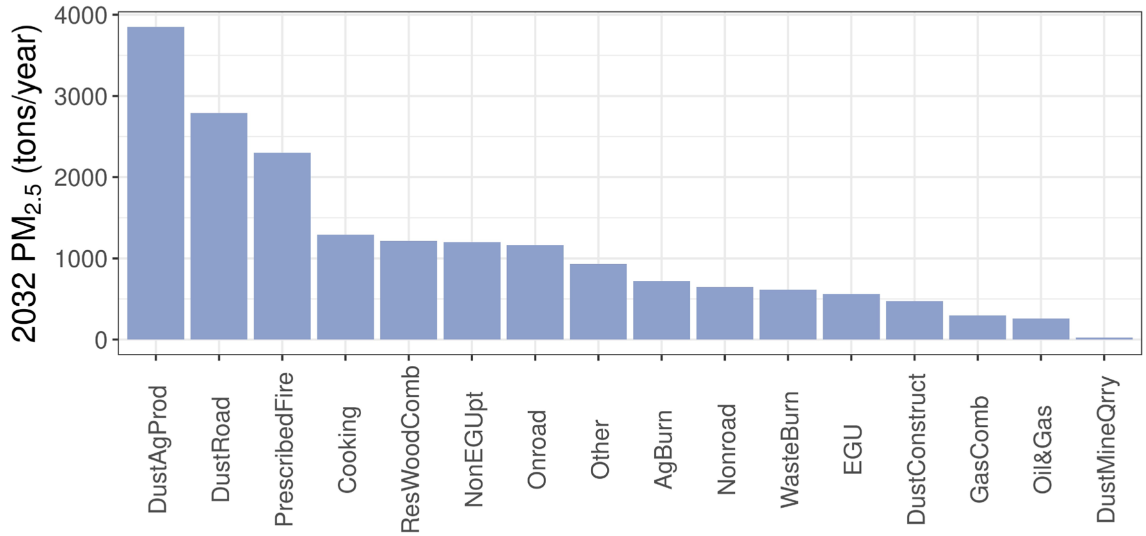

Figure 2-24 Annual Source Sector $PM_{2.5}$ Emission Totals in SJV Counties for 2032 Modeling Case

Note that DustAgProd: Dust from Agricultural Production; AgBurn: Open Agricultural Burning; DustRoad: Paved and Unpaved Road Dust; NonEGUpt: Non-EGU Point Sources; Onroad: Onroad Mobile Sources; ResWoodComb: Residential Wood Combustion; Cooking: Commercial Cooking and Residential Grilling; Other: Airports, Commercial Marine Vehicles, Rail, Solvents, and Other Non-Point Area Sources; Nonroad: Nonroad Mobile Sources; WasteBurn: Open Waste Burning; DustConstruct: Construction Dust; GasComb: Gas Combustion; and DustMineQrry: Dust from Mining and Quarrying. Wildfire emissions (Not Shown) are 13,100 tons. Point Source Emissions for NonIPM, EGU, and Oil&Gas Reflect Levels in the Nonattainment Area.

2.4.4.2 South Coast Air Basin, CA

The South Coast Air Basin (SoCAB) is formed by mountain ranges on three sides and the Pacific Ocean in the west (Figure 2-25). SoCAB includes all or part of four counties (LA, Riverside, San Bernardino, and Orange) with a combined population of over 17 million and diverse emission sources associated with the large population, the ports of LA and Long Beach, wildfire, and transportation of goods. The semi-permanent Pacific high-pressure system leads to subsidence temperature inversions over SoCAB that can influence air pollution processes by capping vertical mixing over the basin (Jacobson, 2002; Lu and Turco, 1995). The sea-breeze circulation transports emissions from coastal ports and Los Angeles to inland areas such as Riverside and San Bernardino (Lu and Turco, 1995; Neuman et al., 2003; Pilinis et al., 2000). This transport, along with concurrent formation of secondary $PM_{2.5}$ and limited ventilation due to terrain blocking and temperature inversions, causes the highest $PM_{2.5}$ concentrations to occur downwind of LA in Riverside and San Bernardino. For instance, the projected 2032 annual DV at the highest site in LA is 12.87 μg m^{-3} (site ID: 06-037-1302) and is 13.79 μg m^{-3} in Riverside (site ID: 06-065-8005) and 14.33 μg m^{-3} in San Bernardino (site ID: 06-071-0027).

Figure 2-25 South Coast Air Basin Nonattainment Area and Locations of Highest $PM_{2.5}$ Monitors in Los Angeles (06-037-1302), Riverside (06-065-8005), and San Bernardino (06-071-0027)

Source: Map Data ©2022 Google.

$PM_{2.5}$ DVs in SoCAB exceed the 2012 annual $PM_{2.5}$ NAAQS and the 2006 24-hr $PM_{2.5}$ NAAQS. As in SJV, limited progress is evident in the trend of recent annual DVs in SoCAB (Figure 2-26). However, year-to-year variability in wildfire emissions and meteorology might mask air quality management progress. The 2016 Air Quality Management Plan demonstrates the effectiveness of control programs during the 1999 to 2015 period in which SoCAB experienced significant population growth (SCAQMD, 2017). Emission control programs for SoCAB focus on reducing NOx emissions to lower ammonium nitrate concentrations and primary $PM_{2.5}$ emissions to lower carbonaceous $PM_{2.5}$ concentrations. Ammonium nitrate tends to be elevated in Riverside and San Bernardino due to the mixing of NOx emissions from LA with ammonia emissions from dairy facilities near Chino during transport inland (Neuman et al., 2003; Nowak et al., 2012). The largest primary $PM_{2.5}$ emission sources in our 2032 modeling include commercial and residential cooking, onroad mobile sources, and paved and unpaved road dust (Figure 2-27). $PM_{2.5}$ control strategies in SoCAB are based on decades of study including intensive measurement and modeling campaigns such as the 1987 Southern California Air Quality Study (SQAQS) and the 2010 CalNex campaign.

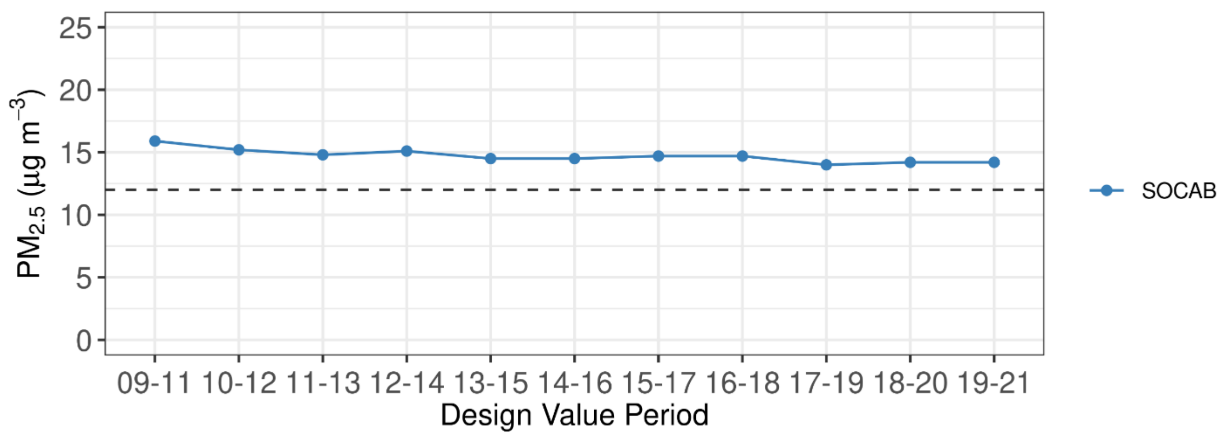

Figure 2-26 Recent Annual $PM_{2.5}$ DVs at the Highest South Coast Monitor for Design Value Periods (e.g., 11-13: 2011-2013). Dashed line is the 2012 Annual $PM_{2.5}$ NAAQS Level (12 μg m^{-3})

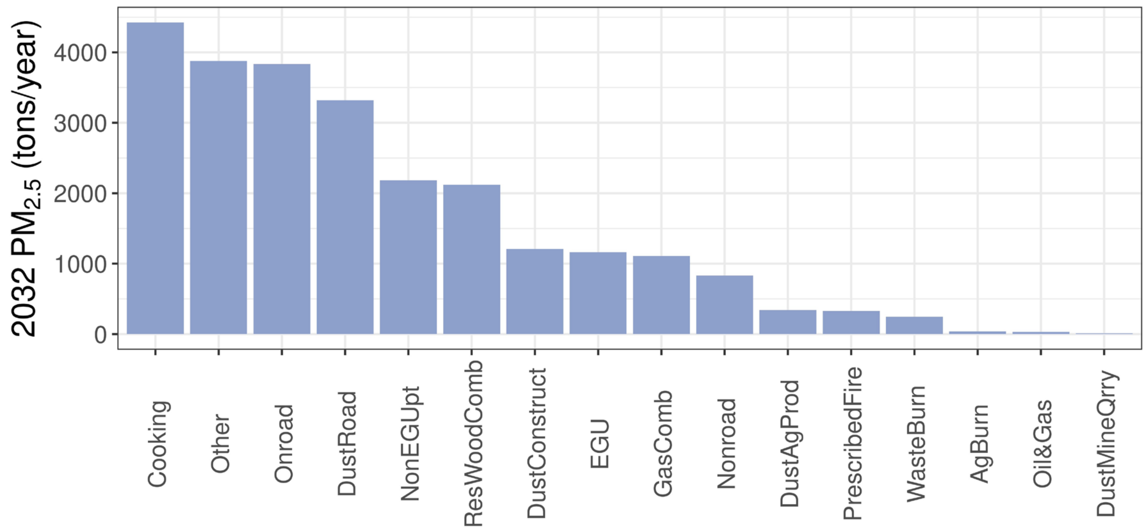

Figure 2-27 Annual Source Sector $PM_{2.5}$ Emission Totals in the SoCAB Counties for 2032 Modeling Case

Note: See Figure 2-23 for Label Definitions. Wildfire emissions (Not Shown) are 10,100 Tons.

To address standard exceedances in SoCAB in the RIA, we applied 75% NOx emission reductions beyond the 2032 modeling case and pursued emission reductions of primary $PM_{2.5}$. However, the RIA is not well suited to identifying the specific measures needed to meet standards in SoCAB given the nature and magnitude of the air quality challenges. Challenges include air quality influenced by complex terrain and meteorological conditions that would be best characterized with a high-resolution modeling platform developed for the specific conditions of the air basin. Also, specific local information on measures for reducing emissions from the major area sources would be valuable given the magnitude of these emissions in SoCAB. Characterizing the influence of wildfire on $PM_{2.5}$ concentrations and potential atypical, extreme, or unrepresentative events in SoCAB would also benefit from a local analysis. Progress toward meeting the alternative standards in SoCAB will likely occur as an outgrowth of existing efforts to meet the 2006 and 2012 $PM_{2.5}$ NAAQS.

2.4.4.3 Additional California Areas

The RIA analysis identified challenges for identifying sufficient emission controls to meet the revised 9/35 standard in three additional counties in California that may have been influenced by wildfire during the 2016-2020 monitoring period used for model projections. To explore the possibility that wildfire influence persists in the 2032 projections, the 2032 DVs were recalculated in Sutter, Calaveras, and Alameda Counties using a threshold of 34 $\mu g/m^3$ (i.e., the 99.0th percentile across 2002-2020 data) rather than 64 $\mu g/m^3$ (i.e., the 99.9th percentile across 2002-2020 data) to exclude days with potential wildfire influence. The recalculated projected DVs are shown in Table 2-3 along with the default projected 2032 DVs. At the Sutter and Calaveras sites, the 2032 DVs decrease from above to below the annual standard of 9 $\mu g/m^3$ when the lower threshold (i.e., 34 $\mu g/m^3$) is applied in a place of the default threshold (i.e., 64 $\mu g/m^3$). These results suggest the important influence of fires on the projected DVs, especially considering that the lower threshold is close to 4x the revised annual standard level of 9 $\mu g/m^3$, and additional wildfire influence likely persists even using the more stringent screening threshold.

For the Alameda site, the 2032 DV decreases from 10.37 $\mu g/m^3$ to 10.07 $\mu g/m^3$ when using the 99.0th percentile (i.e., 34 $\mu g/m^3$) rather than the 99.9th percentile (i.e., 64 $\mu g/m^3$) value to screen wildfire influence. The ambient $PM_{2.5}$ DV for the 2020-2022 period at this site is 8.6 $\mu g/m^3$, and the 2019-2021 DV is 8.5 $\mu g/m^3$. For the 2016-2018, 2017-2019, and 2018-2020 DV periods that overlap the 2016-2020 monitoring period of the RIA projections, higher ambient DVs of 12.0 $\mu g/m^3$, 11.7 $\mu g/m^3$, and 10.8 $\mu g/m^3$ were measured. Wildfire influence during this period may explain the much higher projected 2032 DV than the most recent two ambient DVs (i.e., 2019-2021 and 2020-2022) at the Alameda site. For instance, CalFire reports (https://www.fire.ca.gov/incidents/) that 2017 was the most destructive wildfire year on record in California at the time in terms of property damage; the 2018 wildfire year included a total of over 7,500 fires that burned an area of over 1.7 million acres; and the 2020 wildfire year had nearly 10,000 fires that burned over 4.2 million acres, making 2020 the largest wildfire season recorded in California's modern history. Although detailed analysis of wildfire influence would be needed to determine the full extent of the fire impacts at the Sutter, Calaveras, and Alameda sites, the existing evidence suggests that wildfire has an important contribution to the projected exceedances at these sites in the RIA.

Table 2-3 Design Value Information for Additional California Areas

County	Site ID	Annual 2032 DV ($\mu g\ m^{-3}$)	Annual 2032 DV Alternative Fire Screening[a] ($\mu g\ m^{-3}$)
Sutter	06-101-0003	9.41	8.99
Calaveras	06-009-0001	9.60	8.88
Alameda	06-001-0011	10.37	10.07

[a] Screening based on a 99.0 percentile cutoff concentration of 34 $\mu g\ m^{-3}$ (rather than the default 99.9 percentile value of 64 $\mu g\ m^{-3}$).

2.4.5 Additional Considerations

The 2020-2022 annual $PM_{2.5}$ DV at the North Pole Fire Station site (02-090-0035) in Fairbanks, Alaska is 12.2 $\mu g/m^3$ and the 24-hour $PM_{2.5}$ DV is 70 $\mu g/m^3$. Although the annual DV is greater than the standard levels considered in the RIA, emission reductions to meet the existing 24-hour standard could potentially reduce the annual DV to a concentration below the standard levels considered. The North Pole site experiences local air quality challenges that have led to persistent exceedances of the 24-hour standard set in 2006. Elevated $PM_{2.5}$ concentrations occur in the local area under extreme temperature inversion conditions during winter when residential wood combustion emissions are prevalent. A detailed local analysis that develops information on local emissions, modeling, and controls would be necessary to explore this area further and is beyond the scope of the RIA.

The Hidden Valley site (04-021-3015) in Pinal, AZ was not compared with the annual NAAQS in this assessment because Hidden Valley is a replacement for the Cowtown Road site that was not comparable to the annual standard. The Pinal County Air Quality Control District (PCAQCD) is currently excluding the Hidden Valley monitor in determining minimum monitoring requirements while EPA determines its comparability to the annual NAAQS (PCAQCD, 2020). $PM_{2.5}$ concentrations at the site are influenced by local emissions from a dairy feedlot, unpaved roads, and agricultural cropland. Projected annual $PM_{2.5}$ DVs are more than 4 $\mu g/m^3$ lower at the 04-021-0001 site two CMAQ grid cells away in Pinal County due to the very local nature of the emissions and air quality impacts at the Hidden Valley site.

2.5 Calculating $PM_{2.5}$ Concentration Fields for Standard Combinations

National $PM_{2.5}$ concentration fields corresponding to meeting the existing, revised, and alternative standard levels were developed to inform health benefit calculations. First, a gridded $PM_{2.5}$ concentration field for the 2032 CMAQ modeling case was developed using the enhanced Voronoi Neighbor Average (eVNA) method. Next, the incremental difference in annual $PM_{2.5}$ DVs between the 2032 case and case of meeting standard combinations was calculated at monitors and interpolated to the spatial grid. The resulting field of incremental $PM_{2.5}$ concentration was then subtracted from the 2032 eVNA field to create the gridded field for the standard combinations. The steps in developing the $PM_{2.5}$ concentration fields are described further below.

2.5.1 Creating the $PM_{2.5}$ Concentration Field for 2032

The gridded field of annual average $PM_{2.5}$ concentrations for 2032 was developed using the eVNA method that combines information from the model and monitors to predict $PM_{2.5}$ concentrations. The eVNA approach was applied using SMAT-CE and has been previously described in EPA's modeling guidance document (USEPA, 2018) and the user's guide for the predecessor software to SMAT-CE (Abt, 2014). Briefly, the steps in developing the eVNA $PM_{2.5}$ concentration field for 2032 are as follows:

Step 1. Quarterly average $PM_{2.5}$ component concentrations measured during the 2017-2019 period were interpolated to the spatial grid using inverse distance-squared-weighting of monitored concentrations that were further weighted by the ratio of the 2018 CMAQ value in the prediction grid cell to CMAQ value in the monitor-containing grid cell. The weighting by CMAQ predictions adjusts the interpolation of monitor data to account for spatial gradients in the CMAQ fields. This step results in an interpolated spatial field of gradient-adjusted observed concentrations for each $PM_{2.5}$ component and each quarter representative of 2018.

Step 2. The 2018 eVNA component concentration in each grid cell is multiplied by the corresponding ratio (i.e., RRF) of the quarterly-average CMAQ concentration predictions in 2032 and 2018. This step results in spatial concentration fields for each $PM_{2.5}$ component in each quarter of 2032.

Step 3. The 2032 $PM_{2.5}$ component concentrations are summed to give the total $PM_{2.5}$ concentration for each quarter in 2032. The quarterly $PM_{2.5}$ concentrations are then averaged to create the 2032 $PM_{2.5}$ concentration field. The resulting $PM_{2.5}$ concentration field for 2032 is shown in Figure 2-28.

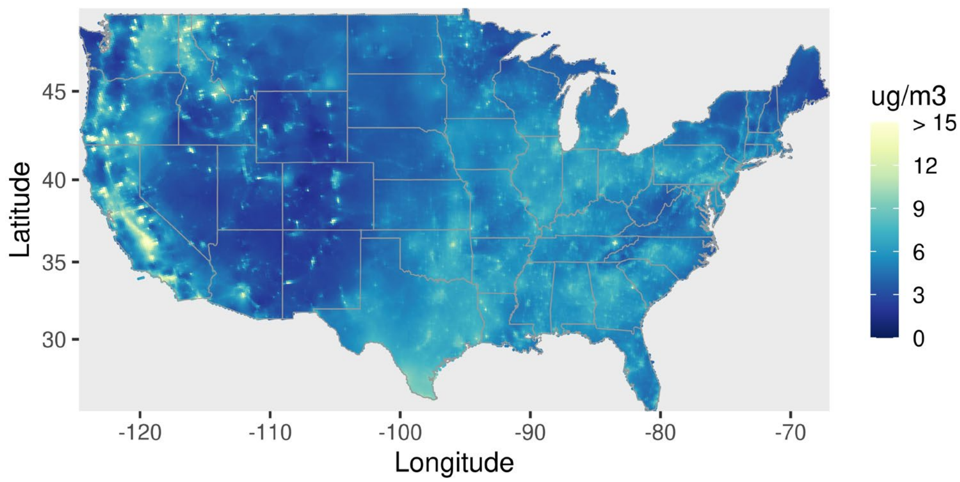

Figure 2-28 $PM_{2.5}$ Concentration for 2032 based on eVNA Method

2.5.2 Creating Spatial Fields Corresponding to Meeting Standards

To create spatial fields corresponding to meeting standard levels, the 2032 concentration field was adjusted according to the change in $PM_{2.5}$ concentrations associated with the difference in annual $PM_{2.5}$ DVs between the 2032 case and the cases where standards are met. To implement this adjustment, the following steps were applied:

Step 1. The difference in annual $PM_{2.5}$ DVs was calculated at the county highest monitor between the 2032 case and cases of meeting the 12/35, 10/30, 10/35, 9/35, and 8/35 standard combinations for counties with monitors exceeding the standard levels. The $PM_{2.5}$ DVs for the cases where alternative standard levels are met were developed by applying the air quality ratios to the emission reductions for the county (i.e., Eqn. 2-2). For the county non-highest monitors, the difference in $PM_{2.5}$ DVs was estimated by proportionally adjusting the DVs according to the percent change in $PM_{2.5}$ DV at the highest monitor.

Step 2. The difference in DVs between the 2032 case and the cases of meeting the standard combinations were then interpolated to the spatial grid using inverse-distance-squared VNA interpolation (Abt, 2014; Gold et al., 1997). The interpolated field was clipped to grid cells within 50 km of monitors whose DVs changed in meeting the standard level (USEPA, 2012a).

Step 3. National $PM_{2.5}$ concentration fields were developed for each standard combination by subtracting the corresponding spatial field of $PM_{2.5}$ concentration differences from Step 2 from the 2032 eVNA concentration field.

In Figure 2-29, the spatial field for the incremental change in $PM_{2.5}$ concentration between the 12/35 analytical baseline and the case of meeting the 9/35 standard combination is shown. Additional details on the method for developing $PM_{2.5}$ concentration fields are available in section 2A.4 of Appendix 2A.

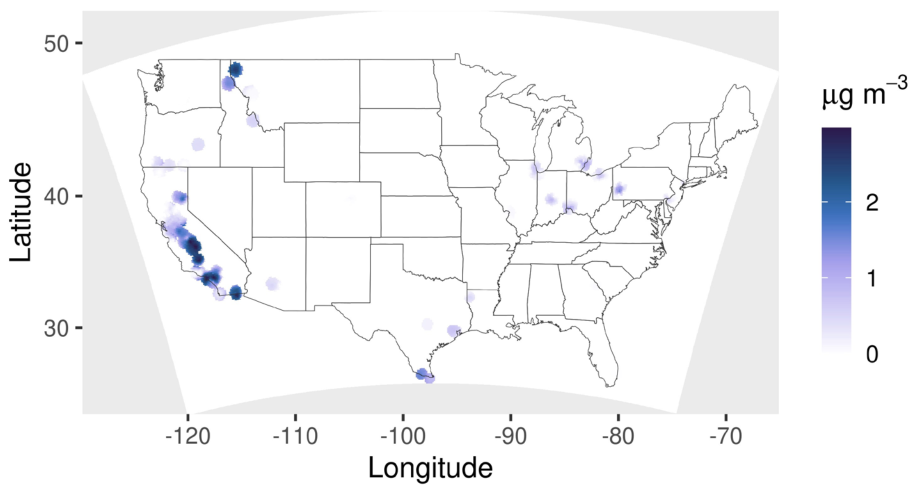

Figure 2-29 $PM_{2.5}$ Concentration Improvement Associated with Meeting 9/35 Relative to the 12/35 Analytical Baseline

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APPENDIX 2A: ADDITIONAL AIR QUALITY MODELING INFORMATION

Overview

A 2018-based modeling platform was used to project future-year air quality for 2032 to identify areas that would exceed the existing, revised, and alternative PM NAAQS after accounting for expected emission reductions from 'on-the-books' rules. This platform uses the Community Multiscale Air Quality (CMAQ; www.epa.gov/cmaq) model for air quality simulation and incorporates the most recent, complete set of base year emissions information available for national modeling. $PM_{2.5}$ design values (DVs) were projected to 2032 using relative response factors (RRFs) developed from CMAQ simulations based on emissions estimated for 2018 and projected to 2032.

Air quality ratios, which relate a change in $PM_{2.5}$ DVs to a change in emissions, were used to estimate the emission reductions needed to just meet the existing, revised, and alternative NAAQS in areas projected to exceed the standards in 2032. The emission reduction estimates are used in identifying controls and associated costs of meeting the standards. To inform calculations of the health benefits of meeting standards, annual-mean $PM_{2.5}$ concentration fields corresponding to cases where the existing, revised, and alternative NAAQS are just met were developed. The $PM_{2.5}$ concentration fields were created by adjusting the 2032 field based on the CMAQ modeling using the incremental change in annual $PM_{2.5}$ DV needed to meet the standards.

The overall steps in the air quality analysis are:

1. Project annual and 24-hour $PM_{2.5}$ DVs to 2032 using a CMAQ simulation for 2018 and a corresponding CMAQ simulation with emissions representative of 2032.

2. Develop air quality ratios that relate a change in $PM_{2.5}$ DVs to a change in emissions for use in estimating the emission reductions needed to just meet the existing and alternative NAAQS. The air quality ratios are developed using the change in DVs associated with CMAQ sensitivity modeling where 50% reductions in anthropogenic emissions were applied in targeted counties relative to previous CMAQ modeling for 2028.

3. Using the air quality ratios from Step 2, estimate the emission reductions needed to meet the existing standards (12/35) beyond the 2032 modeling case. For counties in the San Joaquin Valley (SJV) and South Coast Air Basin of California, 75% reductions in anthropogenic NOx emissions are applied in addition to reductions in primary $PM_{2.5}$ emissions in this step. Concentrations of ammonium nitrate are elevated in SJV and South Coast, and these areas are pursuing both NOx and primary $PM_{2.5}$ emission reductions to meet the existing standards. For other counties, primary $PM_{2.5}$ emission reductions alone are applied. The resulting $PM_{2.5}$ DVs define the *12/35 analytical baseline* that is used as the reference case in estimating the incremental costs and benefits of meeting revised and alternative standards relative to existing standards.
4. Using the air quality ratios from Step 2, estimate the primary $PM_{2.5}$ emission reductions needed to meet the revised and alternative standards beyond the 12/35 analytical baseline.
5. Develop a gridded national $PM_{2.5}$ concentration field associated with the 2032 case by fusing the 2032 CMAQ modeling with projected monitor concentrations. Adjust the 2032 concentration field according to the changes in $PM_{2.5}$ DVs needed to meet standard levels to create national $PM_{2.5}$ concentration fields associated with meeting the existing and alternative standard levels.

In the remainder of this Appendix, the 2018 air quality model configuration and simulation are described and evaluated in Section 2A.1. The projection of air quality from 2018 to 2032 is described in Section 2A.2. The development of air quality ratios and their application to estimating emission reductions is described in Section 2A.3. Finally, the development of the $PM_{2.5}$ concentration fields is described in Section 2A.4.

2A.1 2018 CMAQ Modeling

CMAQ modeling was performed for 2018 to provide a reference simulation for the $PM_{2.5}$ DV projections to 2032 that are described in section 2A.2.

2A.1.1 Model Configuration

CMAQ is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary $PM_{2.5}$ concentrations, and deposition over regional spatial scales (e.g., over the contiguous U.S.) (Appel et al., 2021; Appel et al., 2018; Appel et al., 2017). CMAQ simulates the key processes (e.g., emissions, transport, chemistry, and deposition) that affect primary (directly emitted) and secondary (formed by atmospheric processes) PM using state-of-the-science process parameterizations and input data for emissions, meteorology, and initial and boundary conditions. CMAQ's representation of the chemical and physical mechanisms that govern the formation and fate of air pollution enable simulations of the impacts of emission controls on $PM_{2.5}$ concentrations.

CMAQ version 5.3.2 (doi: 10.5281/zenodo.4081737) was used to simulate air quality for 2018 to provide a reference simulation for the 2032 air quality projection. The geographic extent of the air quality modeling domain (12US2) is shown in Figure 2A-1. The 12US2 modeling domain covers the 48 contiguous states along with parts of Canada and Mexico with a horizontal resolution of 12 x 12 km. Air quality modeling for a larger 12-km domain (US EPA 2021) was used to provide chemical boundary conditions for the 12US2 domain simulation used in projecting air quality to the future. The modeling domains have 35 vertical layers with a top at about 17.6 km (50 millibars). The CMAQ simulation included 10 days of model spin-up in December 2017 and produced hourly pollutant concentrations for each grid cell across each modeling domain.

Gas-phase chemistry in the CMAQ simulations was based on the Carbon Bond 2006 mechanism (CB6r3) (Emery et al., 2015), and deposition was modeled with the M3DRY parameterization. Aerosol processes were parameterized with the AERO7 module using ISORROPIA II for inorganic aerosol thermodynamics (Fountoukis and Nenes, 2007) and the non-volatile treatment for primary organic aerosol (Appel et al., 2017; Simon and Bhave, 2012). Emissions used were based on version 2 of the 2018 emissions modeling platform as described in detail previously (USEPA, 2023a). Emissions of anthropogenic precursors for secondary organic aerosol (SOA) (Murphy et al., 2017) were not added to the simulation beyond what was captured in the National Emissions Inventory. Emissions of biogenic compounds were modeled with the Biogenic Emission Inventory System (BEIS) (Bash et al., 2016). Emissions of sea-spray aerosol (Gantt et al., 2015) were simulated online within CMAQ using 2018 meteorology.

The 2018 meteorological data were derived from running Version 3.8 of the Weather Research Forecasting Model (WRF) (Skamarock et al., 2008). The meteorological outputs from WRF include hourly-varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer. Selected physics options used in the WRF simulations include Pleim-Xiu land surface model (Pleim et al., 2001; Xiu and Pleim, 2001), Asymmetric Convective Model version 2 planetary boundary layer scheme (Pleim, 2007), Kain-Fritsch cumulus parameterization (Kain, 2004) utilizing the moisture-advection trigger (Ma and Tan, 2009), Morrison double moment microphysics (H. Morrison et al., 2005; Hugh Morrison and Gettelman, 2008), and RRTMG longwave and shortwave radiation schemes (Iacono et al., 2008). The meteorological model configuration and evaluation have been described previously (USEPA, 2023b).

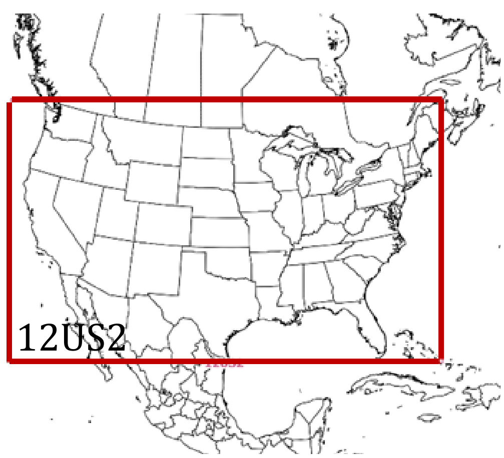

Figure 2A-1 Map of the 12US2 (12 x 12 km Horizontal Resolution) Modeling Domain Used for the PM NAAQS RIA

2A.1.2 Model Performance Evaluation

CMAQ predictions were evaluated by comparison with observations from U.S. monitoring networks in 2018. Modeled $PM_{2.5}$ concentrations were compared with available observations from U.S. EPA's Air Quality System (AQS) database (www.epa.gov/aqs).

Modeled concentrations of $PM_{2.5}$ components (nitrate; sulfate; elemental carbon, EC; and organic carbon, OC) were compared with observations from the Chemical Speciation Network (CSN) and Interagency Monitoring of Protected Visual Environments (IMPROVE) network (USEPA, 2019d). CSN sites tend to be in relatively urban areas and IMPROVE sites in relatively rural areas. Model predictions were paired with observations in space and time by averaging predictions to the observation sampling period and matching predictions with monitors in a model grid cell. Regional performance statistics were summarized according to the U.S. climate regions defined in Figure 2A-2. The absolute and normalized bias and error statistics and Pearson correlation coefficient used in evaluating model performance are defined in Table 2A-1. As described below, performance statistics for this application are generally within the range of model performance statistics reported in previous applications (Kelly et al., 2019; Simon et al., 2012) and suggest that the simulations are suitable for use in our application.

In Figure 2A-3, $PM_{2.5}$ model performance is shown for the AQS sites having the highest $PM_{2.5}$ DVs in the county for counties with projected annual $PM_{2.5}$ DVs greater than 8 $\mu g\ m^{-3}$ or 24-hour DVs greater than 30 $\mu g\ m^{-3}$. For regions in the eastern U.S., normalized mean biases (NMBs) are within 12% and Pearson correlation coefficients are 0.57 or greater for all regions, except for the South (r=0.53). In western regions, the model is generally biased low compared with observations, with NMBs ranging from -35% in the Northwest to -21% in the West. Underpredictions in western regions could be related to challenges in representing the influence of complex terrain in the 12-km modeling, challenges in simulating wildfire impacts, and underestimates of windblown dust influence. $PM_{2.5}$ performance statistics by region and season across all sites are provided in Table 2A-2. For the annual period, NMB is within 20% in eastern regions and correlation coefficients are 0.55 or greater. In the western regions, NMB ranged from -23.4% in the West to -5.5% in the Northwest and correlation coefficients ranged from 0.37 to 0.60.

Model performance statistics for $PM_{2.5}$ sulfate by region and season for sites in the CSN and IMPROVE networks are provided in Table 2A-3. The annual NMBs in sulfate predictions are within ±22% for all regions except the Northwest (NMB: 30.6%) and West (NMB: -32.9%) at CSN sites and within ±26% for all regions except the Southwest (NMB: -

34.1%) and West (NMB: -30.5%) at IMPROVE sites. Overpredictions of $PM_{2.5}$ species concentrations in the Northwest have been previously attributed to challenges in simulating the atmospheric mixing height near the Puget Sound and at coastal sites and in simulating wildfire influence on concentrations (Kelly et al., 2019). Concentrations are relatively low in the Northwest compared with the eastern U.S., and mean biases (MBs) in sulfate predictions are <0.15 $\mu g\ m^{-3}$ for both networks in the Northwest. Correlation coefficients over the annual period for sulfate predictions and observations were greater than 0.55 in six of the nine regions for CSN sites and seven of the nine regions at IMPROVE sites. Spatially, sulfate predictions tend to be biased slightly low in the southern and eastern parts of the domain and biased slightly high toward the Northwestern part of the domain (Figure 2A-4 and 2A-5).

Model performance statistics for $PM_{2.5}$ nitrate by region and season for sites in the CSN and IMPROVE networks are provided in Table 2A-4. In five of the nine regions, the annual NMB in nitrate predictions is within ±13% at CSN sites and within ±22% at IMPROVE sites. Nitrate predictions are biased low in the West at CSN (NMB: -60.6%) and IMPROVE (NMB: -45.6%) sites. Underpredictions of nitrate during meteorological inversion episodes in western mountain basins have been identified in the past due to challenges in resolving the influence of complex terrain and chemical and meteorological coupling in 12-km modeling (Baker et al., 2011; Kelly et al., 2019). Outside of the Northwest, correlation coefficients for the annual period ranged from 0.54 to 0.85 at CSN sites and 0.48 to 0.82 at IMPROVE sites. Spatially, nitrate predictions tend to be biased high in the eastern US and low in western U.S. (Figure 2A-4 and 2A-5).

Model performance statistics for $PM_{2.5}$ OC by region and season for sites in the CSN and IMPROVE networks are provided in Table 2A-5. The annual NMB in OC predictions is within ±40% for six of the nine regions at CSN sites and five of the nine regions at IMPROVE sites. $PM_{2.5}$ OC predictions are biased high (positive NMB) in eight of the nine regions at CSN sites and seven of the nine regions at IMPROVE sites. Correlation coefficients over the annual period for OC predictions and observations were greater than 0.5 in five of the nine regions for CSN sites and six of the nine regions at IMPROVE sites. Spatially, OC predictions tend to be biased high in the eastern U.S. and low in the western U.S., although spatial variability exists (Figure 2A-4 and 2A-5). Modeling of the emissions, volatility and atmospheric chemistry related to organic aerosol formation is an active area of research (USEPA, 2019d).

Model performance statistics for $PM_{2.5}$ EC by region and season for sites in the CSN and IMPROVE networks are provided in Table 2A-6. The annual NMB in EC predictions ranges from -17.2% to -52.5% at CSN sites and from -19.2% to -40.0% at IMPROVE sites. Correlation coefficients for the EC predictions and observations over the annual period were greater than 0.5 in four of the nine regions for CSN sites and seven of nine regions for IMPROVE sites. Spatially, EC predictions tend to be biased slightly low throughout much of the US (Figure 2A-4 and 2A-5).

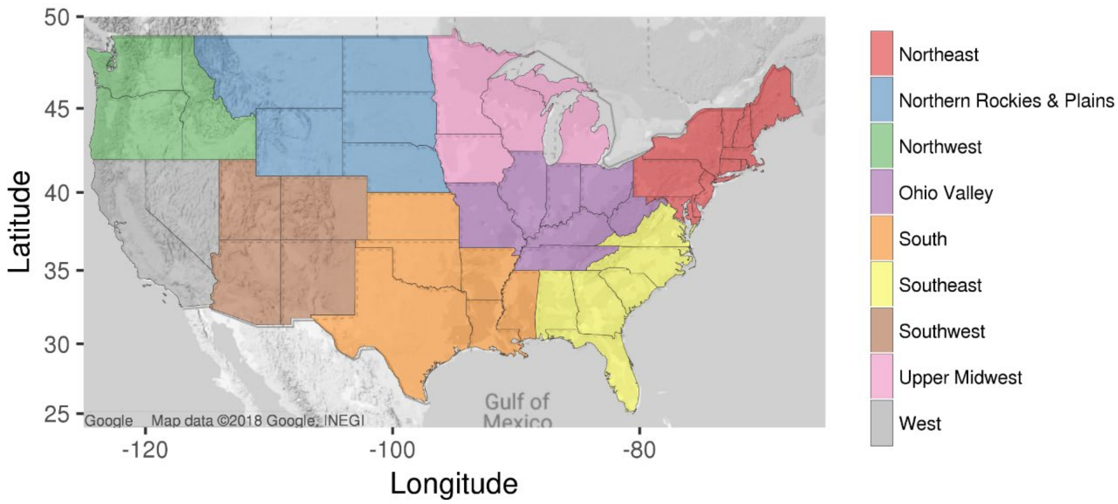

Figure 2A-2 U.S. Climate Regions (Karl and Koss, 1984) Used in the CMAQ Model Performance Evaluation

Table 2A-1 Definition of Statistics Used in the CMAQ Model Performance Evaluation

Statistic	Description
MB (μg m^{-3}) = $\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$	Mean bias (MB) is defined as the average difference between predicted (P) and observed (O) concentrations for the total number of samples (n)
RMSE (μg m^{-3}) = $\sqrt{\sum_{i=1}^{n}(P_i - O_i)^2/n}$	Root mean-squared error (RMSE)
NMB (%) = $\frac{\sum_i^n (P_i - O_i)}{\sum_i^n O_i} \times 100$	The normalized mean bias (NMB) is defined as the sum of the difference between predictions and observations divided by the sum of observed values

Statistic	Description
$\text{NME (\%)} = \frac{\sum_i^n \lvert P_i - O_i \rvert}{\sum_i^n O_i} \times 100$	Normalized mean error (NME) is defined as the sum of the absolute value of the difference between predictions and observations divided by the sum of observed values
$r = \frac{\sum_{i=1}^n (P_i - \overline{P})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2}}$	Pearson correlation coefficient

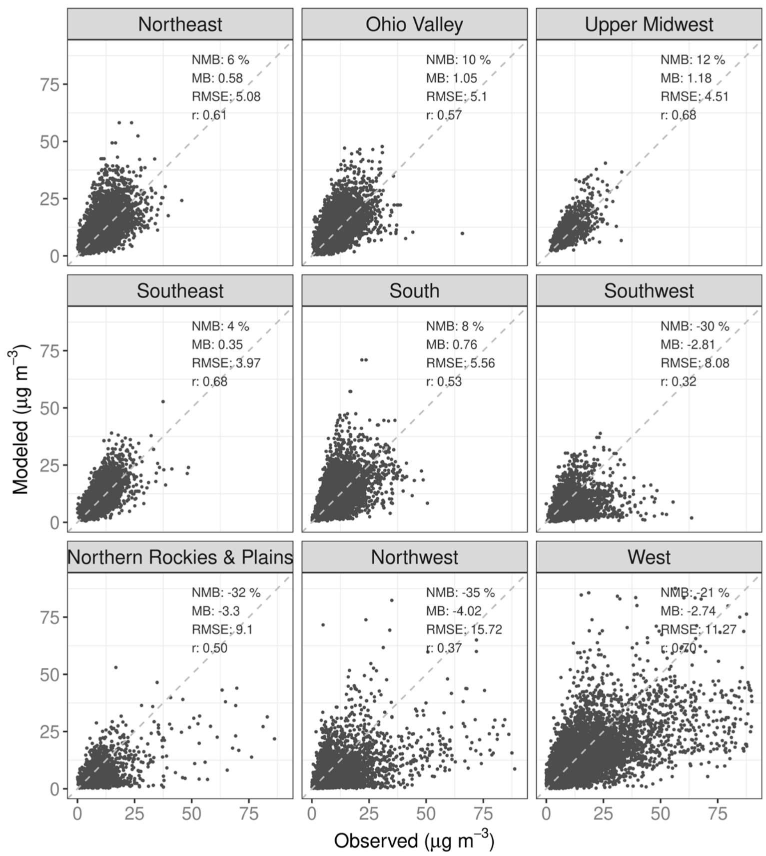

Figure 2A-3 Comparison of CMAQ Predictions of $PM_{2.5}$ and Observations at AQS Sites for County Highest $PM_{2.5}$ Monitors with $PM_{2.5}$ DVs Greater than 8/30

Table 2A-2 CMAQ Performance Statistics for $PM_{2.5}$ at AQS Sites in 2018

Region	Season	N	Avg. Obs. ($\mu g\ m^{-3}$)	Avg. Mod. ($\mu g\ m^{-3}$)	MB ($\mu g\ m^{-3}$)	NMB (%)	RMSE ($\mu g\ m^{-3}$)	NME (%)	*r*
Northeast	Winter	13417	8.57	11.38	2.81	32.8	6.47	51.1	0.62
	Spring	13593	6.28	7.79	1.51	24.0	4.21	46.8	0.58
	Summer	13544	8.22	7.56	-0.65	-7.9	3.99	35.4	0.66
	Fall	13255	5.80	7.23	1.43	24.6	4.72	52.9	0.57
	Annual	53809	7.22	8.49	1.27	17.6	4.94	46.0	0.61
Southeast	Winter	10798	7.39	8.88	1.49	20.2	4.66	44.0	0.66
	Spring	11263	7.97	7.64	-0.33	-4.2	3.40	31.3	0.69
	Summer	11346	8.63	7.69	-0.94	-10.9	3.38	29.5	0.62
	Fall	11026	6.92	7.84	0.92	13.3	3.76	37.6	0.65
	Annual	44433	7.74	8.00	0.27	3.4	3.83	35.1	0.63
Ohio Valley	Winter	11826	8.92	11.18	2.25	25.2	5.51	44.5	0.62
	Spring	12274	7.86	9.18	1.33	16.9	4.54	41.8	0.51
	Summer	12228	9.96	8.95	-1.01	-10.2	4.10	30.6	0.57
	Fall	11837	7.42	9.06	1.64	22.0	4.49	41.9	0.67
	Annual	48165	8.55	9.58	1.04	12.1	4.69	39.2	0.58
Upper Midwest	Winter	6646	9.16	12.20	3.04	33.2	6.47	47.6	0.63
	Spring	6674	6.88	9.12	2.24	32.5	5.90	52.2	0.48
	Summer	6542	8.37	7.28	-1.09	-13.0	4.78	37.3	0.49
	Fall	6681	5.85	7.65	1.80	30.9	3.94	46.9	0.72
	Annual	26543	7.56	9.07	1.51	20.0	5.36	45.7	0.58
South	Winter	8418	7.28	9.27	2.00	27.5	5.28	51.2	0.49
	Spring	8786	8.98	8.96	-0.02	-0.2	4.30	33.1	0.54
	Summer	8919	11.41	9.70	-1.72	-15.0	5.18	32.5	0.66
	Fall	8861	6.52	7.94	1.42	21.8	4.93	49.2	0.56
	Annual	34984	8.57	8.97	0.40	4.6	4.93	39.7	0.55
	Winter	6379	7.33	6.81	-0.51	-7.0	6.97	54.4	0.44
Southwest	Spring	6567	5.39	4.99	-0.40	-7.5	3.97	47.0	0.28
	Summer	6868	8.31	4.64	-3.66	-44.1	7.13	54.6	0.49
	Fall	6716	5.72	5.93	0.21	3.7	5.14	53.8	0.52
	Annual	26530	6.69	5.57	-1.12	-16.7	5.95	52.8	0.42
N. Rockies & Plains	Winter	5319	5.07	4.64	-0.44	-8.6	8.41	65.8	0.18
	Spring	5331	4.98	4.61	-0.37	-7.5	3.41	46.0	0.51
	Summer	5235	8.94	5.19	-3.75	-41.9	8.14	53.6	0.65
	Fall	5450	4.96	5.30	0.33	6.7	4.50	57.6	0.46
	Annual	21335	5.97	4.93	-1.04	-17.3	6.48	55.5	0.37
Northwest	Winter	10537	6.51	6.50	-0.01	-0.2	8.39	77.3	0.27
	Spring	10953	4.31	5.30	0.99	23.0	4.36	63.0	0.31
	Summer	11279	12.57	8.22	-4.35	-34.6	18.21	57.8	0.55
	Fall	10988	8.31	10.06	1.74	21.0	10.16	66.9	0.51
	Annual	43757	7.98	7.54	-0.44	-5.5	11.54	64.7	0.43
West	Winter	11744	10.05	7.95	-2.10	-20.9	7.79	46.2	0.61
	Spring	12181	6.81	5.60	-1.21	-17.7	4.24	41.1	0.49
	Summer	12288	12.97	9.79	-3.18	-24.5	13.86	45.7	0.46
	Fall	12123	12.78	9.31	-3.47	-27.1	15.03	45.1	0.75
	Annual	48336	10.66	8.17	-2.49	-23.4	11.17	44.9	0.60

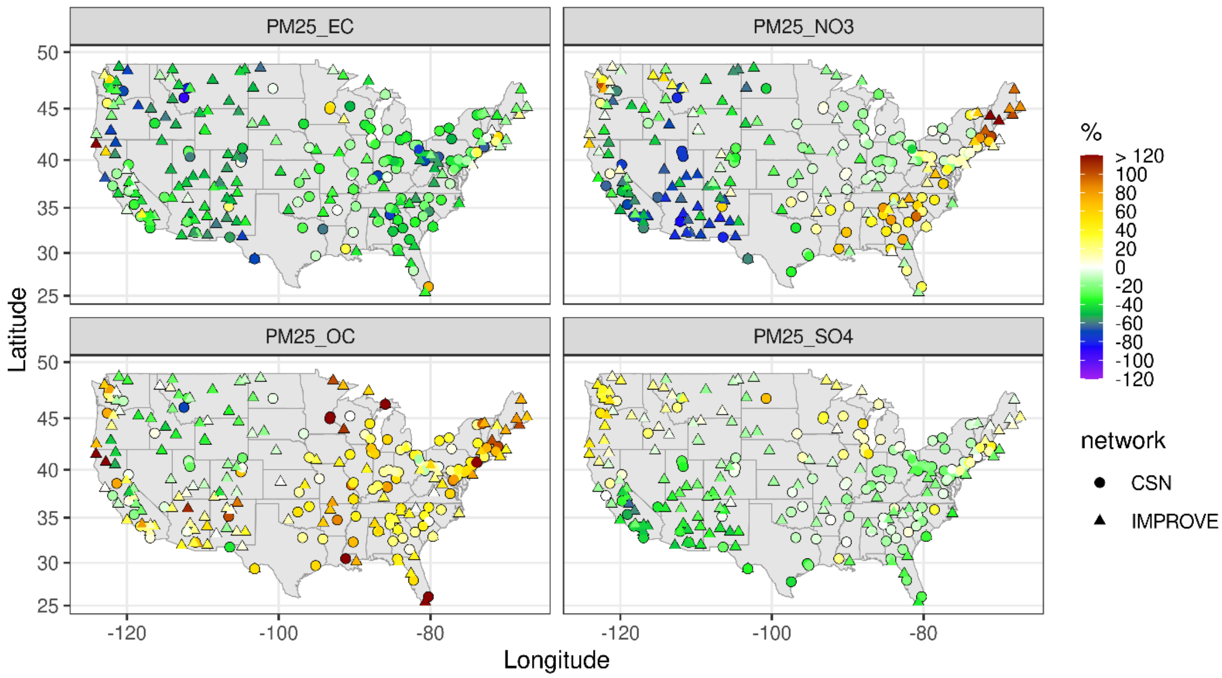

Figure 2A-4 NMB in 2018 CMAQ Predictions of $PM_{2.5}$ Components at CSN and IMPROVE Sites

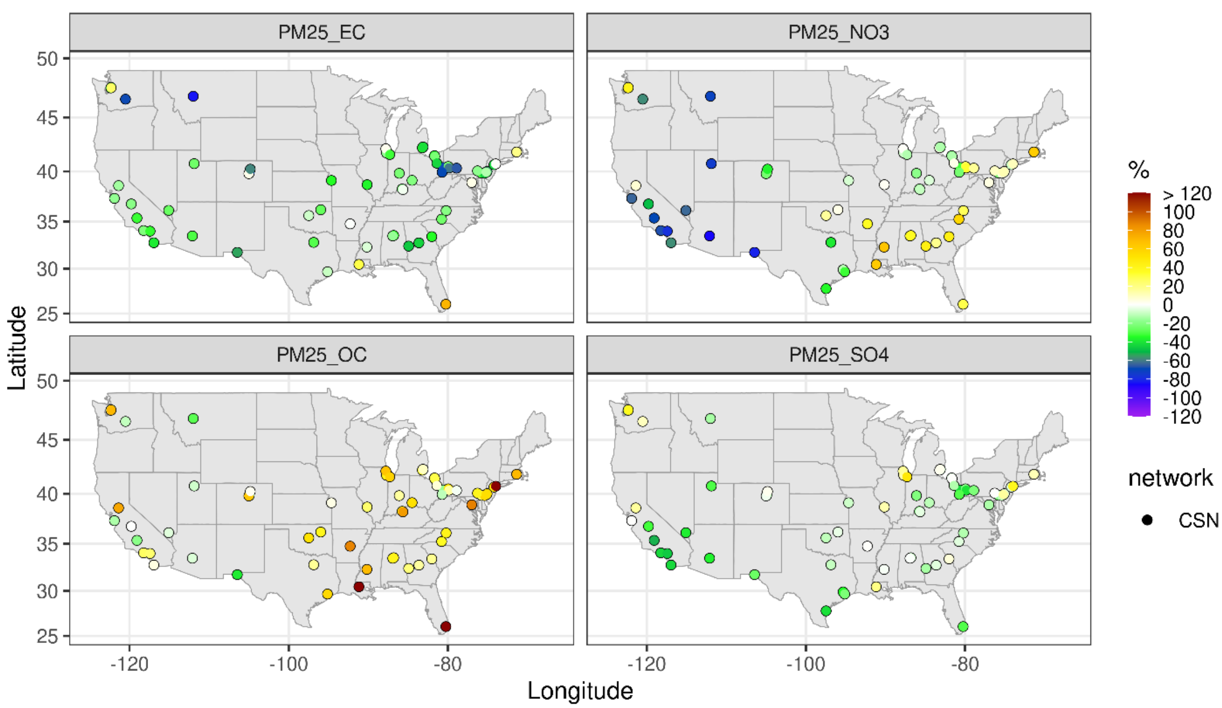

Figure 2A-5 NMB in 2016 CMAQ Predictions of $PM_{2.5}$ Components at CSN and IMPROVE Sites for Monitors in Counties with $PM_{2.5}$ DVs Greater than 8/30

Table 2A-3 CMAQ Performance Statistics for $PM_{2.5}$ Sulfate at CSN and IMPROVE Sites in 2018

Region	Network	Season	N	Avg. Obs. ($\mu g\ m^{-3}$)	Avg. Mod. ($\mu g\ m^{-3}$)	MB ($\mu g\ m^{-3}$)	NMB (%)	RMSE ($\mu g\ m^{-3}$)	NME (%)	*r*
Northeast	CSN	Winter	717	0.97	0.99	0.02	2.3	0.76	45.5	0.29
		Spring	741	0.98	1.00	0.02	2.3	0.45	30.8	0.68
		Summer	765	1.06	0.88	-0.18	-17.0	0.54	32.2	0.78
		Fall	719	0.80	0.78	-0.02	-1.9	0.37	31.4	0.67
		Annual	2942	0.96	0.92	-0.04	-4.2	0.55	35.0	0.60
	IMPROVE	Winter	365	0.71	0.69	-0.02	-2.2	0.28	28.7	0.72
		Spring	371	0.67	0.66	-0.01	-1.3	0.31	29.5	0.74
		Summer	381	0.80	0.57	-0.23	-29.0	0.44	37.6	0.83
		Fall	376	0.51	0.51	0.00	0.1	0.26	36.8	0.71
		Annual	1493	0.67	0.61	-0.07	-9.7	0.33	33.1	0.75
Southeast	CSN	Winter	515	0.80	0.80	0.00	0.0	0.40	35.4	0.49
		Spring	505	0.99	0.91	-0.07	-7.5	0.41	29.7	0.61
		Summer	524	0.99	0.88	-0.11	-11.4	0.54	34.3	0.47
		Fall	471	0.90	0.84	-0.05	-6.1	0.34	28.7	0.66
		Annual	2015	0.92	0.86	-0.06	-6.6	0.43	32.0	0.55
	IMPROVE	Winter	361	0.80	0.69	-0.11	-13.6	0.34	33.7	0.60
		Spring	376	1.09	0.84	-0.25	-22.6	0.45	30.8	0.68
		Summer	385	1.19	0.77	-0.42	-35.4	0.60	39.5	0.68
		Fall	358	0.91	0.72	-0.20	-21.4	0.39	33.0	0.73
		Annual	1480	1.00	0.76	-0.25	-24.5	0.46	34.5	0.67
Ohio Valley	CSN	Winter	531	1.23	1.11	-0.13	-10.2	0.73	38.8	0.43
		Spring	549	1.18	1.18	0.00	0.0	0.56	33.8	0.55
		Summer	576	1.37	1.18	-0.19	-13.5	0.70	32.1	0.52
		Fall	530	1.09	1.02	-0.07	-6.5	0.50	31.2	0.71
		Annual	2186	1.22	1.12	-0.10	-7.9	0.63	34.0	0.55
	IMPROVE	Winter	197	0.93	0.78	-0.16	-16.6	0.45	33.7	0.69
		Spring	210	1.18	0.99	-0.19	-15.8	0.44	27.1	0.74
		Summer	208	1.37	0.95	-0.41	-30.3	0.66	37.9	0.61
		Fall	207	0.98	0.83	-0.15	-15.1	0.48	36.3	0.71
		Annual	822	1.12	0.89	-0.23	-20.3	0.51	33.8	0.69
Upper Midwest	CSN	Winter	310	1.00	1.06	0.06	5.6	0.51	33.7	0.69
		Spring	305	0.86	1.01	0.15	17.6	0.42	37.6	0.69
		Summer	315	0.93	0.94	0.01	1.0	0.73	39.3	0.55
		Fall	311	0.69	0.89	0.21	30.1	0.42	47.6	0.77
		Annual	1241	0.87	0.98	0.11	12.1	0.54	38.9	0.65
	IMPROVE	Winter	202	0.76	0.84	0.08	10.6	0.49	36.1	0.61
		Spring	210	0.78	0.82	0.04	5.0	0.35	31.9	0.67
		Summer	207	0.68	0.54	-0.14	-20.5	0.32	32.3	0.84
		Fall	207	0.47	0.59	0.12	25.3	0.30	49.2	0.80
		Annual	826	0.67	0.70	0.02	3.7	0.37	36.2	0.69
South	CSN	Winter	325	1.08	1.15	0.06	5.8	0.71	40.6	0.61
		Spring	338	1.40	1.13	-0.27	-19.2	0.71	32.4	0.74
		Summer	353	1.51	1.14	-0.37	-24.6	0.80	36.0	0.57
		Fall	315	0.99	1.05	0.06	6.0	0.68	43.2	0.59
		Annual	1331	1.25	1.12	-0.14	-10.9	0.73	37.3	0.60
	IMPROVE	Winter	222	0.74	0.80	0.06	7.9	0.45	41.4	0.64
		Spring	228	1.17	0.87	-0.30	-25.3	0.60	33.6	0.62
		Summer	213	1.33	0.81	-0.52	-39.2	0.71	41.9	0.69
		Fall	230	0.89	0.76	-0.13	-14.6	0.50	37.8	0.71
		Annual	893	1.03	0.81	-0.22	-21.3	0.57	38.5	0.63
Southwest	CSN	Winter	213	0.44	0.39	-0.04	-10.2	0.36	50.7	0.37
		Spring	207	0.43	0.44	0.01	2.7	0.19	32.4	0.48
		Summer	210	0.64	0.32	-0.33	-50.9	0.45	53.2	0.21
		Fall	207	0.46	0.39	-0.06	-13.9	0.20	34.0	0.42

Region	Network	Season	N	Avg. Obs. (μg m⁻³)	Avg. Mod. (μg m⁻³)	MB (μg m⁻³)	NMB (%)	RMSE (μg m⁻³)	NME (%)	*r*
		Annual	837	0.49	0.38	-0.11	-21.6	0.32	43.7	0.24
	IMPROVE	Winter	833	0.23	0.24	0.01	5.1	0.17	43.6	0.62
		Spring	876	0.43	0.36	-0.07	-17.2	0.22	32.4	0.57
		Summer	841	0.65	0.25	-0.40	-62.2	0.49	63.1	0.56
		Fall	851	0.38	0.27	-0.11	-29.1	0.23	41.5	0.73
		Annual	3401	0.42	0.28	-0.14	-34.1	0.30	47.6	0.53
N. Rockies & Plains	CSN	Winter	160	0.53	0.71	0.19	35.2	0.52	59.9	0.61
		Spring	158	0.75	0.82	0.07	9.1	0.46	40.4	0.74
		Summer	164	0.58	0.62	0.04	6.6	0.40	42.8	0.63
		Fall	161	0.53	0.67	0.14	26.5	0.42	52.1	0.66
		Annual	643	0.60	0.70	0.11	18.1	0.45	47.9	0.67
	IMPROVE	Winter	520	0.29	0.32	0.03	10.1	0.25	47.3	0.82
		Spring	576	0.53	0.52	-0.01	-1.8	0.35	35.9	0.75
		Summer	595	0.46	0.32	-0.14	-30.9	0.24	37.8	0.74
		Fall	584	0.37	0.38	0.01	2.1	0.27	39.4	0.68
		Annual	2275	0.42	0.39	-0.03	-7.5	0.28	39.1	0.74
Northwest	CSN	Winter	144	0.28	0.52	0.24	83.9	0.41	106.8	0.23
		Spring	133	0.41	0.60	0.19	45.3	0.27	53.0	0.73
		Summer	144	0.61	0.71	0.09	15.1	0.69	59.5	0.18
		Fall	165	0.54	0.61	0.07	12.6	0.29	38.8	0.56
		Annual	586	0.47	0.61	0.14	30.6	0.44	58.4	0.36
	IMPROVE	Winter	437	0.13	0.24	0.11	84.5	0.19	104.0	0.43
		Spring	476	0.30	0.38	0.08	28.4	0.19	51.5	0.70
		Summer	475	0.42	0.45	0.03	6.6	0.32	50.8	0.41
		Fall	446	0.26	0.33	0.07	26.2	0.21	52.4	0.51
		Annual	1834	0.28	0.35	0.07	25.7	0.23	57.3	0.57
West	CSN	Winter	270	0.58	0.50	-0.08	-13.4	0.60	58.4	0.31
		Spring	270	0.78	0.62	-0.16	-20.8	0.52	43.7	0.61
		Summer	270	1.31	0.68	-0.63	-48.4	0.97	54.5	0.30
		Fall	266	0.92	0.61	-0.31	-33.5	0.60	44.5	0.61
		Annual	1076	0.90	0.60	-0.30	-32.9	0.69	50.2	0.48
	IMPROVE	Winter	542	0.25	0.26	0.01	5.1	0.29	61.4	0.50
		Spring	553	0.52	0.40	-0.12	-22.9	0.36	45.4	0.55
		Summer	565	0.85	0.45	-0.40	-47.0	0.63	54.4	0.26
		Fall	562	0.46	0.33	-0.12	-26.6	0.30	43.0	0.59
		Annual	2222	0.52	0.36	-0.16	-30.5	0.42	50.5	0.51

Table 2A-4 CMAQ Performance Statistics for $PM_{2.5}$ Nitrate at CSN and IMPROVE Sites in 2018

Region	Network	Season	N	Avg. Obs. ($\mu g\ m^{-3}$)	Avg. Mod. ($\mu g\ m^{-3}$)	MB ($\mu g\ m^{-3}$)	NMB (%)	RMSE ($\mu g\ m^{-3}$)	NME (%)	*r*
Northeast	CSN	Winter	717	1.81	2.11	0.30	16.4	1.23	48.2	0.70
		Spring	741	0.89	0.92	0.03	3.5	0.69	51.5	0.71
		Summer	765	0.35	0.24	-0.10	-30.0	0.42	65.6	0.49
		Fall	719	0.62	0.79	0.17	27.5	0.71	66.6	0.74
		Annual	2942	0.91	1.00	0.09	10.5	0.81	53.8	0.77
	IMPROVE	Winter	365	0.66	1.19	0.53	81.3	0.91	102.6	0.62
		Spring	371	0.29	0.33	0.05	16.2	0.31	66.3	0.62
		Summer	381	0.15	0.15	-0.00	-1.2	0.15	66.0	0.55
		Fall	376	0.21	0.34	0.13	61.1	0.42	98.3	0.58
		Annual	1493	0.32	0.50	0.17	53.8	0.53	89.5	0.70
Southeast	CSN	Winter	515	0.79	1.36	0.57	71.9	1.42	99.6	0.62
		Spring	505	0.43	0.34	-0.08	-19.8	0.34	51.4	0.60
		Summer	525	0.21	0.21	0.01	2.6	0.27	76.5	0.33
		Fall	474	0.39	0.64	0.26	66.5	0.79	98.3	0.65
		Annual	2019	0.45	0.64	0.19	41.0	0.84	85.3	0.66
	IMPROVE	Winter	361	0.55	0.75	0.20	35.7	0.85	85.9	0.48
		Spring	376	0.41	0.30	-0.11	-26.5	0.35	56.2	0.61
		Summer	385	0.18	0.19	0.01	7.3	0.19	70.9	0.52
		Fall	358	0.26	0.38	0.12	48.2	0.46	84.9	0.65
		Annual	1480	0.35	0.40	0.05	15.5	0.52	74.8	0.56
Ohio Valley	CSN	Winter	531	3.01	2.61	-0.40	-13.2	2.01	41.1	0.72
		Spring	549	1.34	1.20	-0.14	-10.6	0.85	42.3	0.73
		Summer	576	0.40	0.27	-0.13	-31.7	0.42	67.8	0.34
		Fall	530	1.10	1.18	0.09	8.0	0.91	47.9	0.82
		Annual	2186	1.44	1.29	-0.14	-10.0	1.19	44.6	0.80
	IMPROVE	Winter	197	1.51	1.31	-0.21	-13.6	1.29	53.4	0.67
		Spring	210	0.81	0.60	-0.21	-26.0	0.67	51.1	0.65
		Summer	208	0.20	0.18	-0.02	-9.6	0.18	59.9	0.58
		Fall	207	0.57	0.59	0.02	3.9	0.66	62.1	0.73
		Annual	822	0.76	0.66	-0.10	-13.4	0.79	54.8	0.73
Upper Midwest	CSN	Winter	310	3.08	2.92	-0.16	-5.3	1.54	34.1	0.81
		Spring	305	1.44	1.17	-0.27	-18.6	1.06	43.6	0.76
		Summer	315	0.36	0.22	-0.14	-39.6	0.34	64.1	0.48
		Fall	311	0.89	1.00	0.11	12.6	0.77	50.7	0.79
		Annual	1241	1.44	1.32	-0.11	-7.9	1.02	40.9	0.85
	IMPROVE	Winter	202	2.06	1.73	-0.33	-16.2	1.40	43.6	0.77
		Spring	210	0.80	0.52	-0.29	-35.7	0.75	53.3	0.74
		Summer	207	0.14	0.11	-0.02	-17.8	0.14	61.3	0.58
		Fall	207	0.41	0.55	0.14	34.5	0.50	64.6	0.83
		Annual	826	0.84	0.72	-0.13	-14.9	0.83	49.2	0.82
South	CSN	Winter	325	1.24	1.24	-0.00	-0.1	1.05	56.2	0.67
		Spring	338	0.62	0.34	-0.28	-44.6	0.66	60.4	0.63
		Summer	353	0.30	0.26	-0.04	-12.4	0.39	79.0	0.24
		Fall	315	0.44	0.69	0.25	55.3	1.09	102.5	0.72
		Annual	1331	0.65	0.62	-0.02	-3.4	0.84	67.6	0.64
	IMPROVE	Winter	222	0.97	0.84	-0.12	-12.8	0.81	53.3	0.69
		Spring	228	0.63	0.32	-0.31	-49.3	0.66	57.5	0.69
		Summer	213	0.25	0.14	-0.11	-45.6	0.22	66.1	0.44
		Fall	230	0.31	0.38	0.07	22.1	0.45	79.6	0.68
		Annual	893	0.54	0.42	-0.12	-22.2	0.58	59.8	0.68
Southwest	CSN	Winter	213	2.19	0.94	-1.25	-57.2	2.69	66.2	0.49
		Spring	207	0.58	0.24	-0.33	-58.0	0.63	71.4	0.49
		Summer	209	0.31	0.20	-0.11	-35.7	0.46	99.3	-0.14
		Fall	207	0.86	0.52	-0.34	-39.9	1.34	75.2	0.38

Region	Network	Season	N	Avg. Obs. (μg m^{-3})	Avg. Mod. (μg m^{-3})	MB (μg m^{-3})	NMB (%)	RMSE (μg m^{-3})	NME (%)	*r*
		Annual	836	0.99	0.48	-0.51	-51.9	1.56	71.5	0.54
	IMPROVE	Winter	833	0.28	0.12	-0.16	-55.6	0.52	75.3	0.50
		Spring	876	0.20	0.06	-0.14	-70.1	0.20	76.9	0.29
		Summer	841	0.18	0.03	-0.15	-82.9	0.20	83.4	0.44
		Fall	851	0.15	0.08	-0.08	-50.4	0.26	77.6	0.51
		Annual	3401	0.20	0.07	-0.13	-64.3	0.32	77.9	0.48
N. Rockies & Plains	CSN	Winter	160	1.51	1.18	-0.33	-22.0	1.38	50.9	0.66
		Spring	158	1.28	0.65	-0.63	-49.3	1.15	54.4	0.75
		Summer	164	0.25	0.14	-0.11	-44.3	0.23	68.3	0.48
		Fall	161	0.57	0.67	0.10	18.5	0.57	62.8	0.82
		Annual	643	0.90	0.66	-0.24	-26.7	0.95	55.2	0.71
	IMPROVE	Winter	520	0.39	0.34	-0.05	-13.9	0.65	75.4	0.53
		Spring	576	0.48	0.19	-0.30	-61.2	0.75	72.9	0.49
		Summer	595	0.14	0.03	-0.11	-78.3	0.18	80.6	0.50
		Fall	584	0.20	0.21	0.01	3.2	0.35	89.4	0.50
		Annual	2275	0.30	0.19	-0.11	-37.9	0.53	77.4	0.50
Northwest	CSN	Winter	144	0.93	1.04	0.11	11.8	1.48	88.6	0.26
		Spring	133	0.43	0.53	0.10	23.9	0.57	79.3	0.62
		Summer	144	0.36	0.27	-0.08	-23.5	0.46	89.5	0.17
		Fall	165	0.96	1.18	0.21	21.9	1.36	82.0	0.50
		Annual	586	0.69	0.78	0.09	13.0	1.09	84.8	0.44
	IMPROVE	Winter	437	0.20	0.25	0.05	24.9	0.47	109.4	0.41
		Spring	476	0.14	0.11	-0.03	-23.9	0.22	74.3	0.53
		Summer	475	0.19	0.07	-0.12	-63.4	0.25	75.0	0.38
		Fall	446	0.22	0.19	-0.03	-12.3	0.51	95.0	0.40
		Annual	1834	0.19	0.15	-0.03	-18.4	0.38	89.3	0.40
West	CSN	Winter	270	3.82	1.54	-2.28	-59.6	4.85	68.1	0.62
		Spring	270	1.52	0.59	-0.93	-61.3	1.95	66.9	0.64
		Summer	270	1.14	0.50	-0.64	-56.2	1.25	60.3	0.61
		Fall	266	2.47	0.90	-1.57	-63.7	3.62	70.1	0.59
		Annual	1076	2.24	0.88	-1.35	-60.6	3.24	67.4	0.64
	IMPROVE	Winter	542	0.71	0.44	-0.27	-38.5	1.48	59.0	0.88
		Spring	553	0.40	0.23	-0.17	-41.8	0.38	56.6	0.73
		Summer	565	0.47	0.22	-0.25	-54.1	0.58	66.1	0.41
		Fall	562	0.54	0.27	-0.27	-50.0	1.15	70.7	0.70
		Annual	2222	0.53	0.29	-0.24	-45.6	0.99	63.2	0.81

Table 2A-5 CMAQ Performance Statistics for $PM_{2.5}$ EC at CSN and IMPROVE Sites in 2018

Region	Network	Season	N	Avg. Obs. (μg m^{-3})	Avg. Mod. (μg m^{-3})	MB (μg m^{-3})	NMB (%)	RMSE (μg m^{-3})	NME (%)	*r*
Northeast	CSN	Winter	725	0.68	0.62	-0.06	-9.2	0.48	44.0	0.54
		Spring	726	0.58	0.44	-0.14	-23.7	0.66	48.4	0.35
		Summer	723	0.66	0.43	-0.24	-35.6	0.43	46.0	0.60
		Fall	719	0.64	0.53	-0.10	-16.2	0.45	45.6	0.59
		Annual	2893	0.64	0.51	-0.13	-21.1	0.51	45.9	0.48
	IMPROVE	Winter	393	0.24	0.26	0.02	10.4	0.13	37.4	0.81
		Spring	399	0.18	0.14	-0.04	-22.4	0.13	42.4	0.69
		Summer	422	0.25	0.13	-0.12	-48.1	0.19	50.6	0.82
		Fall	395	0.19	0.16	-0.02	-11.2	0.10	35.1	0.84
		Annual	1609	0.22	0.17	-0.04	-19.2	0.14	42.0	0.74
Southeast	CSN	Winter	409	0.57	0.48	-0.10	-16.6	0.30	34.4	0.76
		Spring	423	0.52	0.35	-0.17	-32.7	0.35	43.1	0.67
		Summer	471	0.47	0.35	-0.12	-25.1	0.32	46.6	0.45
		Fall	410	0.64	0.44	-0.20	-31.0	0.43	40.4	0.69
		Annual	1713	0.55	0.40	-0.14	-26.4	0.35	41.0	0.66
	IMPROVE	Winter	386	0.30	0.24	-0.06	-20.0	0.18	37.8	0.83
		Spring	406	0.33	0.19	-0.14	-43.3	0.27	48.5	0.78
		Summer	417	0.29	0.15	-0.15	-50.0	0.24	53.7	0.83
		Fall	386	0.33	0.20	-0.13	-39.8	0.32	45.9	0.84
		Annual	1595	0.31	0.19	-0.12	-38.7	0.26	46.6	0.80
Ohio Valley	CSN	Winter	537	0.57	0.50	-0.07	-12.9	0.30	34.7	0.58
		Spring	544	0.59	0.40	-0.19	-31.8	0.36	42.1	0.54
		Summer	549	0.67	0.36	-0.30	-45.6	0.45	48.3	0.41
		Fall	537	0.63	0.44	-0.18	-29.3	0.41	39.8	0.49
		Annual	2167	0.62	0.43	-0.19	-30.6	0.38	41.5	0.47
	IMPROVE	Winter	192	0.24	0.20	-0.05	-18.8	0.11	33.2	0.72
		Spring	209	0.28	0.16	-0.11	-41.2	0.16	46.9	0.66
		Summer	213	0.29	0.12	-0.17	-58.7	0.21	60.3	0.57
		Fall	208	0.24	0.18	-0.06	-26.5	0.13	40.0	0.63
		Annual	822	0.26	0.16	-0.10	-37.9	0.16	46.1	0.57
Upper Midwest	CSN	Winter	308	0.45	0.51	0.06	14.3	0.36	49.7	0.52
		Spring	303	0.43	0.38	-0.04	-9.9	0.32	46.6	0.55
		Summer	327	0.53	0.31	-0.22	-41.7	0.43	52.6	0.47
		Fall	304	0.45	0.34	-0.11	-25.0	0.34	43.4	0.49
		Annual	1242	0.47	0.38	-0.08	-17.2	0.37	48.4	0.46
	IMPROVE	Winter	231	0.21	0.24	0.03	12.5	0.15	39.9	0.72
		Spring	236	0.22	0.18	-0.04	-18.9	0.15	47.2	0.69
		Summer	242	0.30	0.14	-0.16	-53.6	0.41	68.6	0.52
		Fall	227	0.19	0.14	-0.05	-26.2	0.18	46.4	0.65
		Annual	936	0.23	0.17	-0.06	-25.0	0.25	52.6	0.53
South	CSN	Winter	303	0.55	0.48	-0.07	-12.9	0.36	38.7	0.58
		Spring	297	0.51	0.36	-0.15	-29.2	0.28	37.1	0.69
		Summer	316	0.39	0.32	-0.07	-18.9	0.25	46.6	0.53
		Fall	313	0.57	0.46	-0.10	-18.3	0.31	37.8	0.72
		Annual	1229	0.51	0.41	-0.10	-19.6	0.30	39.6	0.65
	IMPROVE	Winter	219	0.17	0.13	-0.04	-22.8	0.11	44.0	0.61
		Spring	228	0.26	0.15	-0.11	-42.5	0.18	51.3	0.70
		Summer	215	0.20	0.08	-0.11	-58.0	0.18	62.2	0.58
		Fall	230	0.18	0.12	-0.06	-33.7	0.11	43.5	0.75
		Annual	892	0.20	0.12	-0.08	-40.0	0.15	50.6	0.64
Southwest	CSN	Winter	214	1.27	0.71	-0.57	-44.5	2.35	59.5	0.39
		Spring	180	0.46	0.38	-0.08	-16.5	0.54	45.0	0.41
		Summer	200	0.51	0.34	-0.17	-32.7	0.31	43.8	0.49
		Fall	195	0.79	0.60	-0.19	-23.8	0.44	39.2	0.61

Region	Network	Season	N	Avg. Obs. (μg m^{-3})	Avg. Mod. (μg m^{-3})	MB (μg m^{-3})	NMB (%)	RMSE (μg m^{-3})	NME (%)	*r*
		Annual	789	0.77	0.51	-0.26	-33.5	1.28	49.8	0.42
	IMPROVE	Winter	819	0.16	0.10	-0.05	-34.2	0.20	46.4	0.87
		Spring	885	0.10	0.06	-0.03	-33.8	0.08	46.7	0.83
		Summer	838	0.16	0.08	-0.08	-50.0	0.15	59.3	0.64
		Fall	849	0.15	0.10	-0.05	-33.8	0.17	50.8	0.75
		Annual	3391	0.14	0.09	-0.05	-38.5	0.15	51.3	0.79
N. Rockies & Plains	CSN	Winter	140	0.39	0.23	-0.16	-40.2	0.61	73.4	-0.01
		Spring	139	0.28	0.16	-0.12	-42.4	0.26	53.3	0.45
		Summer	155	0.56	0.17	-0.39	-69.6	0.98	72.2	0.20
		Fall	140	0.41	0.23	-0.19	-45.0	0.43	57.8	0.21
		Annual	574	0.41	0.20	-0.22	-52.5	0.64	65.9	0.14
	IMPROVE	Winter	532	0.07	0.07	-0.00	-3.8	0.12	72.2	0.33
		Spring	570	0.11	0.06	-0.05	-48.5	0.12	56.5	0.52
		Summer	594	0.28	0.11	-0.17	-59.4	0.27	63.3	0.73
		Fall	582	0.17	0.14	-0.03	-16.4	0.24	61.6	0.51
		Annual	2278	0.16	0.10	-0.06	-40.0	0.20	62.6	0.56
Northwest	CSN	Winter	143	0.89	0.87	-0.02	-2.0	0.77	58.9	0.41
		Spring	135	0.51	0.56	0.05	10.6	0.36	49.1	0.63
		Summer	145	0.69	0.36	-0.33	-47.5	0.86	55.1	0.62
		Fall	158	1.14	0.86	-0.28	-24.3	0.70	43.1	0.62
		Annual	581	0.82	0.67	-0.15	-18.1	0.70	50.7	0.50
	IMPROVE	Winter	440	0.10	0.14	0.04	36.1	0.20	92.5	0.78
		Spring	473	0.11	0.09	-0.02	-18.8	0.14	64.3	0.70
		Summer	475	0.48	0.21	-0.27	-55.8	1.48	74.3	0.34
		Fall	457	0.31	0.26	-0.05	-15.3	0.49	66.5	0.71
		Annual	1845	0.25	0.17	-0.08	-30.8	0.80	72.6	0.39
West	CSN	Winter	265	1.24	0.82	-0.42	-33.7	0.76	43.6	0.55
		Spring	253	0.42	0.41	-0.01	-2.4	0.21	34.3	0.70
		Summer	273	0.55	0.50	-0.05	-8.9	0.38	37.9	0.65
		Fall	246	1.09	0.72	-0.38	-34.3	1.12	40.4	0.78
		Annual	1037	0.82	0.61	-0.21	-25.7	0.70	40.4	0.68
	IMPROVE	Winter	539	0.15	0.11	-0.03	-22.2	0.18	56.3	0.81
		Spring	555	0.11	0.07	-0.04	-37.4	0.09	53.7	0.70
		Summer	563	0.53	0.35	-0.17	-32.7	1.48	64.4	0.36
		Fall	555	0.32	0.24	-0.08	-23.8	1.03	70.1	0.37
		Annual	2212	0.28	0.20	-0.08	-29.3	0.91	63.9	0.39

Table 2A-6 CMAQ Performance Statistics for $PM_{2.5}$ OC at CSN and IMPROVE Sites in 2018

Region	Network	Season	N	Avg. Obs. ($\mu g\ m^{-3}$)	Avg. Mod. ($\mu g\ m^{-3}$)	MB ($\mu g\ m^{-3}$)	NMB (%)	RMSE ($\mu g\ m^{-3}$)	NME (%)	*r*
Northeast	CSN	Winter	725	1.57	3.35	1.78	113.7	2.55	119.2	0.60
		Spring	726	1.50	2.63	1.12	74.5	1.68	85.6	0.62
		Summer	723	2.37	2.70	0.34	14.2	1.39	37.4	0.72
		Fall	719	1.33	2.56	1.23	92.2	2.13	98.9	0.63
		Annual	2893	1.69	2.81	1.12	66.0	1.99	79.1	0.57
	IMPROVE	Winter	393	0.84	2.04	1.20	142.3	1.46	145.6	0.73
		Spring	399	0.77	1.45	0.69	89.5	1.02	104.1	0.60
		Summer	422	1.49	1.63	0.14	9.4	1.06	43.8	0.58
		Fall	395	0.77	1.26	0.50	65.0	0.87	77.4	0.74
		Annual	1609	0.97	1.59	0.62	63.8	1.12	83.5	0.57
Southeast	CSN	Winter	409	1.91	2.94	1.04	54.4	1.74	63.0	0.77
		Spring	423	2.00	2.75	0.75	37.6	1.49	50.6	0.77
		Summer	471	2.33	2.81	0.49	20.9	1.26	41.1	0.64
		Fall	410	1.89	2.88	0.98	51.9	1.59	59.5	0.78
		Annual	1713	2.04	2.84	0.80	39.3	1.52	52.4	0.73
	IMPROVE	Winter	386	1.19	1.82	0.63	52.6	1.29	65.7	0.81
		Spring	406	1.39	1.99	0.59	42.6	1.57	63.5	0.69
		Summer	417	1.54	1.76	0.23	14.9	0.91	40.3	0.70
		Fall	386	1.20	1.81	0.62	51.6	2.44	67.7	0.42
		Annual	1595	1.33	1.85	0.51	38.4	1.64	57.9	0.60
Ohio Valley	CSN	Winter	537	1.57	2.81	1.24	79.4	1.80	89.1	0.57
		Spring	544	1.74	2.66	0.92	53.0	1.73	66.3	0.69
		Summer	549	2.63	2.37	-0.26	-9.9	1.07	31.4	0.62
		Fall	537	1.52	2.20	0.68	45.1	1.37	61.8	0.60
		Annual	2167	1.87	2.51	0.64	34.5	1.52	57.7	0.53
	IMPROVE	Winter	192	0.92	1.68	0.76	82.7	1.44	93.7	0.59
		Spring	209	1.20	1.85	0.65	54.5	1.46	74.9	0.72
		Summer	213	1.64	1.72	0.07	4.5	0.89	40.1	0.57
		Fall	208	0.99	1.53	0.55	55.3	1.21	71.8	0.65
		Annual	822	1.19	1.69	0.50	42.0	1.27	65.2	0.58
Upper Midwest	CSN	Winter	308	1.33	3.22	1.89	141.6	2.66	144.9	0.53
		Spring	303	1.38	2.65	1.28	92.6	2.20	104.5	0.42
		Summer	327	2.77	2.60	-0.17	-6.1	5.44	47.4	0.45
		Fall	304	1.21	1.87	0.66	54.7	1.24	73.9	0.41
		Annual	1242	1.69	2.59	0.90	53.0	3.33	82.4	0.38
	IMPROVE	Winter	231	0.72	2.01	1.29	178.7	1.97	180.7	0.52
		Spring	236	0.86	2.00	1.14	133.1	1.81	143.8	0.49
		Summer	242	1.97	2.10	0.12	6.2	6.23	67.1	0.51
		Fall	227	0.65	1.02	0.37	56.7	0.79	82.2	0.50
		Annual	936	1.06	1.79	0.73	68.4	3.46	104.0	0.45
South	CSN	Winter	303	1.66	2.76	1.10	66.3	2.07	87.4	0.49
		Spring	297	2.03	2.74	0.71	35.2	1.60	55.1	0.67
		Summer	316	2.08	2.63	0.56	26.7	1.75	60.9	0.47
		Fall	313	1.60	2.58	0.98	61.2	2.07	77.6	0.74
		Annual	1229	1.84	2.68	0.84	45.4	1.88	68.9	0.56
	IMPROVE	Winter	219	0.66	1.27	0.61	92.9	1.05	100.0	0.64
		Spring	228	1.31	1.98	0.67	51.5	2.06	65.9	0.63
		Summer	215	1.39	1.43	0.04	2.8	1.07	52.4	0.51
		Fall	230	0.77	1.17	0.40	52.2	0.97	76.2	0.71
		Annual	892	1.03	1.46	0.43	42.2	1.37	68.8	0.57
Southwest	CSN	Winter	214	2.30	3.02	0.72	31.4	2.63	69.6	0.43
		Spring	180	1.18	1.74	0.56	47.1	1.07	63.6	0.50
		Summer	200	2.27	1.63	-0.64	-28.3	1.68	46.0	0.51
		Fall	195	1.61	2.51	0.90	56.3	1.75	73.7	0.44

Region	Network	Season	N	Avg. Obs. (μg m⁻³)	Avg. Mod. (μg m⁻³)	MB (μg m⁻³)	NMB (%)	RMSE (μg m⁻³)	NME (%)	*r*
		Annual	789	1.87	2.25	0.38	20.5	1.90	62.3	0.41
	IMPROVE	Winter	819	0.53	0.68	0.15	28.5	0.55	59.9	0.84
		Spring	885	0.46	0.72	0.26	56.0	0.43	70.9	0.71
		Summer	838	1.22	0.84	-0.38	-31.2	1.18	52.7	0.55
		Fall	849	0.60	0.80	0.20	32.5	1.93	69.5	0.33
		Annual	3391	0.70	0.76	0.06	8.4	1.18	60.8	0.43
N. Rockies & Plains	CSN	Winter	140	1.07	1.28	0.20	18.8	1.63	96.3	0.04
		Spring	139	0.98	1.19	0.20	20.7	0.86	60.3	0.62
		Summer	155	2.92	1.36	-1.57	-53.6	3.15	61.3	0.45
		Fall	140	1.12	1.23	0.11	10.2	1.13	62.4	0.26
		Annual	574	1.56	1.27	-0.30	-19.0	1.95	67.2	0.35
	IMPROVE	Winter	532	0.33	0.67	0.34	100.5	0.81	124.4	0.32
		Spring	570	0.57	0.75	0.18	30.8	0.88	67.5	0.40
		Summer	594	2.78	1.38	-1.40	-50.5	2.82	55.9	0.81
		Fall	582	1.12	1.18	0.06	5.8	1.75	68.4	0.44
		Annual	2278	1.23	1.01	-0.23	-18.4	1.79	64.5	0.64
Northwest	CSN	Winter	143	2.32	4.24	1.93	83.1	3.68	99.0	0.58
		Spring	135	1.53	2.94	1.41	92.1	2.08	96.8	0.76
		Summer	145	3.51	2.44	-1.07	-30.5	4.21	52.5	0.64
		Fall	158	2.90	4.46	1.56	53.7	3.07	73.0	0.57
		Annual	581	2.59	3.55	0.96	36.9	3.36	75.0	0.41
	IMPROVE	Winter	440	0.43	0.95	0.51	118.0	1.29	147.2	0.65
		Spring	473	0.54	0.85	0.30	55.9	0.81	79.8	0.57
		Summer	475	3.95	2.59	-1.37	-34.6	6.64	68.1	0.59
		Fall	457	1.93	2.55	0.63	32.5	6.44	91.6	0.69
		Annual	1845	1.74	1.74	0.00	0.2	4.71	80.2	0.57
West	CSN	Winter	265	3.61	4.32	0.72	19.8	2.96	48.9	0.48
		Spring	253	1.63	2.28	0.65	39.6	1.64	52.3	0.57
		Summer	273	3.44	3.37	-0.07	-2.0	3.28	42.9	0.63
		Fall	246	3.77	4.00	0.23	6.2	3.35	41.3	0.85
		Annual	1037	3.12	3.50	0.38	12.1	2.90	45.4	0.67
	IMPROVE	Winter	539	0.70	0.95	0.25	35.9	1.11	70.3	0.68
		Spring	555	0.67	0.79	0.12	17.8	0.47	49.6	0.68
		Summer	563	4.28	3.84	-0.44	-10.2	18.69	70.9	0.26
		Fall	555	2.26	2.08	-0.17	-7.6	8.93	73.7	0.26
		Annual	2212	1.99	1.93	-0.06	-3.2	10.45	69.8	0.24

2A.2 Projecting $PM_{2.5}$ DVs to 2032

$PM_{2.5}$ DVs were projected to 2032 using air quality modeling to inform estimates of the emission reductions needed to meet standards beyond the reductions expected to occur due to finalized rules. The projections were performed by pairing the 2018 CMAQ simulation with a corresponding CMAQ simulation based on emissions representative of 2032. The 2032 emissions case accounts for factors including emission reductions between 2018 and 2032 from 'on-the-books' rules and has been described in detail previously (USEPA, 2023a). Other than differences in the emissions inputs, all aspects of the 2032 CMAQ modeling were specified identical to the 2018 modeling. These aspects include the meteorology, boundary conditions, the 12-km modeling domain, and the model configuration.

To predict the influence of the emission reductions between 2018 and 2032 on $PM_{2.5}$ DVs, $PM_{2.5}$ relative response factors (RRFs) were calculated using the CMAQ results to project monitoring data to 2032. RRFs are the ratios of modeled $PM_{2.5}$ species concentrations in the future year (2032) to the base year (2018). RRFs are used in projecting air quality to help mitigate the influence of systematic biases in model predictions (e.g., systematic biases in the 2018 and 2032 modeling may partially cancel in the ratio) (Cohan and Chen, 2014; NRC, 2004; USEPA, 2018). RRFs are calculated for each $PM_{2.5}$ component (i.e., sulfate, nitrate, organic carbon, elemental carbon, crustal material, and ammonium). The annual and 24-hour $PM_{2.5}$ DVs for the future year are calculated by applying the species-specific RRFs to ambient $PM_{2.5}$ concentrations from the $PM_{2.5}$ monitoring network, which are disaggregated into species concentrations by applying the SANDWICH method (Frank, 2006) and through interpolation of $PM_{2.5}$ species data from the CSN and IMPROVE monitoring networks. Details on the $PM_{2.5}$ projection method using RRFs are provided in the user's guide for the predecessor to the SMAT-CE software (Abt, 2014). The RRF method for calculating future-year $PM_{2.5}$ annual and 24-hour $PM_{2.5}$ DVs was implemented here using the Software for Modeled Attainment Test-Community Edition (SMAT-CE) (USEPA, 2018; Wang et al., 2015).

2A.2.1 Monitoring Data for $PM_{2.5}$ Projections

$PM_{2.5}$ DVs were projected using ambient $PM_{2.5}$ measurements from the 2016-2020 period centered on the 2018 CMAQ modeling period. $PM_{2.5}$ species measurements from the IMPROVE and CSN networks during 2017–2019 were used to disaggregate the measured total $PM_{2.5}$ concentrations into components for the RRF calculations. As in the 2012 $PM_{2.5}$ NAAQS RIA (USEPA, 2012a), limited exclusion of wildfire and fireworks influence on $PM_{2.5}$ concentrations was applied to the 2016-2020 $PM_{2.5}$ monitoring data in addition to exclusion of EPA-concurred exceptional events. Monitoring data were evaluated (i.e., screened) for potential wildfire and fireworks influence because $PM_{2.5}$ concentrations may be influenced by atypical, extreme, or unrepresentative events such as wildfires or fireworks that may be appropriate for exclusion as described in EPA's memorandum *Additional Methods, Determinations, and Analyses to Modify Air Quality Data Beyond Exceptional Events* (USEPA, 2019a). Due to the challenges in identifying wildfire influence on monitored concentrations, only limited screening of extreme values is possible here, and wildfire impacts on concentrations likely persists in the screened data.

The steps in implementing the limited screening of major wildfire and fireworks influence on $PM_{2.5}$ concentrations are as follows:

1. An extreme value cutoff of 64 $\mu g\ m^{-3}$ was identified based the 99.9^{th} percentile value from all daily $PM_{2.5}$ concentrations across all sites in the long-term AQS observation record (2002-2020).
2. Specific months were screened for instances of monitors exceeding the extreme value cutoff. Months included were June-October (while November can be a high fire month for parts of the western U.S., it becomes more difficult to distinguish wildfire $PM_{2.5}$ from residential wood smoke and other anthropogenic sources during the late fall).
3. The presence of visible wildfire smoke was corroborated using satellite imagery from NASA's Worldview platform (https://worldview.earthdata.nasa.gov) for the time periods and geographic locations identified through steps 1 and 2. Timeseries for individual sites

flagged were also examined to confirm $PM_{2.5}$ enhancements temporally consistent with the wildfire events identified (Figures 2A-16 to 2A-25).

4. For extreme wildfire smoke periods identified through steps 1-3 above, all concentrations above the extreme value cutoff of 64 μg m^{-3} at impacted sites were removed.

5. In addition to the evaluation criteria above, data corresponding to the Creek Fire (eastern CA during September-November 2020), the Camp Fire (northern CA during November 2018), and the Appalachian Fires (NC, TN, GA during November 2016) were evaluated for exclusion if concentrations exceeded the extreme value threshold of 64 μg m^{-3}. These large fire episodes show obvious impacts across multiple monitors and were clearly documented with satellite imagery (Figures 2A-6 to and 2A-15).

6. In addition to the limited exclusion of major wildfire influence, data were evaluated to identify days for potential exclusion due to the influence of isolated fireworks events on $PM_{2.5}$ concentrations. The 99.9th percentile value of 64 μg m^{-3} was applied as the cutoff across all sites for New Year's Eve and the Fourth of July.

The list of counties that were evaluated for fire impacts for the November episodes are shown in Table 2A-7. Example satellite imagery and timeseries of $PM_{2.5}$ at impacted monitors for episodes are shown in Figures 2A-6 to 2A-15. The percentage of days excluded from the 2016-2020 dataset was 0.9% at affected sites; the total percentage of days excluded overall from the dataset was 0.09%.

Table 2A-7 November Wildfire Episodes and Counties Where Data Were Excluded if $PM_{2.5}$ Concentrations Exceeded the Extreme Value Threshold of 64 μg m^{-3}

Episode	Dates	Impacted County	State
Creek Fire	Nov. 1-10, 2020	Mono	CA
Camp Fire	Nov. 8-20, 2018	Alameda	CA
		Stanislaus	CA
		San Joaquin	CA
		Sonoma	CA
		Butte	CA
		Contra Costa	CA
		Colusa	CA
		Fresno	CA
		Mendocino	CA
		Sacramento	CA
		Napa	CA
		Solano	CA
		Placer	CA
		San Francisco	CA
		Marin	CA
		Yolo	CA
		Tehama	CA
		Lake	CA
		Santa Clara	CA
		Santa Cruz	CA
		Nevada	CA
		Kings	CA
		Merced	CA
		San Mateo	CA
		Madera	CA
		Monterey	CA
Appalachian Fires	Nov. 7-24, 2016	Hamilton	TN
		Knox	TN
		Loudon	TN
		Roane	TN
		Blount	TN
		Swain	NC
		Mitchell	NC
		Buncombe	NC
		Jackson	NC
		Walker	GA
		Clarke	GA
		Richmond	GA
		Hall	GA

Episode	Dates	Impacted County	State
		Greenville	SC
		Richland	SC
		Edgefield	SC
		Lexington	SC
		Charleston	SC

Figure 2A-6 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the Camp Fire on 11/10/2018

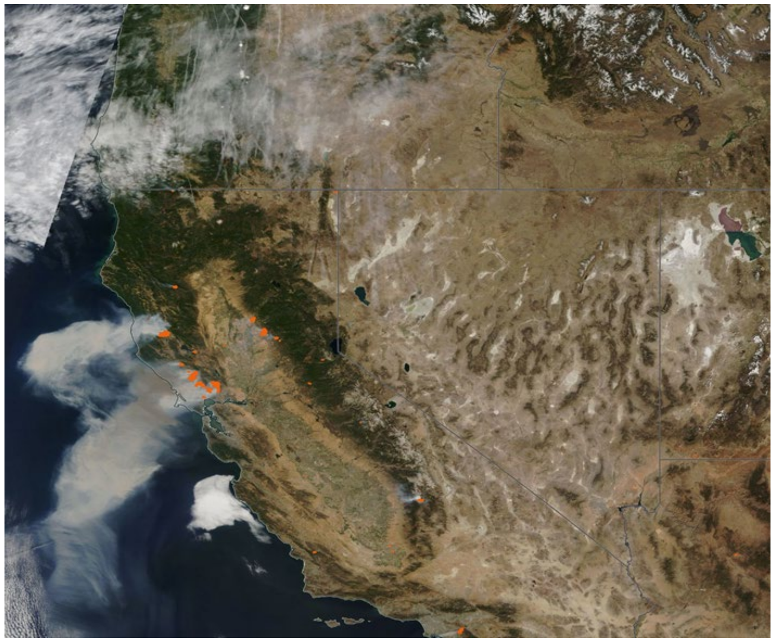

Figure 2A-7 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the North Bay/Wine Country Fires on 10/09/2017

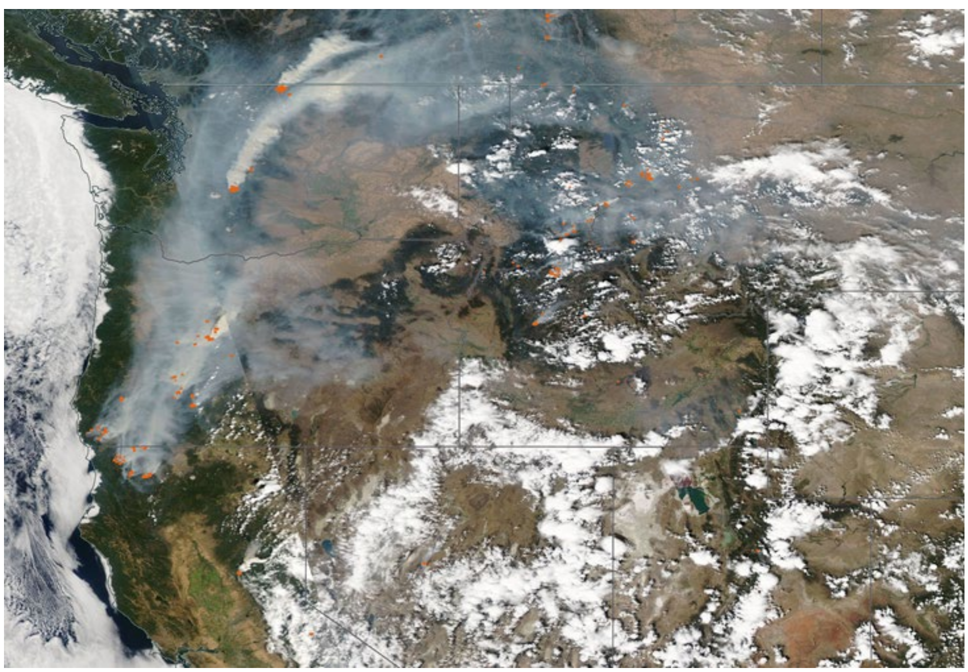

Figure 2A-8 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires Across the Pacific Northwest/Northern California on 08/29/2017

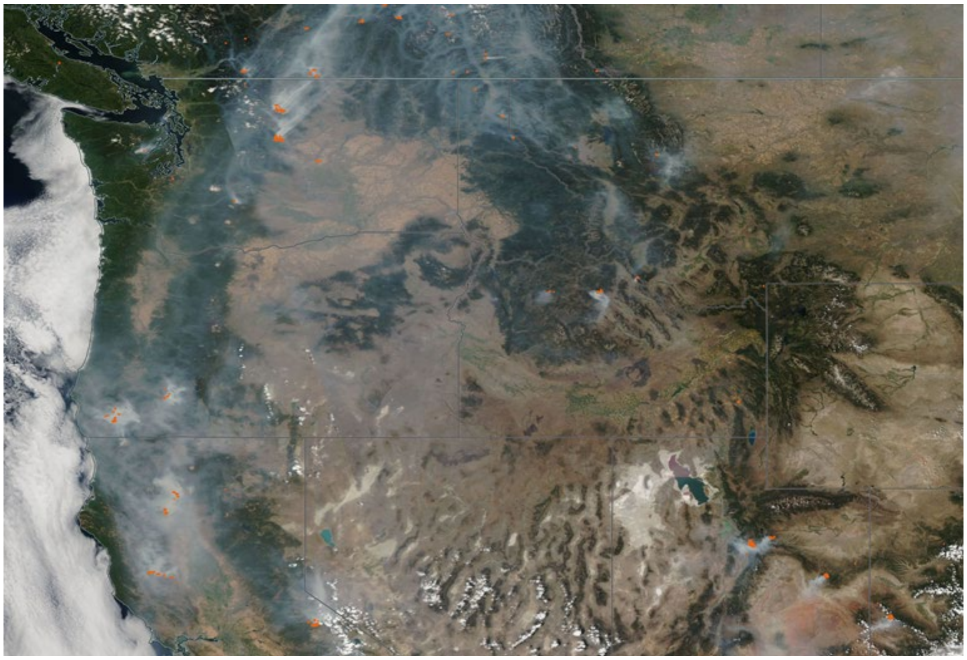

Figure 2A-9 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in Washington and Oregon on 08/09/2018

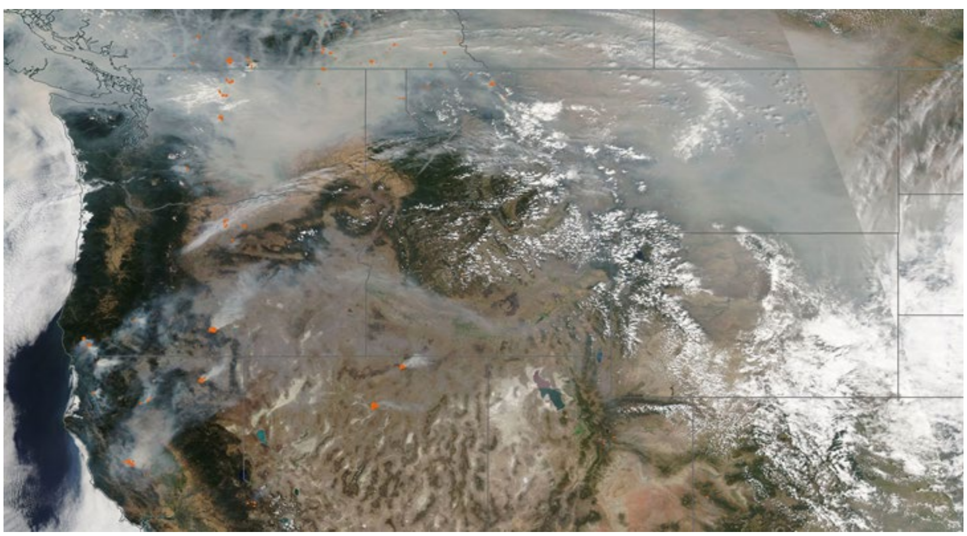

Figure 2A-10 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in Montana on 08/19/2018

Figure 2A-11 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Several Fires in eastern California including the Empire Fire on 9/1/2017

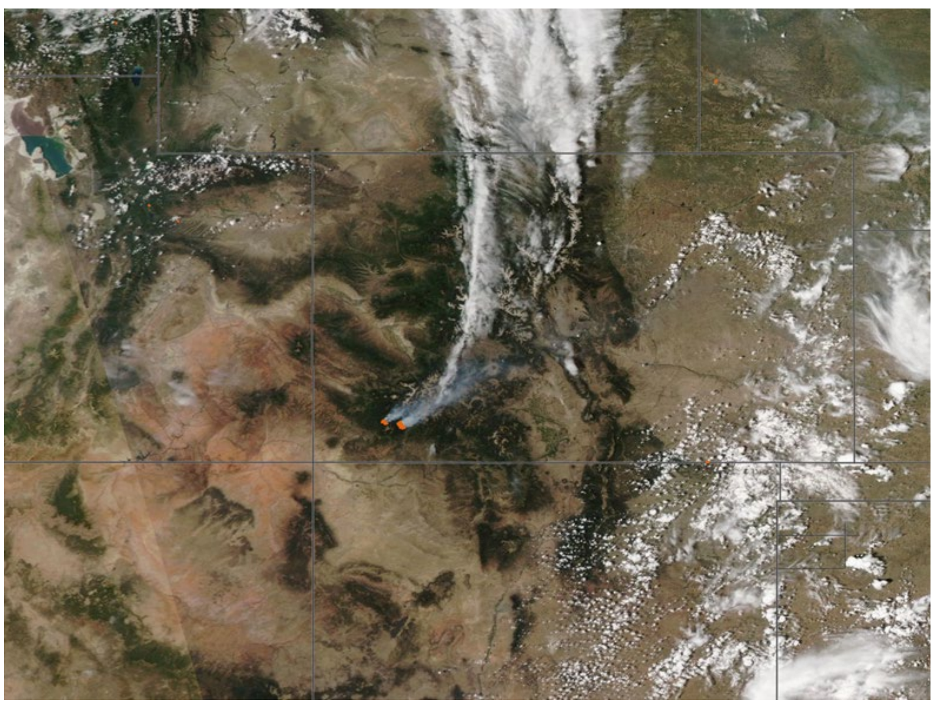

Figure 2A-12 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the 416/Burro Complex Fires on 06/10/2018

Figure 2A-13 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the Creek Fire on 10/26/2020

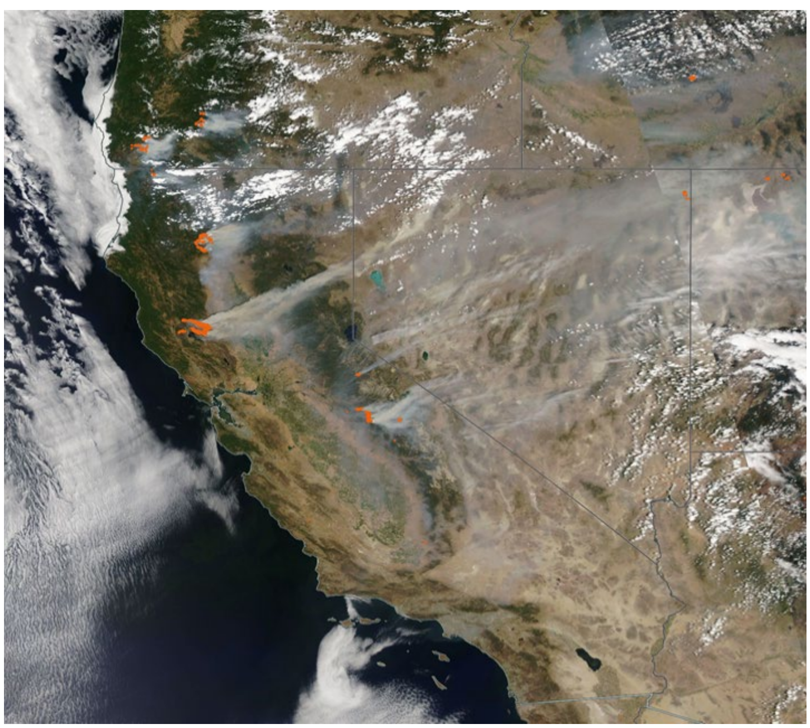

Figure 2A-14 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the Carr/Mendocino/Ferguson Fires on 08/04/2018

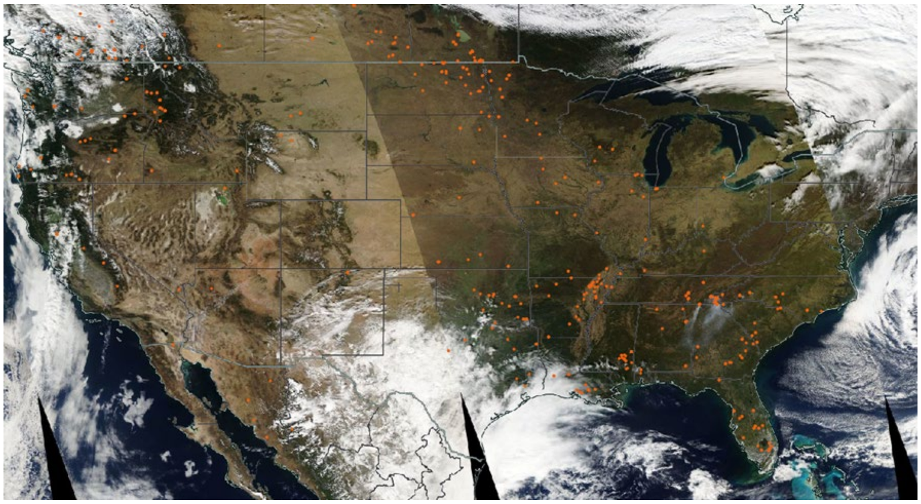

Figure 2A-15 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in the Appalachians on 11/10/2016

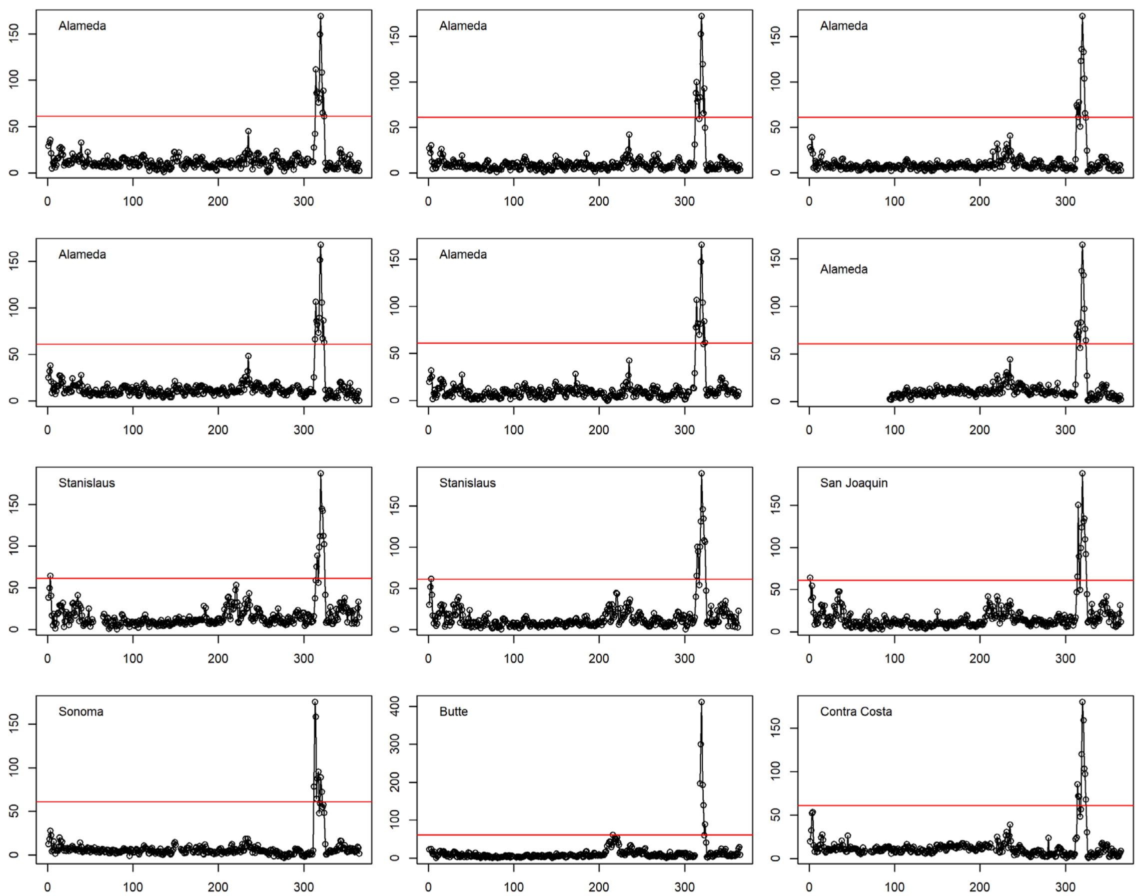

Figure 2A-16 Daily PM2.5 (in µg m^{-3}) from a Subset of Monitors Impacted by the Camp Fire in November 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

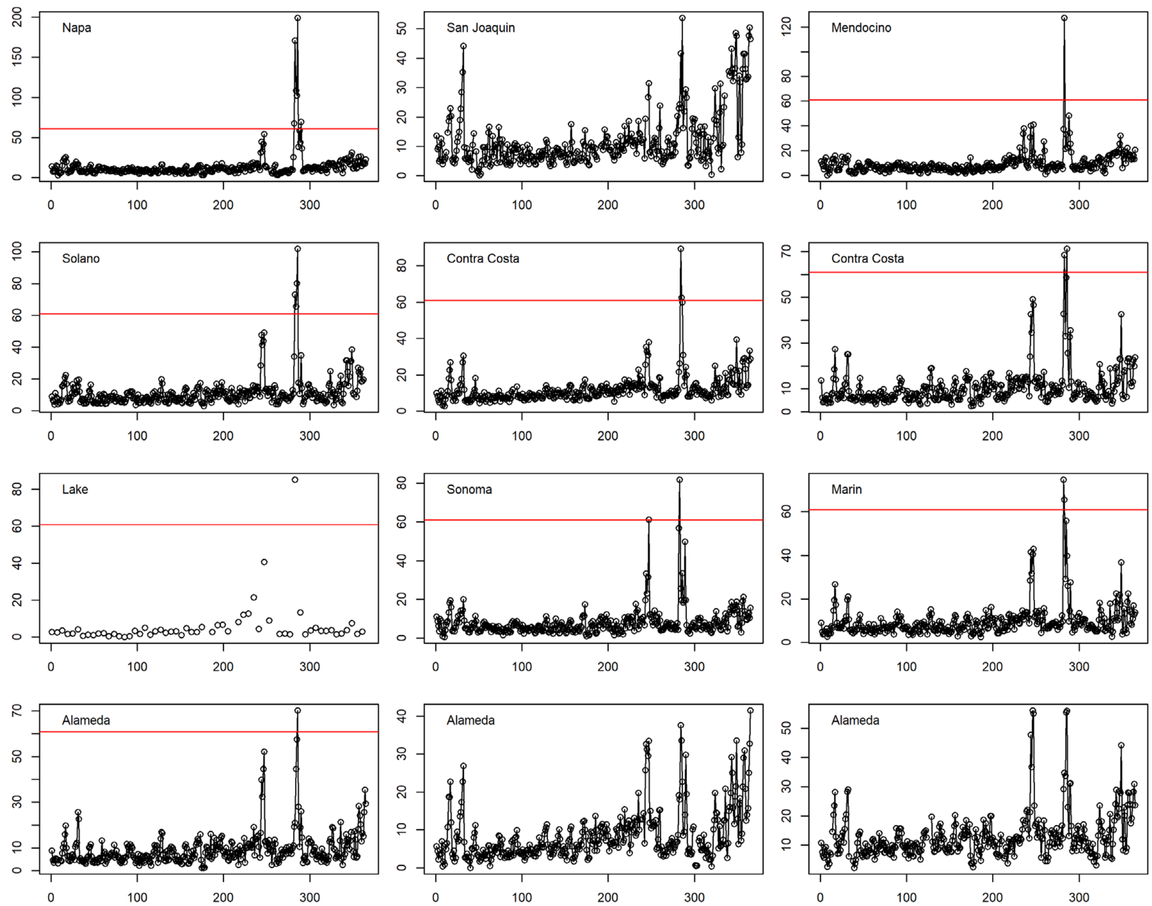

Figure 2A-17 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by the North Bay/Wine Country Fires in October 2017

Note: Bottom axis shows day in 2017. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

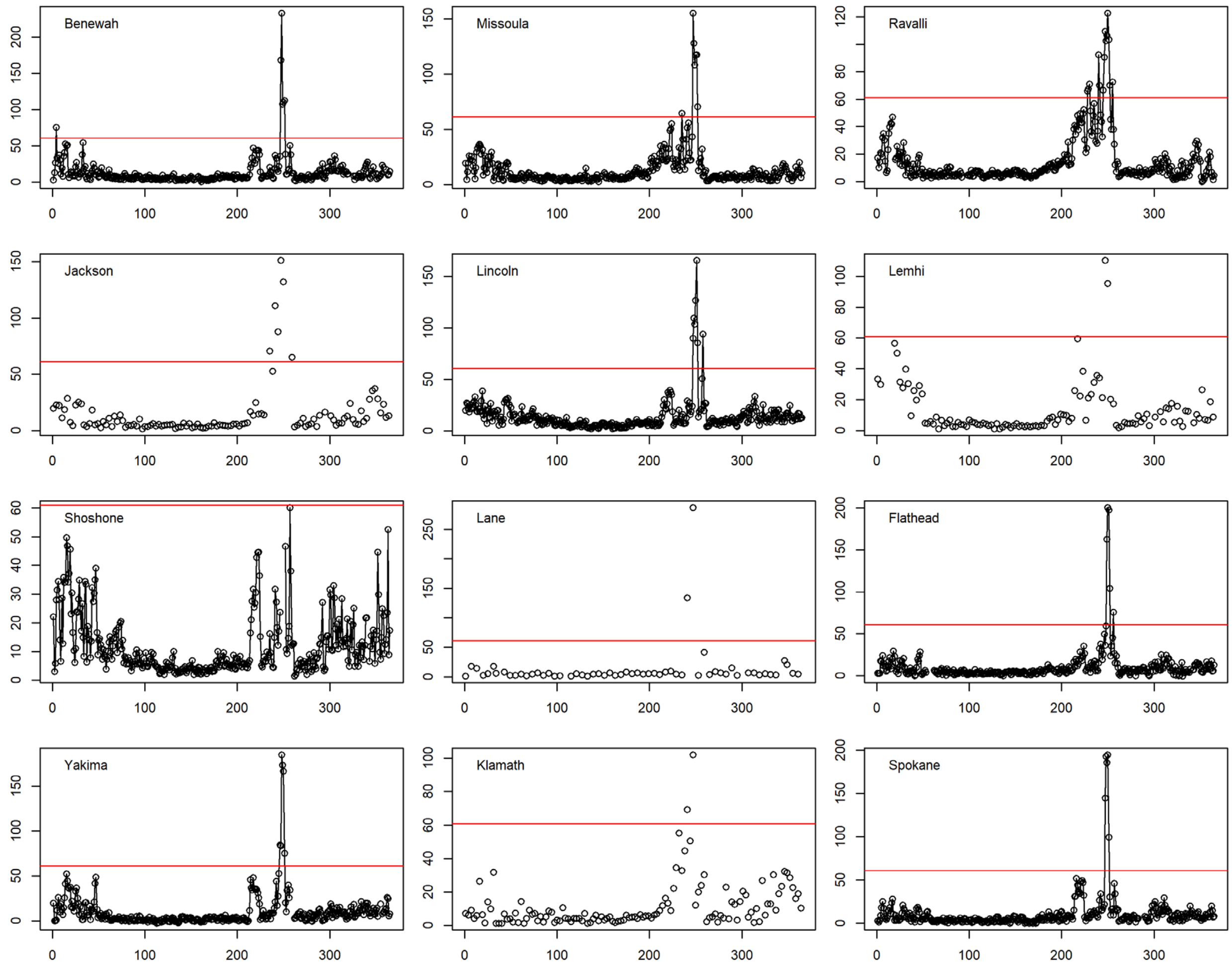

Figure 2A-18 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by Fires in the Pacific Northwest/Northern California in August-September 2017

Note: Bottom axis shows day in 2017. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

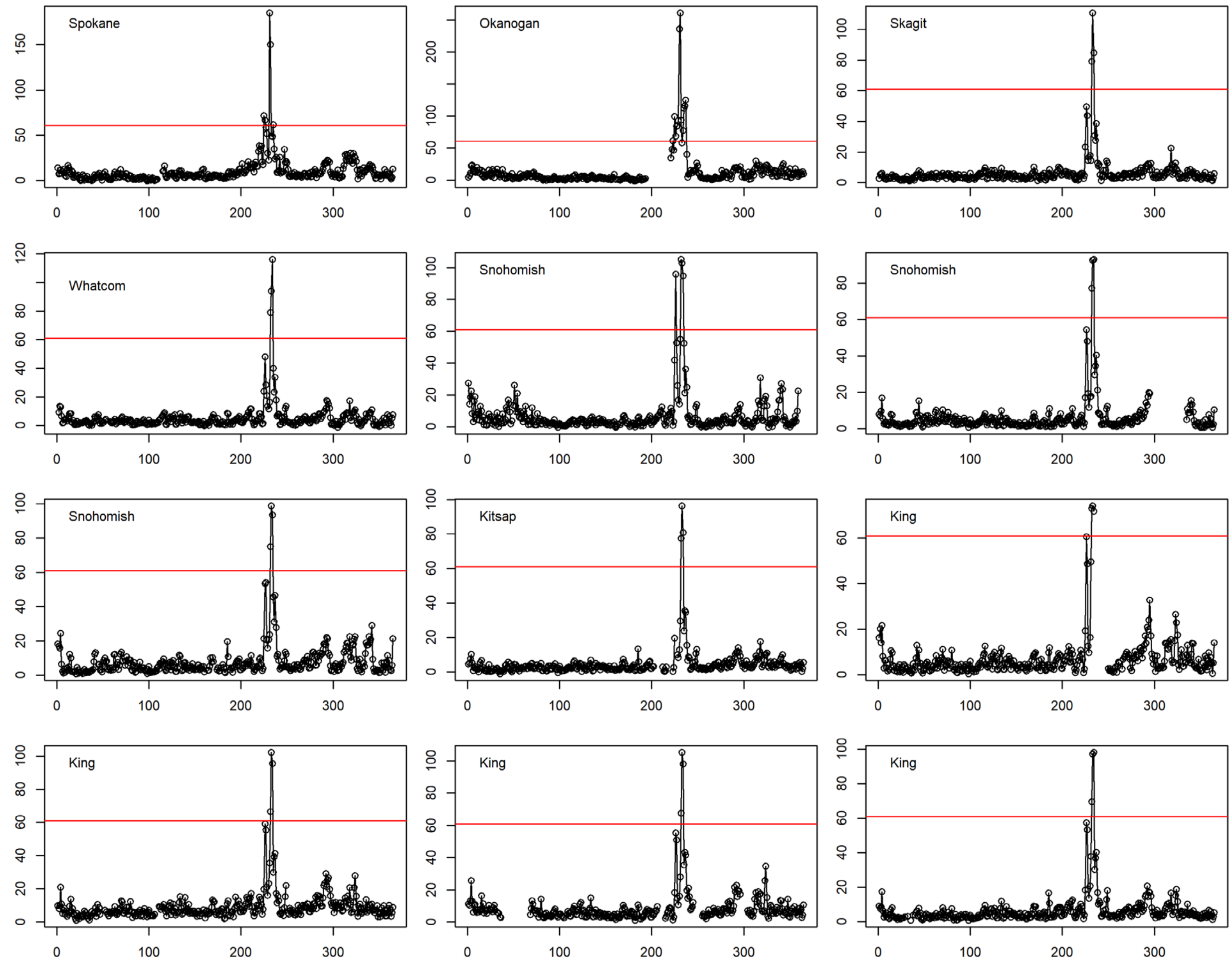

Figure 2A-19 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by Fires in Washington and Oregon in July-August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

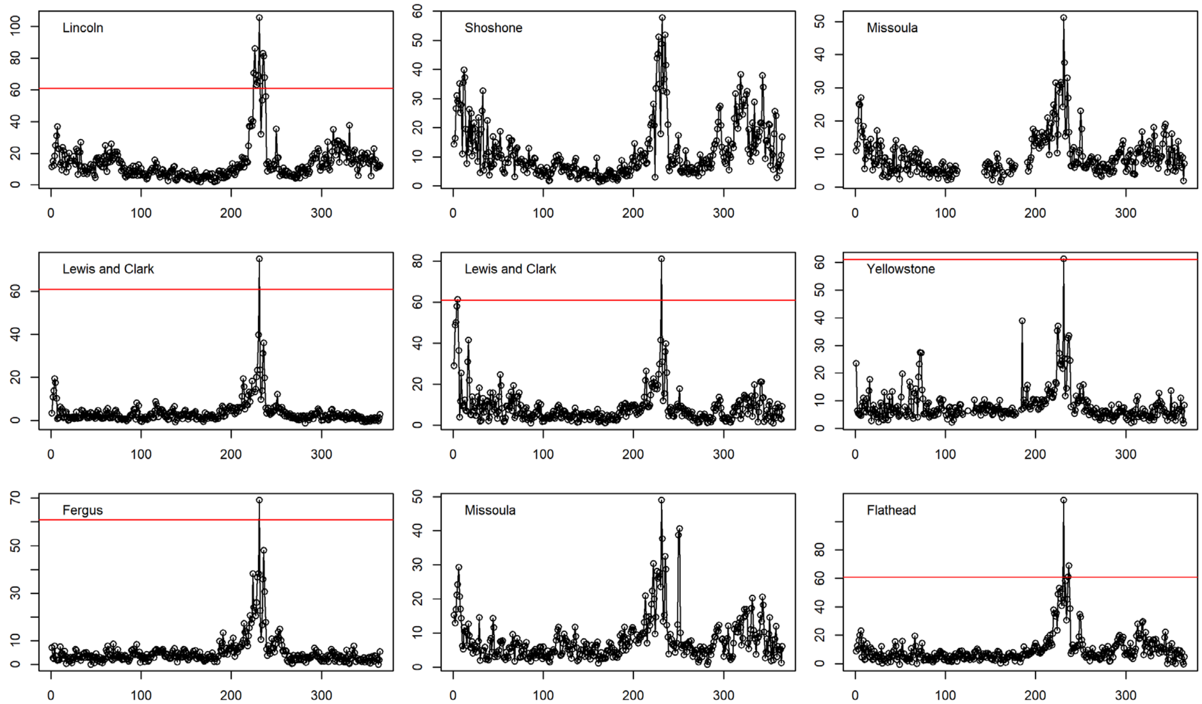

Figure 2A-20 Daily $PM_{2.5}$ (in µg m^{-3}) from the Monitors Impacted by Fires and Smoke in Montana in August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

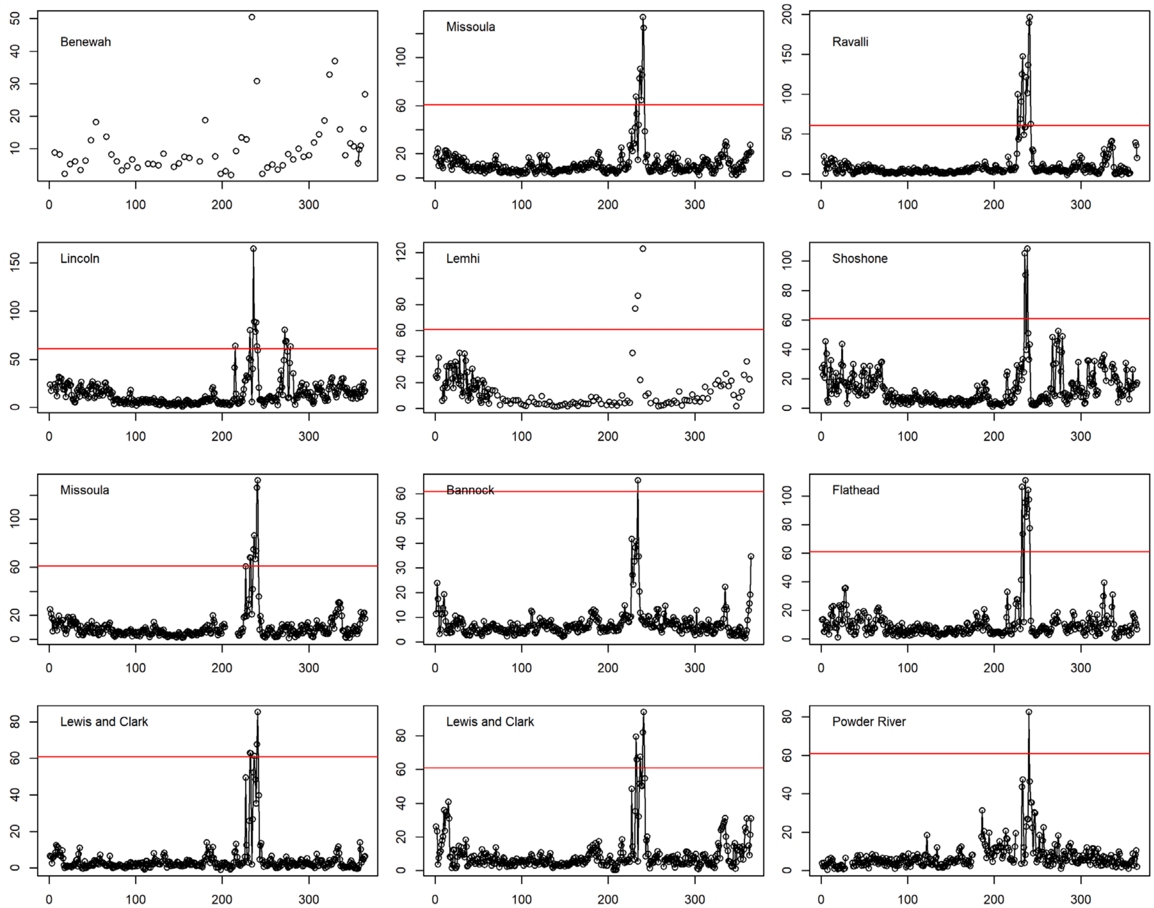

Figure 2A-21 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by Fires in Montana, Washington and Idaho in August 2015

Note: Bottom axis shows day in 2015. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

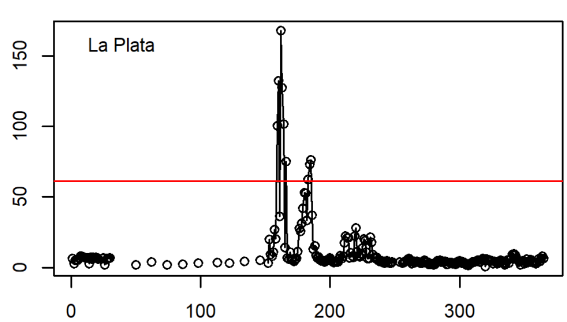

Figure 2A-22 Daily $PM_{2.5}$ (in µg m^{-3}) from the Monitor in Plata, CO Impacted by the 416/Burro Fire Complex in June 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

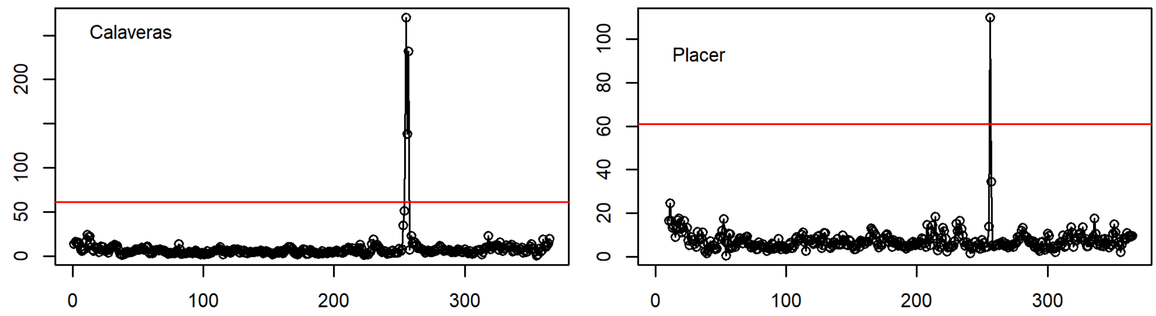

Figure 2A-23 Daily $PM_{2.5}$ (in µg m^{-3}) from the Two monitors Impacted by the Butte Fire in September 2015

Note: Bottom axis shows day in 2015. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

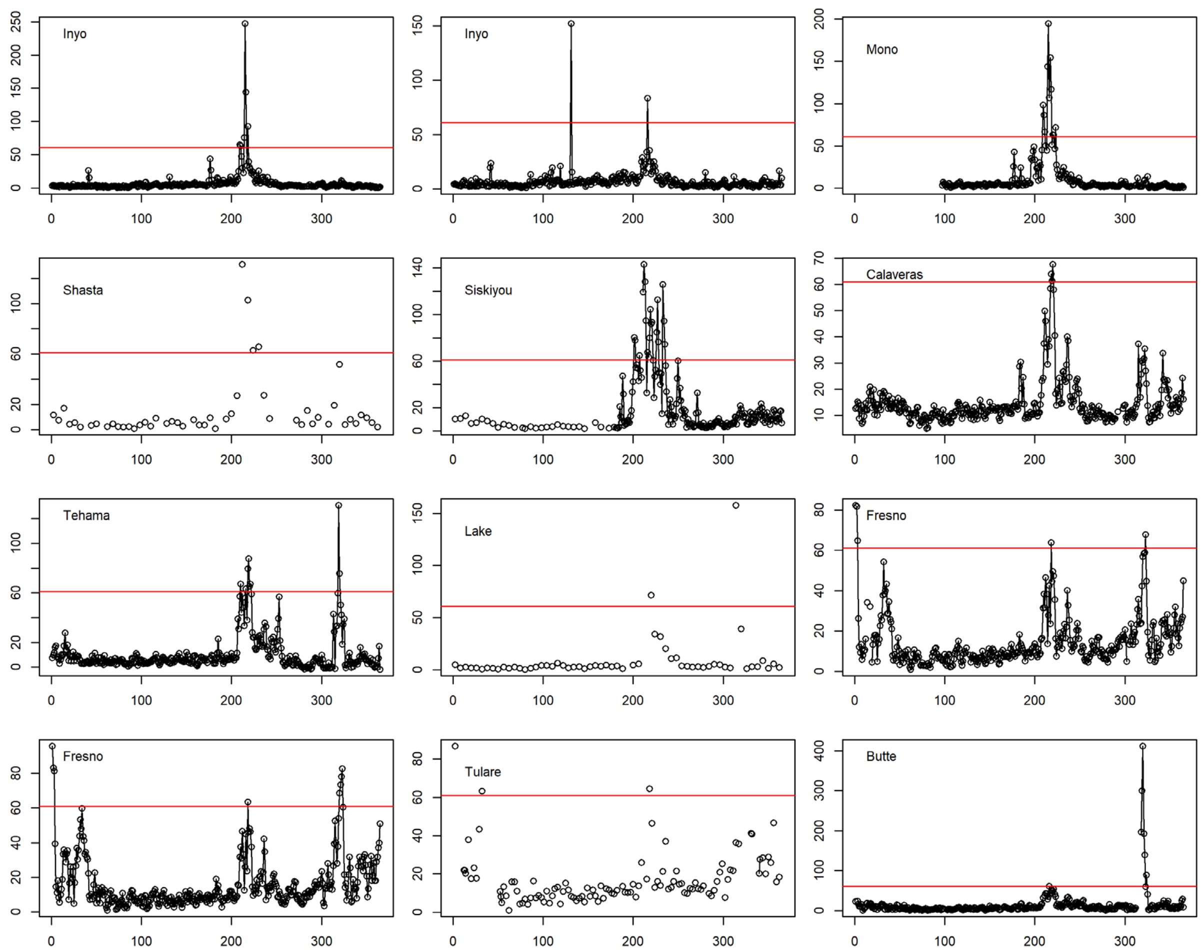

Figure 2A-24 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by the Carr/Mendocino/Ferguson Fires in August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

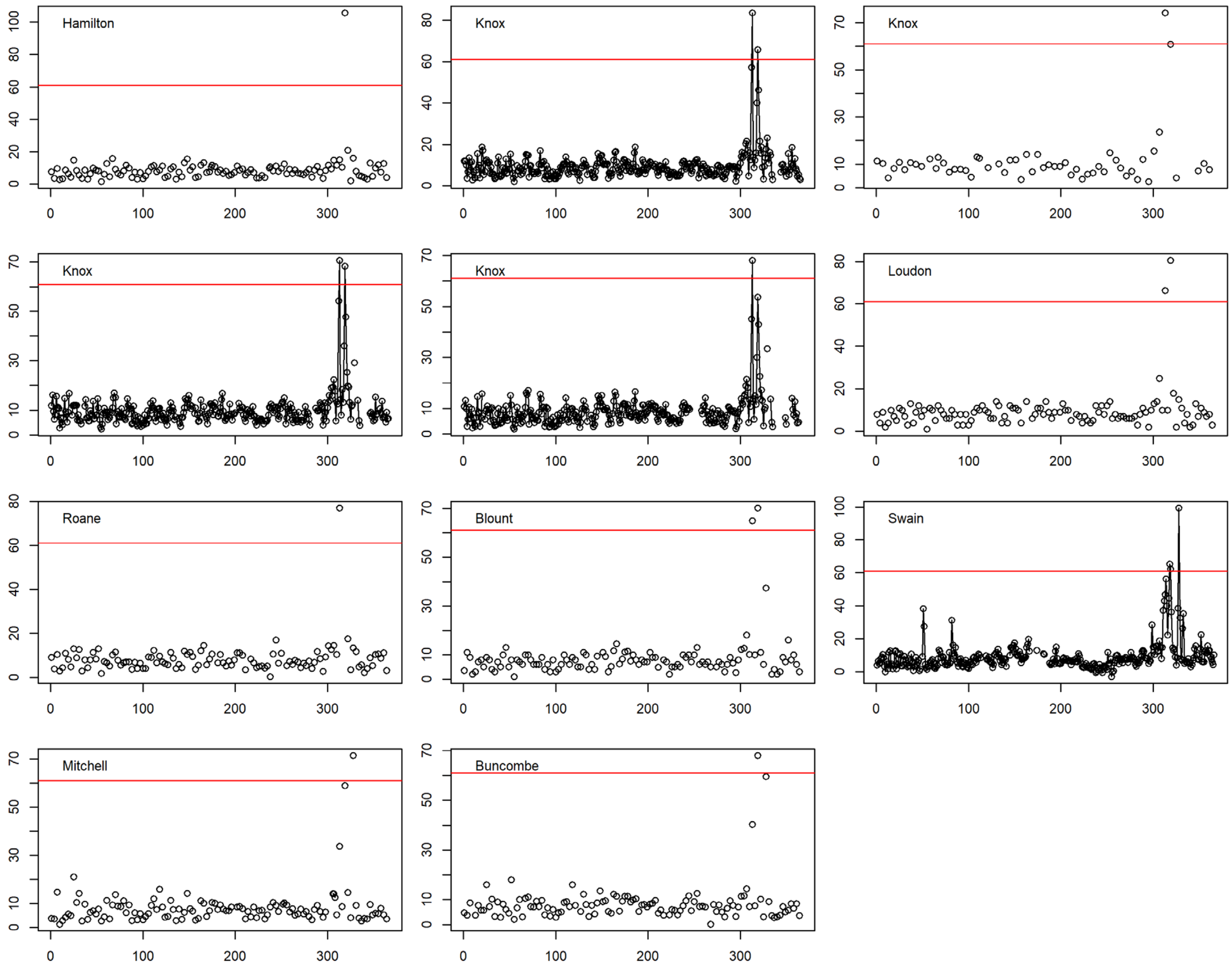

Figure 2A-25 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by Fires in the Appalachians in November 2016

Note: Bottom axis shows day in 2016. Red line indicates extreme value threshold of 64 µg m^{-3} used for screening.

2A.2.2 Future-Year $PM_{2.5}$ Design Values

$PM_{2.5}$ DVs were projected to 2032 using air quality modeling as described above and compared with the existing standard combination, 12/35. Counties with projected 2032 $PM_{2.5}$ DVs exceeding the existing standards are shown in Figure 2A-26. Counties that exceed only the 24-hour standard are in northern California, Oregon, Washington, Idaho, and Montana. Elevated $PM_{2.5}$ episodically occurs in winter in these areas due to meteorological temperature inversions that concentrate $PM_{2.5}$ in shallow layers, especially in mountainous terrain. In California, multiple counties exceed both the annual and 24-

hour standards and two counties (San Bernardino and Imperial) exceed only the annual standard.

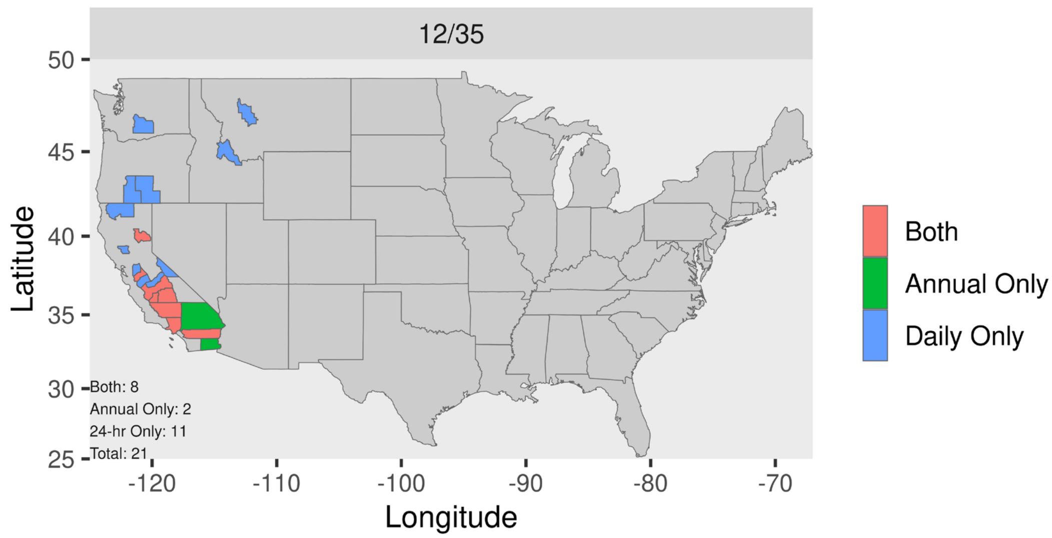

Figure 2A-26 Counties with Projected 2032 $PM_{2.5}$ DVs that Exceed the 24-Hour (Daily Only), Annual (Annual Only) or Both the 24-Hour and Annual (Both) Standards for the Combination of Existing Standards (12/35)

As described below in section 2A.3.4, $PM_{2.5}$ DVs for 2032 were adjusted to correspond with just meeting the existing standard level to form the 12/35 analytical baseline used in estimating the incremental costs and benefits of meeting the revised and alternative standards relative to the existing standards. The county exceedances of the alternative standards in the 12/35 analytical baseline are shown in Figure 2A-27. Since the $PM_{2.5}$ DVs have been adjusted to meet the 24-hour standard level of 35 μg m^{-3} in the analytical baseline, there are no exceedances of the 24-hour standard for the cases of 10/35, 9/35, and 8/35. For the 10/35 case, five counties in the east, two in the northwest, and thirteen in California have annual $PM_{2.5}$ DVs greater than 10 μg m^{-3} in the 12/35 analytical baseline. For the 10/30 case, twenty-nine counties have 24-hr DVs greater than 30 μg m^{-3} and annual DVs less than 10 μg m^{-3}, and nine counties exceed both the 24-hr and annual standards. For the 9/35 case, nineteen counties exceed the annual standard in the eastern US, compared with five for the 10/35 and 10/30 cases. The total number of counties exceeding the standards increases from 52 to 117 when moving from 9/35 to 8/35. In Table 2A-8, $PM_{2.5}$ DVs are shown for the 2032 projections and 12/35 analytical baseline for sites with the highest annual and 24-hour $PM_{2.5}$ DVs in counties with 2032 DVs that exceed an annual standard 8 μg m^{-3} or a 24-hour standard of 30 μg m^{-3}.

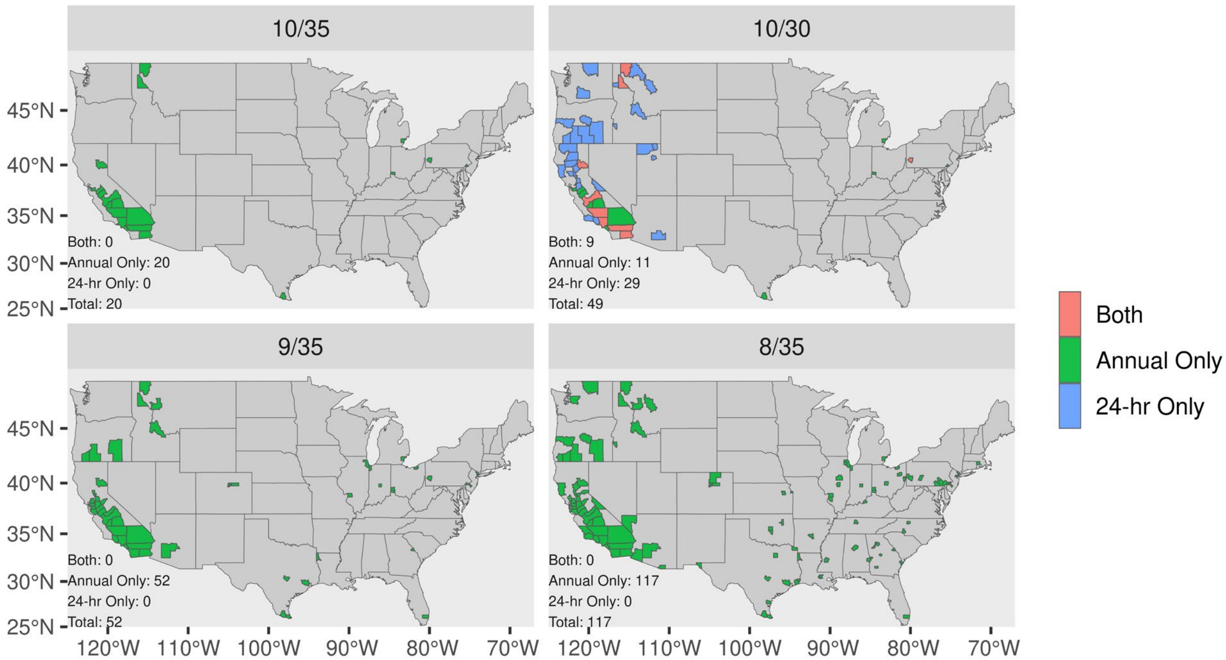

Figure 2A-27 Counties with $PM_{2.5}$ DVs in the 12/35 Analytical Baseline that Exceed the 24-Hour (24-hr Only), Annual (Annual Only) or Both the 24-Hour and Annual (Both) Standards for Combinations of Alternative Standards

Table 2A-8 PM$_{2.5}$ DVs for 2032 Projection and 12/35 Analytical Baseline for the Highest DVs in the County for Counties with Annual 2032 DVs Greater 8 μg m^{-3} or 24-hour 2032 DVs Greater than 30 μg m^{-3}

State	County	Annual 2032 DV (μg m^{-3})	24-hour 2032 DV (μg m^{-3})	Annual 12/35 DV (μg m^{-3})	24-hour 12/35 DV (μg m^{-3})
AL	Jefferson	9.00	19.4	9.00	19.4
AL	Russell	8.44	17.1	8.44	17.1
AZ	Maricopa	9.59	29.2	9.59	29.2
AZ	Pinal[a]	7.95	34.6	7.95	34.6
AZ	Santa Cruz	8.71	24.9	8.71	24.9
AZ	Yuma	8.30	20.8	8.30	20.8
AR	Pulaski	8.92	21.3	8.92	21.3
CA	Alameda	10.37	27.6	10.37	27.6
CA	Butte	8.82	33.4	8.82	33.4
CA	Calaveras	9.60	30.0	9.60	30.0
CA	Colusa	8.24	37.4	7.61	35.4
CA	Contra Costa	9.44	25.2	9.44	25.2
CA	Fresno	13.66	48.2	12.04	33.8
CA	Imperial	12.36	33.5	12.04	32.8
CA	Kern	15.34	53.0	12.04	31.2
CA	Kings	14.51	44.0	11.64	25.5
CA	Los Angeles	12.87	37.7	12.04	33.5
CA	Madera	11.47	37.3	9.96	28.7
CA	Mendocino	8.07	32.7	8.07	32.7
CA	Merced	11.85	36.7	10.77	29.6
CA	Mono	9.63	38.7	8.59	35.4
CA	Napa	8.90	25.6	8.90	25.6
CA	Orange	11.07	32.7	10.74	29.6
CA	Placer	8.07	29.9	8.07	29.9
CA	Plumas	14.02	44.9	11.01	35.4
CA	Riverside	13.79	36.9	12.04	30.7
CA	Sacramento	9.55	32.4	9.55	32.4
CA	San Bernardino	14.33	35.0	12.04	27.6
CA	San Diego	9.32	24.8	9.32	24.8
CA	San Francisco	8.62	24.3	8.62	24.3
CA	San Joaquin	11.91	37.2	10.00	30.7
CA	San Luis Obispo	8.08	24.8	8.08	24.8
CA	San Mateo	8.40	24.1	8.40	24.1
CA	Santa Barbara	8.12	33.5	8.12	33.5
CA	Santa Clara	9.79	28.3	9.79	28.3
CA	Shasta	7.86	30.7	7.86	30.7
CA	Siskiyou	8.25	37.3	7.65	35.4
CA	Solano	9.55	23.7	9.55	23.7
CA	Stanislaus	12.32	38.5	10.99	29.7

State	County	Annual 2032 DV ($\mu g\ m^{-3}$)	24-hour 2032 DV ($\mu g\ m^{-3}$)	Annual 12/35 DV ($\mu g\ m^{-3}$)	24-hour 12/35 DV ($\mu g\ m^{-3}$)
CA	Sutter	9.41	32.3	9.41	32.3
CA	Tehama	7.51	33.3	7.51	33.3
CA	Tulare	14.43	44.0	12.04	23.7
CA	Ventura	9.09	34.8	9.09	34.8
CO	Adams	9.13	24.2	9.13	24.2
CO	Denver	9.06	25.6	9.06	25.6
CO	Weld	8.76	24.9	8.76	24.9
DC	District of Columbia	8.37	20.1	8.37	20.1
FL	Broward	9.06	19.1	9.06	19.1
GA	Bibb	8.18	16.5	8.18	16.5
GA	Chatham	8.14	18.2	8.14	18.2
GA	Dougherty	8.29	21.5	8.29	21.5
GA	Fulton	8.86	18.5	8.86	18.5
GA	Gwinnett	8.78	21.2	8.78	21.2
GA	Muscogee	8.29	27.6	8.29	27.6
GA	Richmond	9.10	20.4	9.10	20.4
ID	Benewah	-	34.1	-	34.1
ID	Canyon	8.66	32.7	8.66	32.7
ID	Lemhi	9.85	36.5	9.58	35.4
ID	Shoshone	10.56	35.3	10.56	35.3
IL	Cook	9.77	22.5	9.77	22.5
IL	DuPage	8.05	18.7	8.05	18.7
IL	McLean	8.08	17.1	8.08	17.1
IL	Macon	8.34	17.8	8.34	17.8
IL	Madison	9.15	19.1	9.15	19.1
IL	Saint Clair	8.44	18.2	8.44	18.2
IN	Lake	9.18	21.9	9.18	21.9
IN	Marion	10.00	23.1	10.00	23.1
KS	Shawnee	8.38	20.5	8.38	20.5
KS	Wyandotte	8.41	22.7	8.41	22.7
KY	Jefferson	8.68	20.8	8.68	20.8
LA	Caddo	9.53	20.5	9.53	20.5
LA	East Baton Rouge	8.44	21.1	8.44	21.1
LA	West Baton Rouge	8.58	19.7	8.58	19.7
MI	Wayne	10.34	26.3	10.34	26.3
MS	Hinds	8.42	17.6	8.42	17.6
MT	Flathead	7.72	31.7	7.72	31.7
MT	Lewis and Clark	8.79	36.5	8.52	35.4
MT	Lincoln	11.63	31.6	11.63	31.6
MT	Missoula	9.09	28.2	9.09	28.2
NV	Clark	9.04	26.3	9.04	26.3
NJ	Bergen	9.78	21.6	9.78	21.6

State	County	Annual 2032 DV ($\mu g\ m^{-3}$)	24-hour 2032 DV ($\mu g\ m^{-3}$)	Annual 12/35 DV ($\mu g\ m^{-3}$)	24-hour 12/35 DV ($\mu g\ m^{-3}$)
NJ	Camden	9.27	22.2	9.27	22.2
NJ	Union	8.35	20.5	8.35	20.5
NY	New York	8.94	22.4	8.94	22.4
NC	Forsyth	8.07	22.1	8.07	22.1
NC	Mecklenburg	8.35	18.1	8.35	18.1
OH	Butler	9.42	21.1	9.42	21.1
OH	Cuyahoga	9.87	21.6	9.87	21.6
OH	Franklin	8.11	20.2	8.11	20.2
OH	Hamilton	10.44	21.8	10.44	21.8
OH	Jefferson	8.06	19.4	8.06	19.4
OH	Stark	8.29	18.8	8.29	18.8
OK	Cleveland	8.63	19.1	8.63	19.1
OK	Oklahoma	8.71	19.2	8.71	19.2
OK	Tulsa	8.66	21.9	8.66	21.9
OR	Crook	8.23	32.8	8.23	32.8
OR	Harney	9.47	31.4	9.47	31.4
OR	Jackson	9.55	30.5	9.55	30.5
OR	Josephine	8.62	26.0	8.62	26.0
OR	Klamath	10.69	40.5	9.44	35.4
OR	Lake	8.68	38.1	8.02	35.4
OR	Lane	8.48	32.1	8.48	32.1
PA	Allegheny	10.71	32.7	10.71	32.7
PA	Beaver	8.20	19.2	8.20	19.2
PA	Cambria	8.46	20.7	8.46	20.7
PA	Chester	8.69	21.8	8.69	21.8
PA	Delaware	10.08	24.9	10.08	24.9
PA	Lancaster	8.71	24.6	8.71	24.6
PA	Lebanon	8.27	24.9	8.27	24.9
PA	Philadelphia	8.74	21.4	8.74	21.4
PA	York	8.42	19.6	8.42	19.6
RI	Providence	8.12	17.6	8.12	17.6
TN	Davidson	8.46	17.2	8.46	17.2
TX	Bowie	8.27	17.6	8.27	17.6
TX	Cameron	9.90	25.7	9.90	25.7
TX	Dallas	8.24	19.7	8.24	19.7
TX	El Paso	8.84	23.5	8.84	23.5
TX	Harris	9.79	23.5	9.79	23.5
TX	Hidalgo	10.69	28.4	10.69	28.4
TX	Jefferson	8.46	21.4	8.46	21.4
TX	Nueces	8.65	24.5	8.65	24.5
TX	Orange	8.47	20.5	8.47	20.5
TX	Travis	9.22	21.9	9.22	21.9

State	County	Annual 2032 DV ($\mu g\ m^{-3}$)	24-hour 2032 DV ($\mu g\ m^{-3}$)	Annual 12/35 DV ($\mu g\ m^{-3}$)	24-hour 12/35 DV ($\mu g\ m^{-3}$)
UT	Box Elder	6.65	31.7	6.65	31.7
UT	Cache	6.20	31.4	6.20	31.4
UT	Salt Lake	7.64	30.9	7.64	30.9
WA	King	8.13	25.6	8.13	25.6
WA	Okanogan	8.27	32.6	8.27	32.6
WA	Yakima	8.28	38.4	7.54	35.4

[a] The Hidden Valley site in Pinal County (04-021-3015) was not compared with the annual NAAQS in this analysis because it is a replacement site for the Cowtown Road site that was not comparable to the annual NAAQS (PCAQCD, 2020).

2A.3 Developing Air Quality Ratios and Estimating Emission Reductions

As in the RIAs for the 2012 $PM_{2.5}$ NAAQS review (USEPA, 2012a, 2012b), air quality ratios are used here to estimate the emission reductions beyond the 2032 modeling case that are needed to meet the existing, revised, and alternative standards. Air quality ratios are developed from sensitivity modeling with CMAQ and relate a change in $PM_{2.5}$ DV to a change in emissions. Air quality ratios have units of $\mu g\ m^{-3}$ per kton of emissions. The remainder of this section describes the development of air quality ratios and their application to estimating emission reductions for meeting the existing, revised, and alternative standards.

2A.3.1 Developing Air Quality Ratios for Primary $PM_{2.5}$ Emissions

To develop air quality ratios that relate the change in DV in a county to the change in primary $PM_{2.5}$ emissions in that county, CMAQ sensitivity modeling was performed with reductions in primary $PM_{2.5}$ emissions in selected counties. The modeling was conducted using CMAQ version 5.2.1 for a 2028 modeling case similar to that of recent regional haze modeling (USEPA, 2019b) due to the availability of the 2028 (but not 2032) modeling platform at the time of the work.

To develop air quality ratios for primary $PM_{2.5}$ emissions, a 2028 CMAQ sensitivity simulation was conducted with 50% reductions in primary $PM_{2.5}$ emissions from anthropogenic sources in counties with annual 2028 DVs greater than 8 $\mu g\ m^{-3}$ (Figure 2A-28). The change in annual and 24-hour $PM_{2.5}$ DVs in these counties was then divided by the change in emissions in the respective counties to determine the air quality ratio at individual monitors as follows:

$$AQratio_{PM2.5,i,j} = \frac{\Delta DV_i}{\Delta EmissCty_j} \times 1000 \quad (2A\text{-}1)$$

where ΔDV is the change in design value (μg m^{-3}) between the 2028 base case and the simulation with 50% reduction in primary $PM_{2.5}$ emissions at a monitor *i* in a county ***j***, $\Delta EmissCty$ is the change in primary $PM_{2.5}$ emissions (tons) in county *j* between the 2028 base case and the simulation with 50% reduction in primary $PM_{2.5}$ emissions, and the factor of 1000 converts units from (μg m^{-3} per ton) to (μg m^{-3} per kton).

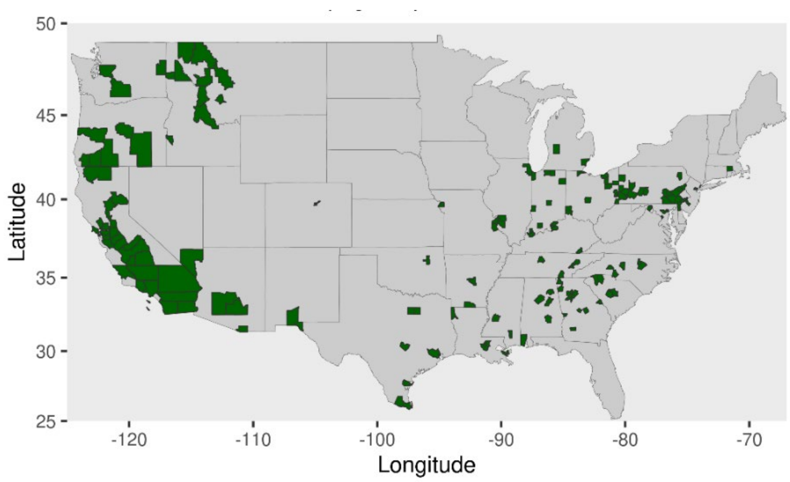

Figure 2A-28 Counties with 50% Reduction in Anthropogenic Primary $PM_{2.5}$ Emissions in 2028 Sensitivity Modeling

Representative air quality ratios for regions of the US were developed from the ratios at individual monitors as in the 2012 $PM_{2.5}$ NAAQS review (USEPA, 2012b). Regional ratios were calculated as the 75th percentile of air quality ratios at monitors within five regions: Northeast, Southeast, Northern California, Southern California, and West (Figure 2A-29). The Northeast region was defined by combining the Upper Midwest, Ohio Valley, and Northeast US climate regions (Figure 2A-2); the Southeast region was defined by combining the Southeast and South climate regions (Figure 2A-2); and California was separated into Southern and Northern regions as done previously (USEPA, 2012b). The air quality ratios for primary $PM_{2.5}$ emissions used in estimating the emission reductions needed to just meet standards are listed in Table 2A-9.

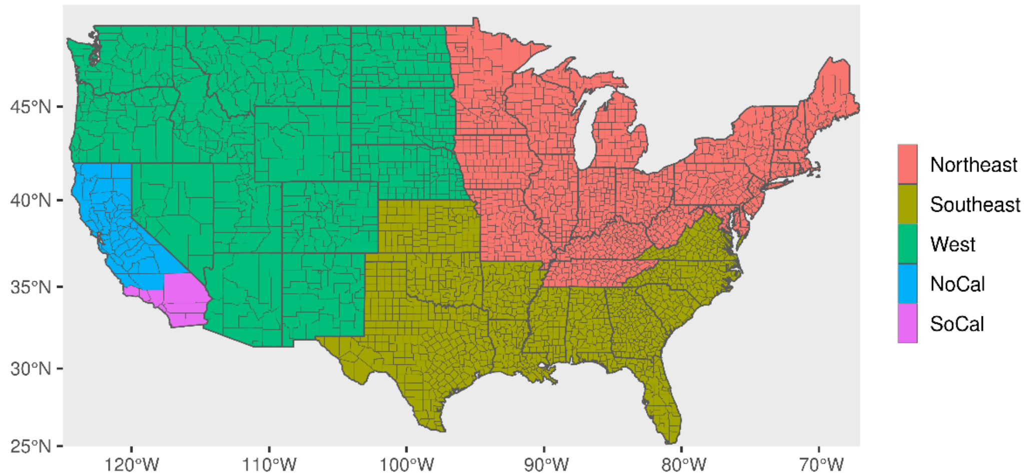

Figure 2A-29 Regional Groupings for Calculating Air Quality Ratios

Table 2A-9 Annual and 24-Hour Air Quality Ratios for Primary $PM_{2.5}$ Emissions

Region	Annual Air Quality Ratio ($\mu g\ m^{-3}$ per kton)	24-hour Air Quality Ratio ($\mu g\ m^{-3}$ per kton)
Northeast	1.37	4.33
Southeast	1.22	3.51
West	2.14	8.70
Northern California	3.15	9.97
Southern California	1.18	2.56

The air quality ratios in Table 2A-9 relate the change in DV in a given county to a change in emissions in that county. The ratios are developed for local spatial scales because concentrations are most responsive to changes in local emissions. However, emission controls may not always be identified in the local county, and emission reductions in neighboring counties may sometimes be appropriate, such as in the eastern US where counties are relatively small, and terrain is relatively flat. To apply emission reductions in the neighboring counties in the eastern US, the responsiveness of annual $PM_{2.5}$ DVs to emission reductions within a county was compared with the responsiveness for neighboring counties as estimated from the 2028 sensitivity modeling.

First, county groups of most relevance were identified from the 2028 sensitivity modeling. These groups were selected as eastern counties where emission reductions were applied and whose neighbors were not also neighbors of another county where emission reductions were applied. This set of county groups was then subset from the full list of counties and filtered to ensure that at least one monitor was included in the neighbor counties for the county group. The resulting county groups are shown in Figure 2A-30. The average relative responsiveness of annual DVs in the east for emission reductions in a core county to reductions in a neighboring county was then calculated as follows:

$$ImpactRatio = \frac{mean(\Delta DV_{core})}{mean(\Delta DV_{neighbor})} = 4 \qquad (2A\text{-}2)$$

where the numerator is the average impact on annual $PM_{2.5}$ DVs in the core counties with 50% reduction in anthropogenic primary $PM_{2.5}$ emissions, and the denominator is the average impact on annual $PM_{2.5}$ DVs in neighboring counties. The resulting impact ratio suggests that primary $PM_{2.5}$ emission reductions in neighboring counties would be 4x less effective as in the core county.

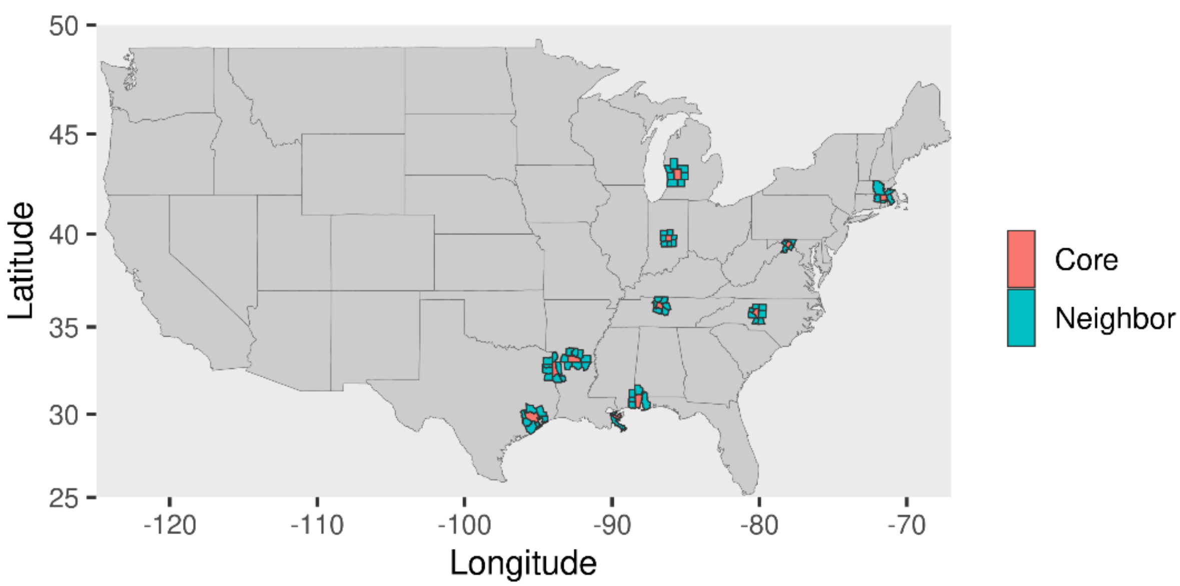

Figure 2A-30 Counties Used in Estimating the Relative Impact of Emissions in Core and Neighboring Counties

2A.3.2 Developing Air Quality Ratios for NOx in Southern California

As described above, $PM_{2.5}$ DVs exceeded the existing standards at monitors in the South Coast Air Basin in the 2032 modeling case. $PM_{2.5}$ DVs were adjusted to meet the existing standards in these counties in creating the 12/35 analytical baseline. Since concentrations of ammonium nitrate are elevated in South Coast, NOx emission reductions were applied in these counties in addition to primary $PM_{2.5}$ emission reductions to meet 12/35. For this purpose, air quality ratios were developed that relate a change in $PM_{2.5}$ DVs to a change in NOx emissions at monitors in Southern California.

The air quality ratios were developed from a CMAQ sensitivity simulation with 50% reductions in anthropogenic NOx emissions relative to the 2028 modeling case. The 50% emission reductions were applied in counties with annual 2028 DVs greater than 8 μg m^{-3} and their neighboring counties (Figure 2A-31). The change in annual and 24-hour DVs in these counties was then divided by the change in emissions in the respective county groups to determine the air quality ratio at individual monitors as follows:

$$AQratio_{PM2.5,i,j} = \frac{\Delta DV_i}{\Delta EmissCtyGroup_j} \times 1000 \qquad \text{(2A-3)}$$

where *ΔDV* is the change in design value (μg m^{-3}) between the 2028 base case and the simulation with 50% reduction in NOx emissions at monitor *i*, *ΔEmissCtyGroup* is the change in NOx emissions (ton) in the county group associated with county *j* between the 2028 base case and the simulation with 50% reduction in NOx emissions, and the factor of 1000 converts units from (μg m^{-3} per ton) to (μg m^{-3} per kton).

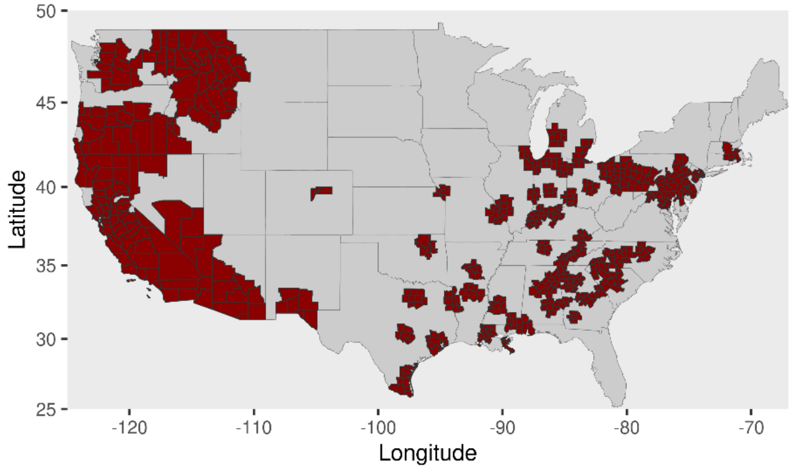

Figure 2A-31 Counties with 50% Reduction in Anthropogenic NOx Emissions in 2028 Sensitivity Modeling

The county groups for determining the emission change to associate with the DV change in Equation 2A-3 are defined in Table 2A-10. These county groups were identified by first selecting the county of focus plus the neighboring counties to reflect the regional nature of ammonium nitrate formation from NOx emissions. These county groups were then refined to account for the influence of terrain, which limits air mixing between different air basins, on meteorology and air pollution. For instance, although Kern County neighbors Los Angeles County, Kern is part of the SJV air basin while Los Angeles is part of the South Coast Air Basin. Kern is therefore not included in the county group associated with Los Angeles County, because Kern is separated from Los Angeles County by mountain ranges.

Table 2A-10 County Groups for Calculating Air Quality Ratios for NOx Emission Changes in Southern California

FIPS	County	County Group
06025	Imperial	Imperial; San Diego
06037	Los Angeles	Los Angeles; Orange; San Bernardino; Ventura
06065	Riverside	Riverside; Orange; San Bernardino
06071	San Bernardino	San Bernardino; Los Angeles; Orange; Riverside
06073	San Diego	San Diego; Imperial; Orange
06111	Ventura	Ventura; Los Angeles; Santa Barbara

To develop representative air quality ratios (USEPA, 2012b) for Southern California, the 75th percentile of the air quality ratios for individual monitors in the six counties in Table 2A-10 was calculated. The resulting air quality ratio for the annual standard is 0.004 μg m^{-3} per kton and for the 24-hour standard ratio is 0.038 μg m^{-3} per kton. These ratios were applied to adjust 2032 $PM_{2.5}$ DVs according to 75% reductions in anthropogenic NOx emissions for counties in South Coast Air Basin (i.e., LA, San Bernardino, Riverside, and Orange). The 75% reduction in emissions corresponded to 81,200 tons. The 2032 DVs and the NOx-adjusted DVs are shown in Table 2A-11 for the highest annual and 24-hour DV monitors in the county. Note that these emission reductions were applied in meeting the existing standards (12/35) and are therefore not part of the incremental cost and benefits of meeting revised and alternative standards relative to the existing standards.

Table 2A-11 2032 $PM_{2.5}$ DVs and NOx-adjusted $PM_{2.5}$ DVs for the Highest Annual and 24-Hour DV Monitors in South Coast Counties

Site ID	County	AQ Ratio Annual (μg m^{-3} per kton)	AQ Ratio 24-hour (μg m^{-3} per kton)	2032 DV Annual (μg m^{-3})	2032 DV 24-hour (μg m^{-3})	NOx-Adj DV Annual (μg m^{-3})	NOx-Adj DV 24-hour (μg m^{-3})
060371302	Los Angeles	0.004	0.038	12.87	37.7	12.54	34.6
060590007	Orange	0.004	0.038	11.07	32.7	10.74	29.6
060658005	Riverside	0.004	0.038	13.79	36.9	13.46	33.8
060710027	San Bernardino	0.004	0.038	14.33	35.0	14.00	31.9

2A.3.3 Developing Air Quality Ratios for NOx in SJV, CA

As in the South Coast Air Basin, $PM_{2.5}$ DVs exceed existing standards in SJV in the 2032 modeling case, and concentrations of ammonium nitrate are elevated in SJV. To develop $PM_{2.5}$ DVs for SJV counties in the 12/35 analytical baseline, NOx emission reductions were applied in addition to primary $PM_{2.5}$ emission reductions. To develop air quality ratios for NOx emission changes in SJV, information was used from Appendix K of the 2018 SJV $PM_{2.5}$ Plan (SJVAPCD, 2018). The Plan was based on fine-scale CMAQ modeling and provides useful information for characterizing the responsiveness of $PM_{2.5}$ DVs to NOx emissions.

The California Air Resources Board (CARB) modeled $PM_{2.5}$ concentrations in SJV corresponding to 30% reductions in NOx emissions relative to a 2024 base case. The change in annual and 24-hour $PM_{2.5}$ DVs at monitors in SJV was reported for the sensitivity simulation. Using this information, along with $PM_{2.5}$ DVs and emissions information from the 2032 CMAQ modeling developed by EPA, air quality ratios were calculated at monitors in SJV from the following equation:

$$AQratio_i = \left(\frac{\%Chg.DV_i}{\%Chg.Emision_{SJV}}\right)_{CARB} \left(\frac{DV_i}{Emission_{SJV}}\right)_{2032} \tag{2A-4}$$

The parenthesis labeled *CARB* indicates values from the SJV Plan, and the parenthesis labeled *2032* indicates values from the 2032 CMAQ modeling. $\%Chg.DV_i$ indicates the percent change in the design value for a given monitor, *i,* from Table 49 and 50 of Appendix K of the SJV Plan (SJVAPCD, 2018). $\%Chg.DV_i$ ranged from 2.3% to 7.5% for annual DVs and from 7.0% to 16.3% for 24-hour DVs. $\%Chg.Emission_{SJV}$ indicates the percent change in NOx emissions in SJV and equaled 30%. DV_i corresponds to the design value at monitor *i,* and $Emission_{SJV}$ corresponds to the anthropogenic NOx emissions in SJV in the 2032 CMAQ modeling. Equation 2A-4 normalizes the percent changes from CARB's 2024 modeling to the $PM_{2.5}$ DVs and emissions from the 2032 case for application here.

Air quality ratios were calculated as above for all monitors in SJV, except for the Tranquillity monitor. The Tranquillity monitor is in the Western part of Fresno County, away from the urban exceedance monitors, and has a low $PM_{2.5}$ concentration (e.g., 2024 annual DV for CARB modeling is 5.6 $\mu g\ m^{-3}$). To develop representative air quality ratios for counties in SJV, the 75th percentile of air quality ratios over monitors in the SJV counties was calculated. These ratios were applied to adjust 2032 $PM_{2.5}$ DVs according to 75% reductions in anthropogenic NOx emissions for counties in SJV. The 75% reduction in emissions corresponded to 39,700 tons. The 2032 DVs and the NOx-adjusted DVs are shown in Table 2A-12 for the highest annual and 24-hour DV monitors in the county. Note that these emission reductions were applied in meeting the existing standards (12/35) and are therefore not part of the incremental cost and benefits of meeting revised and alternative standards relative to the existing standards.

Table 2A-12 2032 $PM_{2.5}$ DVs and NOx-adjusted $PM_{2.5}$ DVs for the Highest Annual and 24-Hour DV Monitors in SJV Counties

Site ID	County	AQ Ratio Annual ($\mu g\ m^{-3}$ per kton)	AQ Ratio 24-hour ($\mu g\ m^{-3}$ per kton)	2032 DV Annual ($\mu g\ m^{-3}$)	2032 DV 24-hour ($\mu g\ m^{-3}$)	NOx-Adj DV Annual ($\mu g\ m^{-3}$)	NOx-Adj DV 24-hour ($\mu g\ m^{-3}$)
060195025	Fresno	0.033	0.337	13.66	48.2	12.36	34.9
060290016	Kern	0.041	0.418	15.34	53.0	13.70	36.4
060311004	Kings	0.072	0.467	14.51	44.0	11.64	25.5
060392010	Madera	0.038	0.216	11.47	37.3	9.96	28.7
060470003	Merced	0.027	0.178	11.85	36.7	10.77	29.6
060771002	San Joaquin	0.048	0.164	11.91	37.2	10.00	30.7
060990006	Stanislaus	0.034	0.222	12.32	38.5	10.99	29.7
061072002	Tulare	0.047	0.472	14.43	44.0	12.56	25.3

2A.3.4 Applying Air Quality Ratios to Estimate Emission Reductions

The emissions reductions needed to just meet standards were estimated using the primary $PM_{2.5}$ air quality ratios in combination with the required incremental change in concentration. The emission reductions required to meet the DV target for a standard were calculated as follows:

$$\Delta Emission_{std} = \frac{DV_{Model,std} - DV_{Target,std}}{AQratio_{std}} \times 1000 \qquad \text{(2A-5)}$$

where $\Delta Emission_{std}$ is the emission reduction required to meet an annual or 24-hour standard; $DV_{Target,std}$ is the level of the annual or 24-hour standard to be met; $DV_{Model,std}$ is the modeled $PM_{2.5}$ DV for the annual or 24-hour standard at the county highest monitor; $Aqratio_{std}$ is the air quality ratio for that standard; and the factor of 1000 converts units from kton to ton.

For example, the highest 2032 annual $PM_{2.5}$ DV in Kern County is 13.70 $\mu g\ m^{-3}$ at site 06-029-0016 after applying the 75% NOx emission reduction to the 2032 DVs. The annual air quality ratio for primary $PM_{2.5}$ emissions in Northern California is 3.15 $\mu g\ m^{-3}$ per kton. Therefore, to meet an annual standard of 12 $\mu g\ m^{-3}$, a total of 527 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (13.70-12.04)/3.15 x 1000). The highest 2032 24-hour $PM_{2.5}$ DV in Kern County is 36.4 $\mu g\ m^{-3}$ at site 06-029-0016 after applying the 75% NOx emission reduction to the 2032 DVs. The 24-hour air quality ratio for primary $PM_{2.5}$ emissions in Northern California is 9.97 $\mu g\ m^{-3}$ per kton. Therefore, to meet a 24-hour standard of 35 μg m^{-3}, a total of 100 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (36.4-35.4)/9.97 x 1000). To determine the emission reductions needed to meet an annual and 24-hour standard combination, the maximum needed emission reductions across standards is calculated as follows:

$$\Delta Emission_{std.combo} = max(\Delta Emission_{Annual}, \Delta Emission_{24hr}) \qquad (2A\text{-}6)$$

For the Kern County example, a total 527 tons of primary $PM_{2.5}$ emission reductions are needed to meet the 12/35 standard combination (i.e., maximum of 527 and 100).

The $PM_{2.5}$ DVs associated with meeting a standard combination at the highest monitor in a county are calculated using the required emission reductions as follows:

$$DV_{Annual,std.combo} = DV_{Annual,initial} - \Delta Emission_{std.combo} \times AQratio_{Annual} \qquad (2A\text{-}8)$$

$$DV_{Daily,std.combo} = DV_{Annual,initial} - \Delta Emission_{std.combo} \times AQratio_{Daily} \qquad (2A\text{-}9)$$

In the Kern County example, the adjusted annual DV for the 12/35 case is 12.04 μg m^{-3} (13.70-527*3.15/1000) and the adjusted 24-hour DV is 31.1 μg m^{-3} (36.4-527*9.97/1000).

2A.3.4.1 Emission Reductions Needed to Meet 12/35

In the 2032 projections, $PM_{2.5}$ DVs exceeded the existing standards for some counties in the west (Figure 2A-26). To create the $PM_{2.5}$ DVs for 12/35 analytical baseline, the reductions in primary $PM_{2.5}$ emissions needed to just meet 12/35 at the highest DV monitor by county were calculated using the air quality ratios in Table 2A-9. $PM_{2.5}$ DVs were then adjusted according to those emission reductions. In Table 2A-13, the primary $PM_{2.5}$ emission reductions needed to meet 12/35 is shown by county for counties with annual DVs greater than 8 μg m^{-3} or 24-hour DVs greater than 30 μg m^{-3} (note that required emission reductions are zero for counties with DVs below 12/35). Table 2A-13 also includes the corresponding air quality ratios, the 2032 $PM_{2.5}$ DVs (or NOx-adjusted DVs for South Coast and SJV counties), and the $PM_{2.5}$ DVs that define the 12/35 analytical baseline.

Table 2A-13 Summary of Primary $PM_{2.5}$ Emissions Reductions by County Needed to Meet the Existing Standards (12/35) for Counties with 2032[a] Annual DVs greater than 8 μg m-3 or 24-Hour DVs Greater than 30 μg m^{-3}

State	County	ΔEmission 2032 to 12/35 (ton)	AQ Ratio Annual (μg m^{-3} per kton)	AQ Ratio 24-hour (μg m^{-3} per kton)	2032[a] DV Annual (μg m^{-3})	2032[a] DV 24-hour (μg m^{-3})	12/35 DV Annual (μg m^{-3})	12/35 DV 24-hour (μg m^{-3})
AL	Jefferson	0	1.22	3.51	9.00	19.4	9.00	19.4
AL	Russell	0	1.22	3.51	8.44	17.1	8.44	17.1
AZ	Maricopa	0	2.14	8.70	9.59	29.2	9.59	29.2
AZ	Pinal	0	2.14	8.70	7.95	34.6	7.95	34.6
AZ	Santa Cruz	0	2.14	8.70	8.71	24.9	8.71	24.9
AZ	Yuma	0	2.14	8.70	8.30	20.8	8.30	20.8
AR	Pulaski	0	1.22	3.51	8.92	21.3	8.92	21.3
CA	Alameda	0	3.15	9.97	10.37	27.6	10.37	27.6
CA	Butte	0	3.15	9.97	8.82	33.4	8.82	33.4
CA	Calaveras	0	3.15	9.97	9.60	30.0	9.60	30.0
CA	Colusa	201	3.15	9.97	8.24	37.4	7.61	35.4
CA	Contra Costa	0	3.15	9.97	9.44	25.2	9.44	25.2
CA	Fresno	102	3.15	9.97	12.36	34.9	12.04	33.8
CA	Imperial	272	1.18	2.56	12.36	33.5	12.04	32.8
CA	Kern	525	3.15	9.97	13.70	36.4	12.04	31.2
CA	Kings	0	3.15	9.97	11.64	25.5	11.64	25.5
CA	Los Angeles	423	1.18	2.56	12.54	34.6	12.04	33.5
CA	Madera	0	3.15	9.97	9.96	28.7	9.96	28.7
CA	Mendocino	0	3.15	9.97	8.07	32.7	8.07	32.7
CA	Merced	0	3.15	9.97	10.77	29.6	10.77	29.6
CA	Mono	331	3.15	9.97	9.63	38.7	8.59	35.4
CA	Napa	0	3.15	9.97	8.90	25.6	8.90	25.6
CA	Orange	0	1.18	2.56	10.74	29.6	10.74	29.6
CA	Placer	0	3.15	9.97	8.07	29.9	8.07	29.9
CA	Plumas	953	3.15	9.97	14.02	44.9	11.01	35.4
CA	Riverside	1206	1.18	2.56	13.46	33.8	12.04	30.7
CA	Sacramento	0	3.15	9.97	9.55	32.4	9.55	32.4
CA	San Bernardino	1665	1.18	2.56	14.00	31.9	12.04	27.6
CA	San Diego	0	1.18	2.56	9.32	24.8	9.32	24.8
CA	San Francisco	0	3.15	9.97	8.62	24.3	8.62	24.3
CA	San Joaquin	0	3.15	9.97	10.00	30.7	10.00	30.7
CA	San Luis Obispo	0	3.15	9.97	8.08	24.8	8.08	24.8
CA	San Mateo	0	3.15	9.97	8.40	24.1	8.40	24.1
CA	Santa Barbara	0	1.18	2.56	8.12	33.5	8.12	33.5
CA	Santa Clara	0	3.15	9.97	9.79	28.3	9.79	28.3
CA	Shasta	0	3.15	9.97	7.86	30.7	7.86	30.7
CA	Siskiyou	191	3.15	9.97	8.25	37.3	7.65	35.4
CA	Solano	0	3.15	9.97	9.55	23.7	9.55	23.7

State	County	ΔEmission 2032 to 12/35 (ton)	AQ Ratio Annual (μg m-3 per kton)	AQ Ratio 24-hour (μg m-3 per kton)	2032[a] DV Annual (μg m-3)	2032[a] DV 24-hour (μg m-3)	12/35 DV Annual (μg m-3)	12/35 DV 24-hour (μg m-3)
CA	Stanislaus	0	3.15	9.97	10.99	29.7	10.99	29.7
CA	Sutter	0	3.15	9.97	9.41	32.3	9.41	32.3
CA	Tehama	0	3.15	9.97	7.51	33.3	7.51	33.3
CA	Tulare	164	3.15	9.97	12.56	25.3	12.04	23.7
CA	Ventura	0	1.18	2.56	9.09	34.8	9.09	34.8
CO	Adams	0	2.14	8.70	9.13	24.2	9.13	24.2
CO	Denver	0	2.14	8.70	9.06	25.6	9.06	25.6
CO	Weld	0	2.14	8.70	8.76	24.9	8.76	24.9
DC	District of Columbia	0	1.22	3.51	8.37	20.1	8.37	20.1
FL	Broward	0	1.22	3.51	9.06	19.1	9.06	19.1
GA	Bibb	0	1.22	3.51	8.18	16.5	8.18	16.5
GA	Chatham	0	1.22	3.51	8.14	18.2	8.14	18.2
GA	Dougherty	0	1.22	3.51	8.29	21.5	8.29	21.5
GA	Fulton	0	1.22	3.51	8.86	18.5	8.86	18.5
GA	Gwinnett	0	1.22	3.51	8.78	21.2	8.78	21.2
GA	Muscogee	0	1.22	3.51	8.29	27.6	8.29	27.6
GA	Richmond	0	1.22	3.51	9.10	20.4	9.10	20.4
ID	Benewah	0	NA	8.70	NA	34.1	NA	34.1
ID	Canyon	0	2.14	8.70	8.66	32.7	8.66	32.7
ID	Lemhi	126	2.14	8.70	9.85	36.5	9.58	35.4
ID	Shoshone	0	2.14	8.70	10.56	35.3	10.56	35.3
IL	Cook	0	1.37	4.33	9.77	22.5	9.77	22.5
IL	DuPage	0	1.37	4.33	8.05	18.7	8.05	18.7
IL	McLean	0	1.37	4.33	8.08	17.1	8.08	17.1
IL	Macon	0	1.37	4.33	8.34	17.8	8.34	17.8
IL	Madison	0	1.37	4.33	9.15	19.1	9.15	19.1
IL	Saint Clair	0	1.37	4.33	8.44	18.2	8.44	18.2
IN	Lake	0	1.37	4.33	9.18	21.9	9.18	21.9
IN	Marion	0	1.37	4.33	10.00	23.1	10.00	23.1
KS	Shawnee	0	1.22	3.51	8.38	20.5	8.38	20.5
KS	Wyandotte	0	1.22	3.51	8.41	22.7	8.41	22.7
KY	Jefferson	0	1.37	4.33	8.68	20.8	8.68	20.8
LA	Caddo	0	1.22	3.51	9.53	20.5	9.53	20.5
LA	East Baton Rouge	0	1.22	3.51	8.44	21.1	8.44	21.1
LA	West Baton Rouge	0	1.22	3.51	8.58	19.7	8.58	19.7
MI	Wayne	0	1.37	4.33	10.34	26.3	10.34	26.3
MS	Hinds	0	1.22	3.51	8.42	17.6	8.42	17.6
MT	Flathead	0	2.14	8.70	7.72	31.7	7.72	31.7
MT	Lewis and Clark	126	2.14	8.70	8.79	36.5	8.52	35.4
MT	Lincoln	0	2.14	8.70	11.63	31.6	11.63	31.6
MT	Missoula	0	2.14	8.70	9.09	28.2	9.09	28.2
NV	Clark	0	2.14	8.70	9.04	26.3	9.04	26.3

State	County	ΔEmission 2032 to 12/35 (ton)	AQ Ratio Annual (μg m-3 per kton)	AQ Ratio 24-hour (μg m-3 per kton)	2032[a] DV Annual (μg m-3)	2032[a] DV 24-hour (μg m-3)	12/35 DV Annual (μg m-3)	12/35 DV 24-hour (μg m-3)
NJ	Bergen	0	1.37	4.33	9.78	21.6	9.78	21.6
NJ	Camden	0	1.37	4.33	9.27	22.2	9.27	22.2
NJ	Union	0	1.37	4.33	8.35	20.5	8.35	20.5
NY	New York	0	1.37	4.33	8.94	22.4	8.94	22.4
NC	Forsyth	0	1.22	3.51	8.07	22.1	8.07	22.1
NC	Mecklenburg	0	1.22	3.51	8.35	18.1	8.35	18.1
OH	Butler	0	1.37	4.33	9.42	21.1	9.42	21.1
OH	Cuyahoga	0	1.37	4.33	9.87	21.6	9.87	21.6
OH	Franklin	0	1.37	4.33	8.11	20.2	8.11	20.2
OH	Hamilton	0	1.37	4.33	10.44	21.8	10.44	21.8
OH	Jefferson	0	1.37	4.33	8.06	19.4	8.06	19.4
OH	Stark	0	1.37	4.33	8.29	18.8	8.29	18.8
OK	Cleveland	0	1.22	3.51	8.63	19.1	8.63	19.1
OK	Oklahoma	0	1.22	3.51	8.71	19.2	8.71	19.2
OK	Tulsa	0	1.22	3.51	8.66	21.9	8.66	21.9
OR	Crook	0	2.14	8.70	8.23	32.8	8.23	32.8
OR	Harney	0	2.14	8.70	9.47	31.4	9.47	31.4
OR	Jackson	0	2.14	8.70	9.55	30.5	9.55	30.5
OR	Josephine	0	2.14	8.70	8.62	26.0	8.62	26.0
OR	Klamath	586	2.14	8.70	10.69	40.5	9.44	35.4
OR	Lake	310	2.14	8.70	8.68	38.1	8.02	35.4
OR	Lane	0	2.14	8.70	8.48	32.1	8.48	32.1
PA	Allegheny	0	1.37	4.33	10.71	32.7	10.71	32.7
PA	Beaver	0	1.37	4.33	8.20	19.2	8.20	19.2
PA	Cambria	0	1.37	4.33	8.46	20.7	8.46	20.7
PA	Chester	0	1.37	4.33	8.69	21.8	8.69	21.8
PA	Delaware	0	1.37	4.33	10.08	24.9	10.08	24.9
PA	Lancaster	0	1.37	4.33	8.71	24.6	8.71	24.6
PA	Lebanon	0	1.37	4.33	8.27	24.9	8.27	24.9
PA	Philadelphia	0	1.37	4.33	8.74	21.4	8.74	21.4
PA	York	0	1.37	4.33	8.42	19.6	8.42	19.6
RI	Providence	0	1.37	4.33	8.12	17.6	8.12	17.6
TN	Davidson	0	1.37	4.33	8.46	17.2	8.46	17.2
TX	Bowie	0	1.22	3.51	8.27	17.6	8.27	17.6
TX	Cameron	0	1.22	3.51	9.90	25.7	9.90	25.7
TX	Dallas	0	1.22	3.51	8.24	19.7	8.24	19.7
TX	El Paso	0	1.22	3.51	8.84	23.5	8.84	23.5
TX	Harris	0	1.22	3.51	9.79	23.5	9.79	23.5
TX	Hidalgo	0	1.22	3.51	10.69	28.4	10.69	28.4
TX	Jefferson	0	1.22	3.51	8.46	21.4	8.46	21.4
TX	Nueces	0	1.22	3.51	8.65	24.5	8.65	24.5
TX	Orange	0	1.22	3.51	8.47	20.5	8.47	20.5

State	County	ΔEmission 2032 to 12/35 (ton)	AQ Ratio Annual (μg m-3 per kton)	AQ Ratio 24-hour (μg m-3 per kton)	2032[a] DV Annual (μg m-3)	2032[a] DV 24-hour (μg m-3)	12/35 DV Annual (μg m-3)	12/35 DV 24-hour (μg m-3)
TX	Travis	0	1.22	3.51	9.22	21.9	9.22	21.9
UT	Box Elder	0	2.14	8.70	6.65	31.7	6.65	31.7
UT	Cache	0	2.14	8.70	6.20	31.4	6.20	31.4
UT	Salt Lake	0	2.14	8.70	7.64	30.9	7.64	30.9
WA	King	0	2.14	8.70	8.13	25.6	8.13	25.6
WA	Okanogan	0	2.14	8.70	8.27	32.6	8.27	32.6
WA	Yakima	345	2.14	8.70	8.28	38.4	7.54	35.4

[a] For South Coast and SJV counties, these are DVs that result from applying 75% NOx emission reduction to the 2032 DVs.

2A.3.4.2 Emission Reductions Needed to Meet 10/35, 9/35, 8/35, and 10/30

The primary $PM_{2.5}$ emission reductions needed to meet the revised and alternative standard levels of 10/35, 10/30, 9/35, and 8/35 relative to the 12/35 analytical baseline were calculated to inform identification of emission controls. These emission amounts were calculated using Equations 2A-5 and 2A-6 and the air quality ratios in the Table 2A-9 and are shown in Table 2A-14. The total emission reductions needed in the eastern and western US is also shown in Figure 2A-32 for the standard combinations.

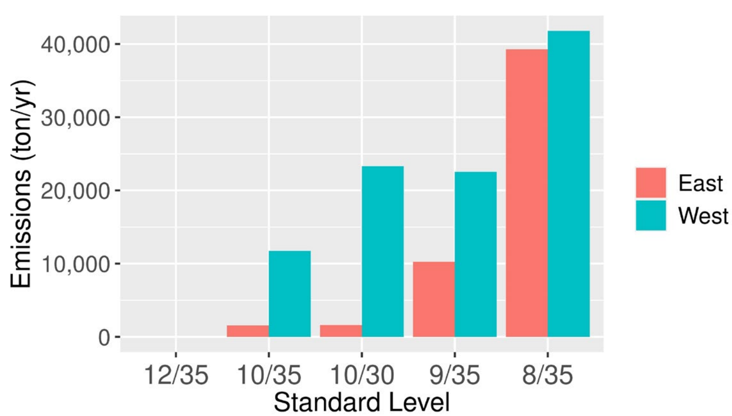

Figure 2A-32 Total Primary $PM_{2.5}$ Emission Reductions Needed to Meet the Revised and Alternative Standard Levels of 10/35, 10/30, 9/35, and 8/35 Relative to the 12/35 Analytical Baseline in the East and West

Table 2A-14 Primary $PM_{2.5}$ Emission Reductions Needed to Meet the Revised and Alternative Standard Levels of 10/35, 10/30, 9/35, and 8/35 Relative to the 12/35 Analytical Baseline

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
Alabama	Jefferson	0	0	785	0
Alabama	Russell	0	0	327	0
Arizona	Maricopa	0	257	725	0
Arizona	Pinal	0	0	0	483
Arizona	Santa Cruz	0	0	313	0
Arizona	Yuma	0	0	122	0
Arkansas	Pulaski	0	0	719	0
California	Alameda	105	422	739	105
California	Butte	0	0	247	301
California	Calaveras	0	178	495	0
California	Colusa	0	0	0	502
California	Contra Costa	0	127	444	0
California	Fresno	634	951	1268	634
California	Imperial	1701	2551	3402	1701
California	Kern	634	951	1268	634
California	Kings	508	825	1142	508
California	Los Angeles	1701	2551	3402	1701
California	Madera	0	292	609	0
California	Mendocino	0	0	10	231
California	Merced	232	549	866	232
California	Mono	0	0	173	502
California	Napa	0	0	273	0
California	Orange	593	1444	2294	593
California	Placer	0	0	10	0
California	Plumas	309	626	943	502
California	Riverside	1701	2551	3402	1701
California	Sacramento	0	162	479	201
California	San Bernardino	1701	2551	3402	1701
California	San Diego	0	238	1089	0
California	San Francisco	0	0	184	0
California	San Joaquin	0	304	621	31
California	San Luis Obispo	0	0	13	0
California	San Mateo	0	0	114	0
California	Santa Barbara	0	0	68	1213
California	Santa Clara	0	238	555	0
California	Shasta	0	0	0	30
California	Siskiyou	0	0	0	502
California	Solano	0	162	479	0
California	Stanislaus	301	618	935	301

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
California	Sutter	0	117	434	191
California	Tehama	0	0	0	291
California	Tulare	634	951	1268	634
California	Ventura	0	43	893	1721
Colorado	Adams	0	42	510	0
Colorado	Denver	0	9	477	0
Colorado	Weld	0	0	337	0
District Of Columbia	District of Columbia	0	0	270	0
Florida	Broward	0	16	834	0
Georgia	Bibb	0	0	114	0
Georgia	Chatham	0	0	82	0
Georgia	Dougherty	0	0	204	0
Georgia	Fulton	0	0	670	0
Georgia	Gwinnett	0	0	605	0
Georgia	Muscogee	0	0	204	0
Georgia	Richmond	0	49	867	0
Idaho	Benewah	0	0	0	425
Idaho	Canyon	0	0	290	264
Idaho	Lemhi	0	252	720	574
Idaho	Shoshone	243	711	1178	563
Illinois	Cook	0	534	1266	0
Illinois	DuPage	0	0	7	0
Illinois	McLean	0	0	29	0
Illinois	Macon	0	0	220	0
Illinois	Madison	0	80	812	0
Illinois	Saint Clair	0	0	293	0
Indiana	Lake	0	102	834	0
Indiana	Marion	0	702	1434	0
Kansas	Shawnee	0	0	278	0
Kansas	Wyandotte	0	0	303	0
Kentucky	Jefferson	0	0	468	0
Louisiana	Caddo	0	401	1218	0
Louisiana	East Baton Rouge	0	0	327	0
Louisiana	West Baton Rouge	0	0	442	0
Michigan	Wayne	220	951	1683	220
Mississippi	Hinds	0	0	311	0
Montana	Flathead	0	0	0	149
Montana	Lewis and Clark	0	0	224	574
Montana	Lincoln	744	1211	1679	744
Montana	Missoula	0	23	491	0
Nevada	Clark	0	0	468	0
New Jersey	Bergen	0	541	1273	0

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
New Jersey	Camden	0	168	900	0
New Jersey	Union	0	0	227	0
New York	New York	0	0	659	0
North Carolina	Forsyth	0	0	25	0
North Carolina	Mecklenburg	0	0	253	0
Ohio	Butler	0	278	1010	0
Ohio	Cuyahoga	0	607	1339	0
Ohio	Franklin	0	0	51	0
Ohio	Hamilton	293	1024	1756	293
Ohio	Jefferson	0	0	15	0
Ohio	Stark	0	0	183	0
Oklahoma	Cleveland	0	0	482	0
Oklahoma	Oklahoma	0	0	548	0
Oklahoma	Tulsa	0	0	507	0
Oregon	Crook	0	0	89	276
Oregon	Harney	0	201	669	115
Oregon	Jackson	0	238	706	11
Oregon	Josephine	0	0	271	0
Oregon	Klamath	0	186	653	574
Oregon	Lake	0	0	0	574
Oregon	Lane	0	0	206	195
Pennsylvania	Allegheny	490	1222	1954	532
Pennsylvania	Beaver	0	0	117	0
Pennsylvania	Cambria	0	0	307	0
Pennsylvania	Chester	0	0	476	0
Pennsylvania	Delaware	29	761	1493	29
Pennsylvania	Lancaster	0	0	490	0
Pennsylvania	Lebanon	0	0	168	0
Pennsylvania	Philadelphia	0	0	512	0
Pennsylvania	York	0	0	278	0
Rhode Island	Providence	0	0	59	0
Tennessee	Davidson	0	0	307	0
Texas	Bowie	0	0	188	0
Texas	Cameron	0	703	1521	0
Texas	Dallas	0	0	164	0
Texas	El Paso	0	0	654	0
Texas	Harris	0	613	1431	0
Texas	Hidalgo	531	1349	2167	531
Texas	Jefferson	0	0	343	0
Texas	Nueces	0	0	499	0
Texas	Orange	0	0	352	0
Texas	Travis	0	147	965	0

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
Utah	Box Elder	0	0	0	149
Utah	Cache	0	0	0	115
Utah	Salt Lake	0	0	0	57
Washington	King	0	0	42	0
Washington	Okanogan	0	0	108	253
Washington	Yakima	0	0	0	574

2A.4 Calculating $PM_{2.5}$ Concentration Fields for Standard Combinations

National $PM_{2.5}$ concentration fields corresponding to meeting the existing, revised, and alternative standards were developed to inform health benefit calculations. First, a gridded $PM_{2.5}$ concentration field for the 2032 CMAQ modeling case was developed using the enhanced Voronoi Neighbor Average (eVNA) method (Ding et al., 2016; Gold et al., 1997; USEPA, 2007). Next, the incremental difference in annual $PM_{2.5}$ DVs between the 2032 case and cases of meeting standard combinations was calculated at monitors and interpolated to the spatial grid. The resulting field of incremental $PM_{2.5}$ concentration was then subtracted from the 2032 eVNA field to create the gridded field for the standard combination. The steps in developing the $PM_{2.5}$ concentration fields are described further below.

2A.4.1 Creating the $PM_{2.5}$ Concentration Field for 2032

The gridded field of annual average $PM_{2.5}$ concentrations for 2032 was developed using the eVNA method that combines information from the model and monitors to predict $PM_{2.5}$ concentrations. The eVNA approach was applied using SMAT-CE and has been previously described in EPA's modeling guidance document (USEPA, 2018) and the user's guide for the predecessor software to SMAT-CE (Abt, 2014). The method is briefly described here, and more details are available in the primary references.

Quarterly average $PM_{2.5}$ component concentrations measured during the 2017-2019 period were interpolated to the spatial grid using inverse distance-squared-weighting of monitored concentrations that were further weighted by the ratio of the 2018 CMAQ value in the prediction grid cell to CMAQ value in the monitor-containing grid cell. Weighting by the ratio of CMAQ values adjusts the interpolation of monitor data to account for spatial gradients in the CMAQ fields. This step results in an interpolated field of gradient-adjusted observed concentrations for each $PM_{2.5}$ component and each quarter:

$$eVNA_{s,q,2018} = \sum Weight_x Monitor_{x,s,q} \frac{Model_{s,q,2018}}{Model_{s,q,2018}} \quad (2A\text{-}10)$$

where $eVNA_{s,q,2018}$ is the gradient-adjusted quarterly-average concentration of $PM_{2.5}$ component species, s, during quarter, q, at the prediction grid cell; $Weight_x$ is the inverse-distance-squared weight for monitor, x, at the location of the prediction grid cell; $Monitor_{x,s,q}$ is the average of the quarterly-average monitored concentrations for species, s, at monitor, x, during quarter, q, in 2017-2019; $Model_{s,q,2018}$ is the quarterly-average 2018 CMAQ concentration of species, s, during quarter, q, in the prediction grid cell; and $Model_{x,s,q,2018}$ is the quarterly-average 2018 CMAQ concentration of species, s, during quarter, q, in the grid cell of monitor, x.

The 2018 eVNA fields for quarterly-average $PM_{2.5}$ component concentrations are the starting point for developing the 2032 $PM_{2.5}$ concentration field. To create eVNA fields for $PM_{2.5}$ components in 2032, the 2018 eVNA component concentration in each grid cell is multiplied by the corresponding ratio of the quarterly-average CMAQ concentration predictions in 2032 and 2018:

$$eVNA_{s,q,2032} = eVNA_{s,q,2018} \frac{Model_{s,q,2032}}{Model_{s,q,2018}} \quad (2A\text{-}11)$$

The $PM_{2.5}$ concentration fields for quarters in 2032 are calculated by summing the 2032 $PM_{2.5}$ component concentration by quarter. The 2032 $PM_{2.5}$ concentration field is then calculated by averaging the 2032 quarterly $PM_{2.5}$ concentrations. The resulting 2032 $PM_{2.5}$ concentration fields is shown in Figure 2A-33.

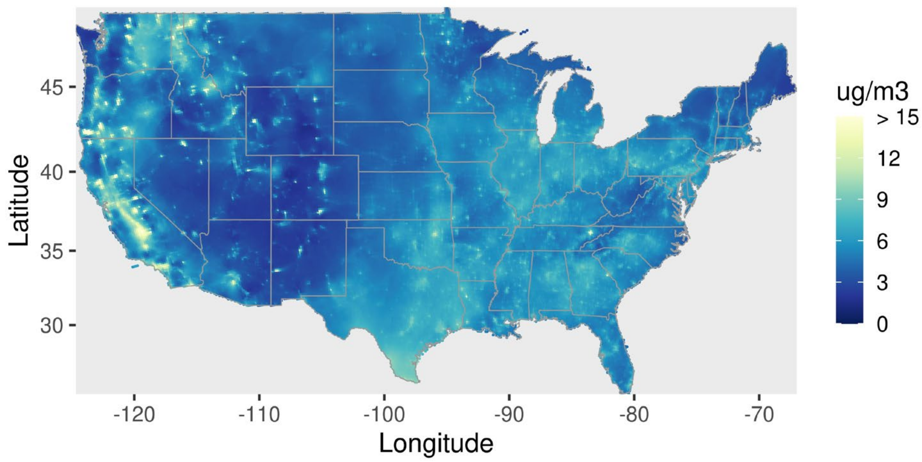

Figure 2A-33 $PM_{2.5}$ Concentration for 2032 based on eVNA Method

2A.4.2 Creating Spatial Fields Corresponding to Meeting Standards

To create spatial fields corresponding to meeting standard levels, the 2032 concentration field was adjusted according to the change in $PM_{2.5}$ concentrations associated with the difference in annual $PM_{2.5}$ DVs between the 2032 case and the cases where standards are met. To implement this adjustment, the difference in annual $PM_{2.5}$ DVs was calculated at the county highest monitor between the 2032 case and cases of meeting the 12/35, 10/30, 10/35, 9/35, and 8/35 standard combinations for counties with monitors exceeding the standard level. The $PM_{2.5}$ DVs for the cases where revised and alternative standard levels are met were developed by applying the air quality ratios to the emission reductions for the county (i.e., Eqn. 2-2). For the county non-highest monitors, the difference in $PM_{2.5}$ DVs was estimated by proportionally adjusting the DVs according to the percent change in $PM_{2.5}$ DV at the highest monitor.

Due to the relatively large size and complex terrain of counties in the western US, the proportional adjustment of DVs within counties was limited in some cases. Proportional adjustment was not applied to six sites that have 2032 annual $PM_{2.5}$ DVs less than 7 $\mu g\ m^{-3}$ and are located within counties that exceed 12/35 standard combination: i.e., 06-029-0011 and 06-029-0018 (Kern, CA), 06-037-9033 (Los Angeles, CA), 06-065-5001 (Riverside, CA), 06-071-8001 (San Bernardino, CA), 30-049-0004 (Lewis and Clark, MT). The relatively low annual $PM_{2.5}$ DVs for these sites compared with the highest-DV monitor suggests they are influenced by different air pollution processes than the highest-DV monitor. Additionally, the annual $PM_{2.5}$ DV at the 06-065-2002 site in Riverside County was not adjusted due to its location outside of the portion of the county within the South Coast Air Basin that contains the highest-DV monitor. The annual $PM_{2.5}$ DV at the 06-051-0001 site in Mono County, CA was also not adjusted because it is outside of the San Joaquin Valley.

After adjusting the annual $PM_{2.5}$ DVs at county monitors and calculating the difference in annual DVs between the 2032 case and cases of meeting the standard combinations, the annual $PM_{2.5}$ DV differences were interpolated to the spatial grid using inverse-distance-squared VNA interpolation. The interpolated field was then clipped to grid cells within 50 km of monitors whose design values changed in meeting the standard level (USEPA, 2012a). National $PM_{2.5}$ concentration fields were then developed for each standard combination by subtracting the corresponding VNA field of incremental $PM_{2.5}$ concentration from the 2032 eVNA concentration field. The resulting $PM_{2.5}$ concentration fields were then compared with regional estimates of background $PM_{2.5}$ concentrations based on a previous CMAQ modeling study with North American anthropogenic emissions set to zero (see Table 3-23 of USEPA, 2009). For a small number of grid cells (three for the 9/35 case and seven for the 8/35 case) in the full attainment scenario, adjusted concentrations were below the Southern California background level of 0.84 $\mu g\ m^{-3}$ and were reset to that value. These grid cells are over the mountain ranges downwind of Los Angeles and Bakersfield where concentrations are much lower than in the South Coast Air Basin and SJV. In the partial attainment case, all concentrations were above the regional background levels and no adjustments were applied.

In Figure 2A-34, the spatial field for the incremental change in $PM_{2.5}$ concentration between the 12/35 analytical baseline and the case of meeting the 9/35 standard combination is shown.

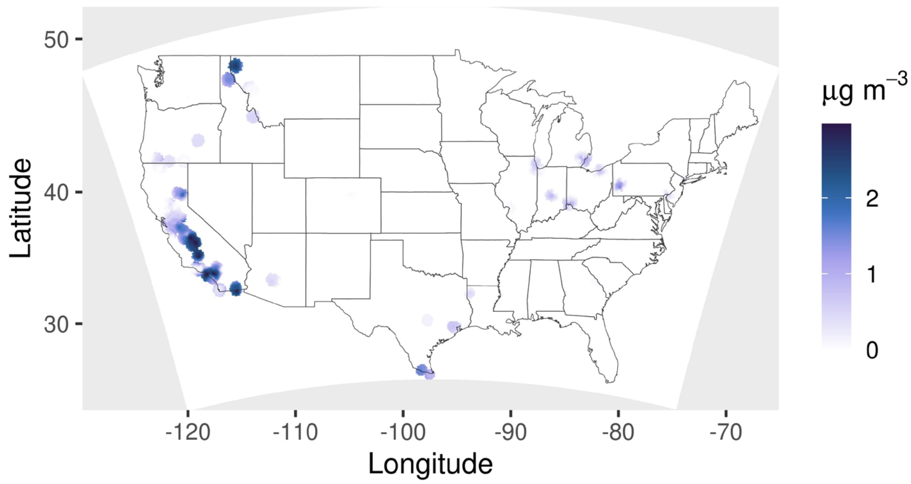

Figure 2A-34 $PM_{2.5}$ Concentration Improvement Associated with Meeting 9/35 Relative to the 12/35 Analytical Baseline

2A.5 References

Abt (2014). User's Guide: Modeled Attainment Test Software. Abt Associates, Prepared for US EPA Office of Air Quality Planning and Standards

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CHAPTER 3: CONTROL STRATEGIES AND $PM_{2.5}$ EMISSIONS REDUCTIONS

Overview

The current primary annual $PM_{2.5}$ standard is 12 μg/m^3, and the current 24-hour standard is 35 μg/m^3. The EPA Administrator is revising the current annual $PM_{2.5}$ standard to a level of 9 μg/m^3. The EPA Administrator is also retaining the current 24-hour standard of 35 μg/m^3. In this Regulatory Impact Analysis (RIA), we analyze the revised annual and current 24-hour standard levels of 9/35 μg/m^3, as well as the following less and more stringent alternative standard levels: (1) a less stringent alternative annual standard level of 10 μg/m^3 in combination with the current 24-hour standard (i.e., 10/35 μg/m^3), (2) a more stringent alternative annual standard level of 8 μg/m^3 in combination with the current 24-hour standard (i.e., 8/35 μg/m^3), and (3) a more stringent alternative 24-hour standard level of 30 μg/m^3 in combination with an alternative annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). Because the EPA is not changing the current secondary PM standards at this time, we did not evaluate alternative secondary standard levels in this RIA.

As discussed in Chapter 1 in the *Overview of the Regulatory Impact Analysis*, the analyses in this RIA rely on national-level data (emissions inventory and control measure information) for use in national-level assessments (air quality modeling, control strategies, environmental justice, and benefits estimation). However, the ambient air quality issues being analyzed are highly complex and local in nature, and the results of these national-level assessments therefore contain uncertainty. It is beyond the scope of this RIA to develop detailed local information for the areas being analyzed, including populating the local emissions inventory, obtaining local information to increase the resolution of the air quality modeling, and obtaining local information on emissions controls, all of which would reduce some of the uncertainty in these national-level assessments. For example, having more refined data would be ideal for agricultural dust and burning, prescribed burning, and non-point (area) sources due to their large contribution to primary $PM_{2.5}$ emissions and the limited availability of emissions controls.[1] In addition, for residential wood combustion emissions, people will respond differently to the various regulations and incentives offered for controlling $PM_{2.5}$ emissions from wood burning, making it important to identify the right balance of controls for each area.

We assume that areas will be designated such that they are required to reach attainment by 2032, and we developed our projected baselines for emissions and air quality for 2032. To estimate the costs and benefits of the revised and less and more stringent annual and 24-hour $PM_{2.5}$ alternative standard levels, we first prepared an analytical baseline for 2032 that assumes full compliance with the current standards of 12/35 $\mu g/m^3$. From that baseline, we then analyze illustrative control strategies that areas might employ toward attaining the revised and less and more stringent annual and 24-hour $PM_{2.5}$ alternative standard levels.[2] Because $PM_{2.5}$ concentrations are most responsive to primary PM emissions reductions, as discussed in Chapter 2, Section 2.1.3, we analyze direct, local $PM_{2.5}$ emissions reductions by individual counties. Section 2.1.3 also includes a discussion of historical and projected emissions trends for direct $PM_{2.5}$ and precursor emissions (i.e., SO_2, NOx, VOC, and ammonia), as well as a discussion of the "urban increment" of consistently higher $PM_{2.5}$ concentrations over urban areas. The projections of additional, large reductions in SO_2 and NO_X emissions in the 2032 case further motivate the need for control of local primary $PM_{2.5}$ sources to address the highest $PM_{2.5}$ concentrations in urban areas.

For the eastern U.S. where counties are relatively small and terrain is relatively flat, we identified potential $PM_{2.5}$ emissions reductions within each county and in adjacent counties within the same state, where needed. As discussed below in Section 3.2.2, when we applied the emissions reductions from adjacent counties, we used a $\mu g/m^3$ per ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions. Because the counties in the western U.S. are generally large

[1] Examples of area source emissions include area fugitive dust, residential wood combustion, and commercial cooking emissions.

[2] We define control strategy as a group of end-of-pipe control technologies and area source controls. In this analysis, we developed control strategies for the revised and alternative standard levels analyzed.

and the terrain is more complex, we only identified potential $PM_{2.5}$ emissions reductions within each county.

Next, we prepare illustrative control strategies. We apply end-of-pipe control technologies to non-electric generating unit (non-EGU) stationary sources (e.g., fabric filters, electrostatic precipitators, venturi scrubbers) and area source controls to non-point (area) sources (e.g., installing controls on charbroilers), to residential wood combustion sources (e.g., converting woodstoves to gas logs), and for area fugitive dust emissions (e.g., paving unpaved roads) in analyzing $PM_{2.5}$ emissions reductions needed toward attaining the revised and alternative standard levels. We did not apply controls to EGUs or mobile sources; Chapter 2, Section 2.1.3 includes a discussion of SO_2 and NO_X emissions decreases reflected in the projections between 2018 and 2032, noting that over the period (1) NO_X emissions are projected to decrease by 3.6 million tons (41 percent), with the greatest reductions from mobile source and EGU emissions inventory sectors, and (2) SO_2 emissions are projected to decrease by 1.1 million tons (48 percent), with the greatest reductions from the EGU emissions inventory sector. In addition, Chapter 2, Section 2.2.1.2 includes a discussion of the EGU and non-EGU rules reflected in the projections for this analysis.

The illustrative control strategy analyses indicate that counties in the northeast and southeast U.S. do not need additional emissions reductions after the application of controls to meet alternative standard levels of 10/35 $\mu g/m^3$ and 10/30 $\mu g/m^3$; however, counties in the northeast and southeast U.S. would need additional $PM_{2.5}$ emissions reductions to meet revised and alternative standard levels of 9/35 $\mu g/m^3$ and 8/35 $\mu g/m^3$. Also, the analysis indicates that counties in the west and California would need additional $PM_{2.5}$ emissions reductions after the application of controls to meet all of the standard levels analyzed.

The remainder of this chapter is organized into four sections. Section 3.1 provides a summary of the steps that we took to create the analytical baseline. Section 3.2 presents the illustrative control strategies identified to assess the revised and less and more stringent annual and 24-hour alternative standard levels in the continental U.S., along with the resulting estimated emissions reductions. Section 3.3 includes a summary of the key limitations and uncertainties associated with the control strategy analyses. Finally, Section

3.4 includes the references for the chapter. We present the costs associated with the estimated $PM_{2.5}$ emissions reductions in Chapter 4.

3.1 Preparing the 12/35 μg/m³ Analytical Baseline

In the 2032 projections, $PM_{2.5}$ DVs exceeded the current standards for some counties in the west and California. As a result, we adjusted the $PM_{2.5}$ DVs for 2032 to correspond with just meeting the current standards to form the 12/35 μg/m³ analytical baseline used in estimating the incremental costs and benefits associated with control strategies for the revised and less and more stringent alternative standard levels relative to the current standards. Figure 3-1 includes a map of the U.S. with the areas identified as northeast, southeast, west, and California; results are summarized for these areas. Table 3-1 presents a summary of the $PM_{2.5}$ emissions reductions needed by area to meet the current standards.

Figure 3-1 Geographic Areas Used in Analysis

Table 3-1 Summary of $PM_{2.5}$ Emissions Reductions Needed by Area in 2032 to Meet Current Primary Annual and 24-hour Standards of 12/35 $\mu g/m^3$ (tons/year)

Area	12/35
Northeast	0
Southeast	0
West	1,494
CA	6,032
Total	7,526

Sixteen counties need $PM_{2.5}$ emissions reductions to meet the current standards in 2032 – 11 counties in California and 5 counties in the west.[3] The counties in California include several counties in the San Joaquin Valley Air Pollution Control District and the South Coast Air Quality Management District, as well as Plumas County, Colusa County, and Siskiyou County in Northern California, Mono County in Eastern California, and Imperial County in Southern California. No counties in the northeast or southeast U.S. need $PM_{2.5}$ emissions reductions to meet the current annual and 24-hour standards.

3.2 Illustrative Control Strategies and $PM_{2.5}$ Emissions Reductions from the Analytical Baseline

To analyze counties projected to exceed the revised and less and more stringent annual and 24-hour alternative standard levels in 2032, we estimate total $PM_{2.5}$ emissions reductions needed by county for the standard levels analyzed. To estimate the $PM_{2.5}$ emissions reductions needed, we start with projected future DVs, DV targets for each area, and the sensitivity of $PM_{2.5}$ DVs to direct $PM_{2.5}$ emissions reductions. For each of the standard levels, we estimate $PM_{2.5}$ emissions reductions needed by county and then identify end-of-pipe and area source controls that can achieve $PM_{2.5}$ emissions reductions. In Section 3.2.1, we discuss the approach for estimating the direct $PM_{2.5}$ emissions reductions needed and present them by area for the revised and alternative standard levels analyzed. In Sections 3.2.2 and 3.2.3, respectively, we present information on the controls and the estimated emissions reductions, from the analytical baseline, associated with applying controls by area for the revised and alternative standard levels analyzed. In Sections 3.2.4 and 3.2.5, we discuss areas with other types of influences affecting $PM_{2.5}$

[3] The 16 counties require primary PM emissions reductions to meet the current standards of 12/35 $\mu g/m^3$ following application of the NOx emission reductions in San Joaquin Valley and the South Coast to adjust the 2032 DVs. For additional discussion, see Appendix 2A, Section 2A.3.2 and Section 2A.3.3.

concentrations. As noted in Chapter 2, Section 2.4, there are certain types of areas for which our illustrative control strategies may not capture important local emissions and air quality dynamics. For these areas, we note that local emissions inventory information and information on potential additional controls for emissions inventory sectors that are traditionally challenging to control may be needed. Section 3.2.4 presents the emissions reductions still needed, and for each area Section 3.2.5 includes a qualitative discussion of the remaining area-specific air quality challenges. Appendix 3A, Table 3A-2 through Table 3A-7 summarize estimated $PM_{2.5}$ emissions reductions by county for the revised and alternative standard levels for the northeast, the adjacent counties in the northeast, the southeast, the adjacent counties in the southeast, the west, and California.

3.2.1 Estimating $PM_{2.5}$ Emissions Reductions Needed for Annual and 24-hour Revised and Alternative Standard Levels Analyzed

We apply regional $PM_{2.5}$ air quality ratios to estimate the emissions reductions needed to reach the revised and less and more stringent annual and 24-hour alternative standard levels analyzed. To develop air quality ratios that relate the change in DV in a county to the change in primary $PM_{2.5}$ emissions in that county, we performed air quality sensitivity modeling with reductions in primary $PM_{2.5}$ emissions in selected counties. More specifically, we conducted a 2028 Community Multiscale Air Quality Modeling System (CMAQ) sensitivity modeling simulation with 50 percent reductions in primary $PM_{2.5}$ emissions from anthropogenic sources in counties with annual 2028 DVs greater than 8 $\mu g/m^3$.[4] We divided the change in annual and 24-hour $PM_{2.5}$ DVs in these counties by the change in emissions in the respective counties to determine the air quality ratio at individual monitors.

We developed representative air quality ratios for regions of the U.S. from the ratios at individual monitors as in the 2012 $PM_{2.5}$ NAAQS review (U.S. EPA, 2012). We calculated regional ratios as the 75th percentile of air quality ratios at monitors within five regions: Northeast, Southeast, Northern California, Southern California, and West. The Northeast

[4] The modeling sensitivity runs were based on 50 percent reductions in emissions to provide estimates of $PM_{2.5}$ sensitivity across the full range of potential emissions changes. Since the response of $PM_{2.5}$ concentrations to changes in primary $PM_{2.5}$ emissions is approximately linear (Kelly et al., 2015, 2019), the air quality ratios are insensitive to the percent emissions change applied in the sensitivity simulations.

region was defined by combining the Upper Midwest, Ohio Valley, and Northeast U.S. climate regions; the Southeast region was defined by combining the Southeast and South climate regions; and California was separated into Southern and Northern regions as done previously. (These regions are shown in Figure 2-7 in Chapter 2[5], and the air quality ratios for primary $PM_{2.5}$ emissions used in estimating the emission reductions needed to just meet the revised and alternative standard levels analyzed are listed in Table 2-1 in Chapter 2.) We estimated the emissions reductions needed to just meet the revised and alternative standard levels analyzed using the primary $PM_{2.5}$ air quality ratios in combination with the required incremental change in concentration. (Chapter 2, Section 2.3.1 includes a brief discussion of developing air quality ratios and estimated emissions reductions needed to just meet the revised and alternative standard levels analyzed, and Appendix 2A, Section 2A.3 includes more detailed discussions.)

Table 3-2 presents a summary of the estimated emissions reductions needed by area to reach the annual and 24-hour alternative standard levels. For the revised and each alternative standard level, Table 3-2 also includes an area's percent of the total estimated emissions reductions needed nationwide to reach that standard level in all locations. For example, for the alternative standard levels of 10/35 $\mu g/m^3$, California's 10,753 estimated tons needed is 81 percent of the total estimated emissions reductions needed nationwide to meet 10/35 $\mu g/m^3$. (See Appendix 2A, Table 2A-14 for the estimated $PM_{2.5}$ emissions reductions, from the analytical baseline, needed by county for the revised and alternative standard levels analyzed.) Figure 3-2 shows the counties projected to exceed the annual and 24-hour revised and alternative standard levels of 10/35 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$ in the analytical baseline. Figure 3-3 shows the counties projected to exceed the annual and 24-hour alternative standard levels of 10/30 $\mu g/m^3$ in the analytical baseline. Additional information on the air quality modeling, as well as information about projected future DVs, DV targets, and air quality ratios is provided in Chapter 2 and Appendix 2A.

[5] To present results throughout this RIA, we combined the Northern California and Southern California regions.

Table 3-2 By Area, Summary of $PM_{2.5}$ Emissions Reductions Needed, in Tons/Year and as Percent of Total Reductions Needed Nationwide, for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032

Area	10/35	10/30	9/35	8/35
Northeast	1,032	1,073	6,974	20,620
Southeast	531	531	3,279	18,658
West	987	6,673	3,132	10,277
CA	10,753	16,660	19,402	31,518
Total	13,303	24,938	32,786	81,073

Area	10/35	10/30	9/35	8/35
Northeast	8%	4%	21%	25%
Southeast	4%	2%	10%	23%
West	7%	27%	10%	13%
CA	81%	67%	59%	39%

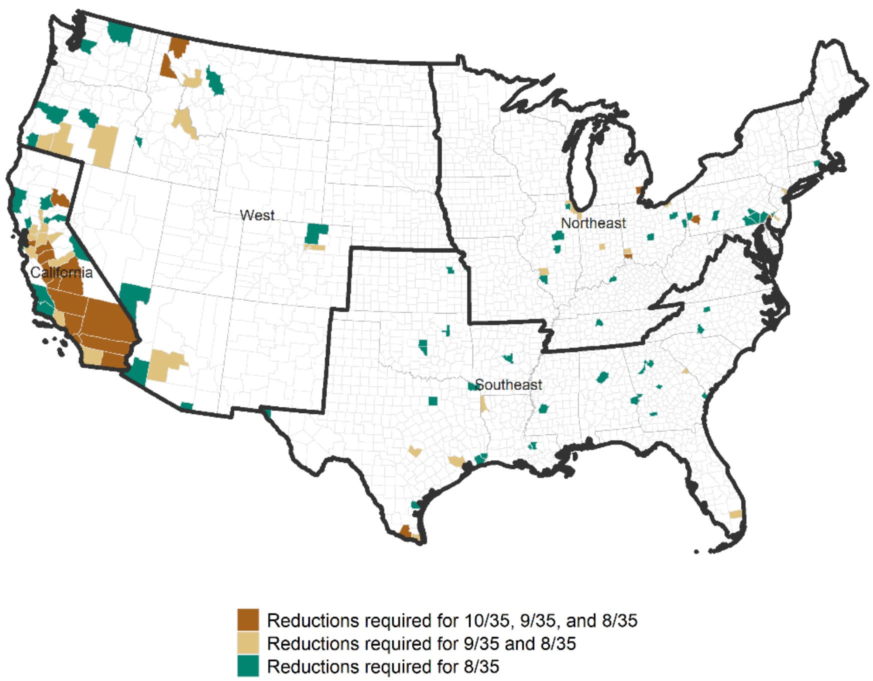

Figure 3-2 Counties Projected to Exceed in Analytical Baseline for Revised and Alternative Standard Levels of 10/35 μg/m³, 9/35 μg/m³, and 8/35 μg/m³

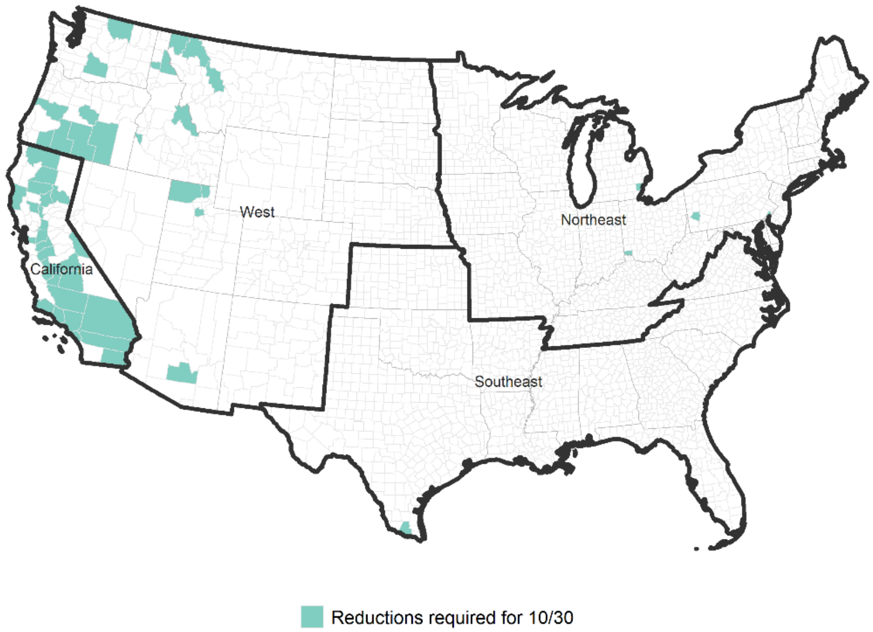

Figure 3-3 Counties Projected to Exceed in Analytical Baseline for Alternative Standard Levels of 10/30 µg/m³

As presented previously, for the revised and alternative standard levels, Chapter 2, Section 2.3.3 includes a discussion of the number of counties that are projected to exceed in 2032, and Figure 2-9 includes maps of counties projected to exceed along with the number of counties. The following summarizes the number of counties, by revised and alternative standard levels, in each geographic area that needs $PM_{2.5}$ emissions reductions from the analytical baseline.

- 10/35 µg/m³-- *20 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 1 county in the southeast, 2 counties in the west, and 13 counties in California.
- 10/30 µg/m³-- *49 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 1 county in the southeast, 19 counties in the west, and 25 counties in California.
- 9/35 µg/m³ -- *52 counties* need $PM_{2.5}$ emissions reductions. This includes 12 counties in the northeast, 7 counties in the southeast, 10 counties in the west, and 23 counties in California.

- 8/35 $\mu g/m^3$ -- *117 counties* need $PM_{2.5}$ emissions reductions. This includes 31 counties in the northeast, 33 counties in the southeast, 21 counties in the west, and 32 counties in California.

3.2.2 Applying End-of-Pipe and Area Source Controls

To identify controls and estimate emissions reductions, we used information about the emissions reductions needed, by county, in the northeast, southeast, west, and California. Given the different county sizes between eastern and western states, as well as different terrain or other topographical features, we estimated potential $PM_{2.5}$ emissions reductions for the eastern U.S. and western U.S. as detailed below. Note that we included a total of 129 counties in the analyses. The total number of counties below (129 counties) does not directly match the number of counties that would need emissions reductions for the more stringent alternative standard levels of 8/35 $\mu g/m^3$ (117 counties) in Section 3.2.1 above. This difference is because there are twelve counties that *do not* need $PM_{2.5}$ emissions reductions to meet alternative standard levels of 8/35 $\mu g/m^3$ but *do* need $PM_{2.5}$ emissions reductions to meet alternative standard levels of 10/30 $\mu g/m^3$.

1. Northeast (31 counties) and Southeast (33 counties) – In the eastern U.S. where counties are relatively small, we were not always able to identify controls within a given county. We identified controls and emissions reductions from neighboring counties because the terrain is relatively flat, and the application of these controls is appropriate in such cases. Because concentrations are most responsive to changes in local emissions and for SIP planning purposes, any emissions reductions from neighboring counties were identified in adjacent counties within the same state.

   To apply emissions reductions in the neighboring counties in the eastern U.S., we compared the responsiveness of annual $PM_{2.5}$ DVs to emissions reductions within a county to the responsiveness for neighboring counties. The resulting impact ratio suggests that primary $PM_{2.5}$ emissions reductions in neighboring counties would be 4 times less effective as in the core county. (Appendix 2A, Section 2A.3.1 includes a more detailed discussion of the comparison.) As such, when we applied the emissions reductions from adjacent counties, we used a $\mu g/m^3$ per ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions (i.e., we applied four tons of $PM_{2.5}$ emissions reductions from an adjacent county for one ton of emissions reduction needed in a given county).

2. West (29 counties) and California (36 counties) - Because these counties are generally large and the terrain is complex, we only identified potential $PM_{2.5}$ emissions reductions within each county.

We identified end-of-pipe and area source controls using the EPA's Control Strategy Tool (CoST) (U.S. EPA, 2019a) and the control measures database.[6,7] CoST estimates emissions reductions and engineering costs associated with end-of-pipe control technologies and area source controls applied to non-electric generating unit (non-EGU) point, non-point (area), residential wood combustion, and area fugitive dust sources of air pollutant emissions by matching controls to emissions sources by source classification code (SCC). For these control strategy analyses, to maximize the number of emissions sources included we applied controls to emissions sources with greater than 5 tons per year of $PM_{2.5}$ emissions at a marginal cost threshold of up to a $160,000/ton. Figure 3-4 presents estimated $PM_{2.5}$ emissions reductions for 5 tons per year (tpy), 10 tpy, 15 tpy, 25 tpy, and 50 tpy emissions unit/source sizes up to the $160,000/ton marginal cost threshold; the figure includes all emissions inventory and control technology data for the counties in the analysis. We selected the $160,000/ton marginal cost threshold because it is around that cost level that (i) road paving controls get selected and applied (as seen by the slight uptick in the curves), and (ii) opportunities for additional emissions reductions diminish (as seen by the flattening of the curve around that cost threshold). While the 2012 PM NAAQS RIA used a $20,000/ton marginal cost threshold and a 50 tpy emissions source size threshold, this analysis uses a higher cost per ton threshold and a lower source size threshold in recognition of the challenges that some areas will experience in identifying

[6] More information about CoST and the control measures database can be found at the following link: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-analysis-modelstools-air-pollution.

[7] The 2032 emissions inventory data, the CoST run results, the CMDB, and the R code that processed these data to prepare the summaries in Chapters 3 and 4 are in the docket and available upon request with the Docket Office.

controls to meet the current, revised, and alternative standard levels analyzed (U.S. EPA, 2012). The estimated costs of the control applications are presented in Chapter 4.

For counties in the northeast and southeast, because we identified controls and reductions from adjacent or neighboring counties, we identified controls and emissions reductions in 2 rounds. Note that a county can be both a core/home county and an adjacent/neighboring county. In round 1 we identified controls and reductions in the home counties for application in the home counties. In round 2 we identified controls and reductions in neighboring counties for application in home counties that still needed reductions. If a county was both a home county and a neighboring county in round 1, before round 2 we adjusted any potential remaining reductions needed for a home county to account for reductions that were applied in round 1 for application in its neighboring county. In addition, in some cases more emissions reductions are selected by CoST than may be needed for some areas to meet the revised and alternative standard levels. There are two primary reasons this may occur. First, because CoST employs a least cost algorithm to determine the bundle of controls that achieves the required emissions reductions at the lowest possible cost, there are instances when a non-point or area fugitive dust source will be selected for control due to its cost-effectiveness. Because the emissions from these sources are summarized at the county level and the controls specify a percent reduction, selection of these sources for control can sometimes lead to overshooting the emissions reduction target.

Second, for counties in the northeast and southeast, we considered emissions reductions from adjacent counties. There are some instances where a neighboring county may be adjacent to multiple counties that need reductions. Furthermore, it is sometimes the case that one of the multiple counties to which a neighboring county is adjacent needs substantially more reductions than the other counties. In these cases, an adjacent (neighboring) county may be called upon to provide reductions to help the county that needs the most reductions, and in so doing it may cause the other counties to which it is adjacent to overshoot their emissions reductions targets.

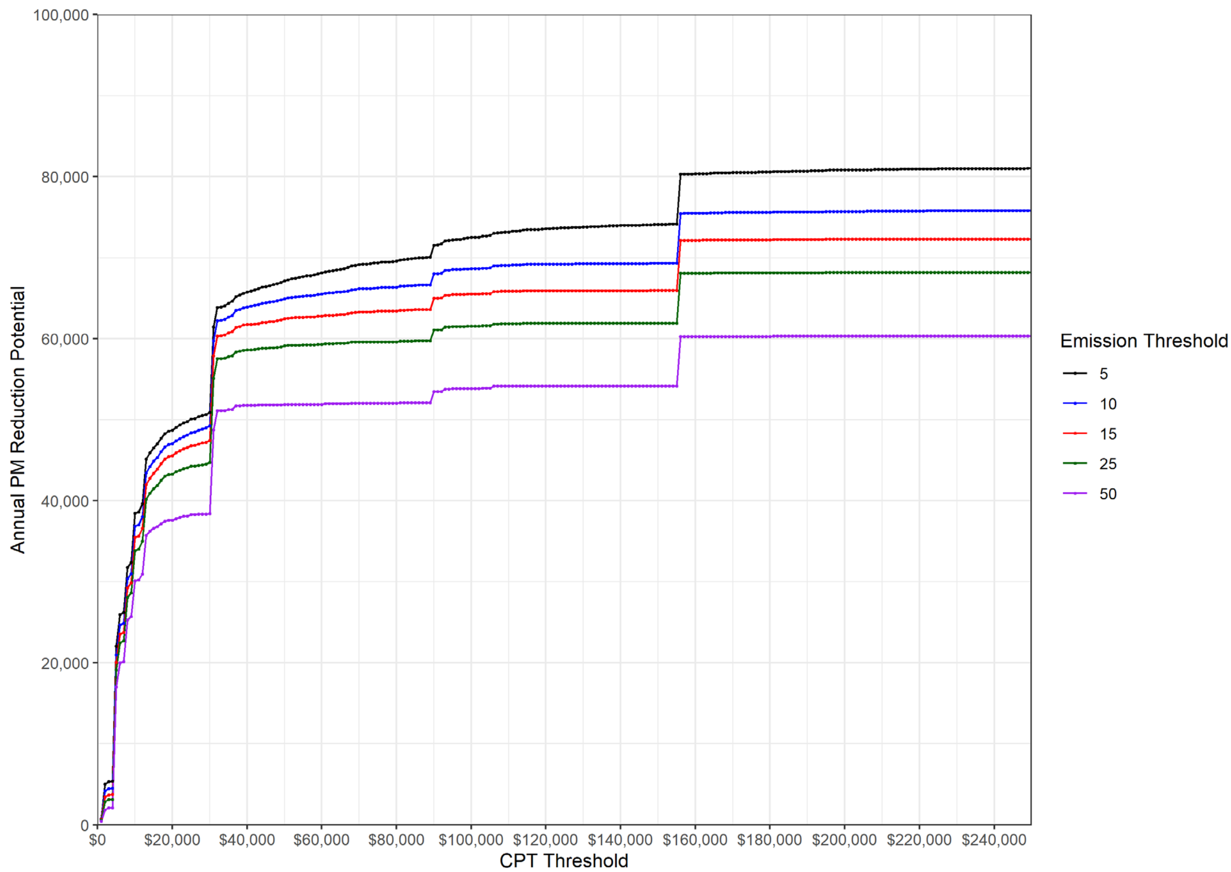

Figure 3-4 $PM_{2.5}$ Emissions Reductions and Costs Per Ton (CPT) in 2032 (tons, 2017$)

We identified end-of-pipe and area source controls for non-electric generating unit point sources (non-EGU point, oil & gas point), non-point (area) sources, residential wood combustion sources, and area fugitive dust emissions. Controls applied for the analyses of the current standards of 12/35 μg/m³ and the annual and 24-hour $PM_{2.5}$ revised and alternative standard levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ are listed in Table 3-3 by emissions inventory sector, with an "X" indicating which controls were applied in analyzing each standard level. See Appendix 3A, Table 3A.1 for a more detailed presentation of controls applied for the revised and alternative standard levels both by geographic area and by emissions inventory sector, as well as a discussion of some of the controls. The non-EGU point source control *Install new drift eliminator* was applied at different rule penetration (RP) rates depending on the reductions needed in particular areas at different standard levels. In addition, with the exception of the *Substitute chipping for burning* and *Watering (Agriculture – Crops and Livestock Dust)* controls, the non-point (area) source, residential wood combustion, and area source fugitive dust controls were applied at different RP rates depending on the reductions needed in particular areas at different standard levels. RP is the percent of the area source inventory emissions that the control is applied to at a specified percent control efficiency. The controls were applied at between 5 percent and 35 percent RP at 5 percent increments.

Non-EGU point source controls are applied to individual point sources. Non-point (area), residential wood combustion, and area fugitive dust emissions data are generated at the county level, and therefore controls for these emissions inventory sectors were applied at the county level.[8] End-of-pipe and area source controls were applied to non-EGU point, non-point (area), residential wood combustion, and area fugitive dust sources of $PM_{2.5}$ emissions including: industrial, commercial, and institutional boilers; industrial processes located in the cement manufacturing, chemical manufacturing, pulp and paper, mining, ferrous and non-ferrous metals, and refining industries; commercial cooking; residential wood combustion; and fugitive construction, agriculture, and road dust.

[8] The point source emissions inventories used may not accurately reflect existing controls on emissions units, and we may inadvertently apply a control to a source that already has that, or a different, control. The non-point emissions inventories may not accurately reflect the portion of existing emissions sources that have already installed some non-point (area) source controls. As such, we may be applying controls that are already accounted for in the underlying emissions inventory.

Table 3-3 By Inventory Sector, Controls Applied in Analyses of the Current Standards and the Revised and Alternative Primary Standard Levels

Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
Non-EGU Point	Electrostatic Precipitator-All Types	x			x	
	Fabric Filter-All Types	x	x	x	x	x
	Install new drift eliminator	x			x	x
	Venturi Scrubber	x	x	x	x	x
Oil & Gas Point	Fabric Filter-All Types		x	x	x	x
Non-Point (Area)	Add-on Scrubber					x
	Annual tune-up	x	x	x	x	x
	Biennial tune-up	x	x	x	x	x
	Catalytic oxidizers	x		x	x	x
	Electrostatic Precipitator	x	x	x	x	x
	HEPA filters				x	x
	Smokeless Broiler	x	x	x	x	x
	Substitute chipping for burning	x	x	x	x	x
Residential Wood Combustion	Convert to Gas Logs	x	x	x	x	x
	EPA Phase 2 Qualified Units	x		x	x	x
	EPA-certified wood stove		x	x	x	
	Install Cleaner Hydronic Heaters	x	x	x	x	x
	Install Retrofit Devices				x	x
	New gas stove or gas logs	x	x	x	x	x
Area Source Fugitive Dust	Chemical Stabilizer	x		x	x	x
	Pave Unpaved Roads	x	x	x	x	x
	Pave existing shoulders	x	x	x	x	x
	Watering	x	x	x	x	x

Note: For residential wood combustion emissions, we did not apply wood stove removal and burn ban controls in the control strategy analyses because we did not want to potentially eliminate or ban any lone home heating source without replacing a heating source.

3.2.3 Estimates of $PM_{2.5}$ Emissions Reductions Resulting from Applying Control Technologies

By area, Table 3-4 includes a summary of the estimated emissions reductions from control applications for the revised and alternative standards analyzed. These emissions reductions were used to create the $PM_{2.5}$ spatial surfaces described in Appendix 2A, Section 2A.4.2 for the human health benefits assessments presented in Chapter 5.

Table 3-4 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST by Area for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

	PM2.5 Emissions Reductions			
Area	**10/35**	**10/30**	**9/35**	**8/35**
Northeast	1,032	1,074	7,226	14,036
Northeast (Adjacent Counties)	0	0	2,599	11,911
Southeast	521	521	1,959	13,995
Southeast (Adjacent Counties)	45	45	354	3,086
West	470	2,715	1,386	5,323
CA	3,010	4,652	5,069	7,181
Total	5,078	9,006	18,592	55,532

Note: Totals may not match related tables due to independent rounding. In the northeast and southeast when we applied the emissions reductions from adjacent counties, we used a ppb/ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions.

By emissions inventory sector, Table 3-5 includes a summary of $PM_{2.5}$ emissions and estimated emissions reductions from control applications for the revised and alternative standard levels analyzed. The $PM_{2.5}$ emissions in Table 3-5 are the total emissions associated with the emissions units/sources that get controls applied within each of the inventory sectors for each of the alternative standard levels (not the total emissions associated with the entire inventory sector). Across the revised and alternative standard levels analyzed, overall total emissions reductions are approximately 28 to 35 percent of the $PM_{2.5}$ emissions from the sources selected by CoST for control. In general, a large percentage of the emissions are being controlled for the revised and alternative standard levels analyzed, while different inventory sectors are selected for control in different areas and additional reductions may be possible in some areas.

The emissions inventory sector with the highest percent of emissions reductions relative to total potentially controllable emissions for that sector is the non-EGU point sector – the estimated emissions reductions are between 88 and 99 percent of total $PM_{2.5}$ emissions from the sources selected for control, with that percent decreasing as the alternative standard level gets more stringent. The emissions inventory sector with the lowest percent of emissions reductions relative to total potentially controllable emissions for that sector is the area fugitive dust sector – the estimated emissions reductions are between 18 and 27 percent of total $PM_{2.5}$ emissions from the sources selected for control, with that percent decreasing as the alternative standard level gets more stringent. The residential wood combustion sector's emissions reductions relative to total potentially controllable emissions are between 31 and 34 percent across the revised and alternative standard levels analyzed. It is worth noting that the control efficiencies associated with area source controls for the non-point (area), area fugitive dust, and residential wood combustion sectors are generally lower than control efficiencies associated with end-of-pipe controls for the non-EGU point and oil and gas point inventory sectors, and many of the controls for these sectors are only applied to a portion of the inventory. For the revised standard levels of 9/35 $\mu g/m^3$, the inventory sectors with the most potentially controllable emissions are the non-point (area) and area fugitive dust sectors. The inventory sectors with the most estimated emissions reductions are the non-point (area) and non-EGU point sectors.

Table 3-5 Summary of $PM_{2.5}$ Emissions and Estimated Emissions Reductions from CoST by Inventory Sector for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Emissions Inventory Sector	10/35	10/30	9/35	8/35
Non-EGU Point				
PM2.5 Emissions	940	1,288	4,887	14,136
PM2.5 Emissions Reductions	928	1,269	4,277	12,534
Oil & Gas Point				
PM2.5 Emissions	5	5	5	21
PM2.5 Emissions Reductions	5	5	5	21
Non-Point (Area)				
PM2.5 Emissions	7,379	10,794	27,286	70,847
PM2.5 Emissions Reductions	2,234	3,264	8,766	25,947
Residential Wood Combustion				
PM2.5 Emissions	1,127	2,730	5,298	12,994
PM2.5 Emissions Reductions	378	872	1,636	4,190
Area Source Fugitive Dust				
PM2.5 Emissions	5,676	16,866	15,608	71,086
PM2.5 Emissions Reductions	1,533	3,596	3,909	12,840
Total				
PM2.5 Emissions	15,127	31,683	53,085	169,086
PM2.5 Emissions Reductions	5,078	9,006	18,592	55,532

Note: The $PM_{2.5}$ emissions in the table are for the emissions sources that get controls applied within each of the inventory sectors (not the total emissions associated with the entire inventory sector) for each of the standard levels.

By emissions inventory sector and by control technology, Table 3-6 includes a summary of estimated $PM_{2.5}$ emissions reductions from control applications for the revised and alternative standard levels analyzed. Across standard levels analyzed, estimated $PM_{2.5}$ emissions reductions from control applications in the (i) non-EGU point and oil and gas point inventory sectors account for between 14 and 23 percent of estimated reductions; (ii) non-point (area) inventory sector account for between 36 and 47 percent of estimated reductions; (iii) residential wood combustion inventory sector account for between 7 and

10 percent; and (iv) area fugitive dust inventory sector account for between 21 and 40 percent.

Also, across standard levels analyzed, six end-of-pipe and area source controls comprise between approximately 76 and 90 percent of the estimated emissions reductions. Those controls include:

- Fabric Filter- All Types (non-EGU point inventory sector) – the control technology is generally applied to industrial, commercial, and institutional boilers and industrial processes located in the cement manufacturing, chemical manufacturing, pulp and paper, mining, ferrous and non-ferrous metals, and refining industries.
- Electrostatic Precipitator (non-point (area) inventory sector) – the control is applied to area source commercial cooking emissions.
- Substitute Chipping for Burning (non-point (area) inventory sector) – the control is applied to area source waste disposal emissions.
- Convert to Gas Logs (residential wood combustion inventory sector) – the control is applied to area source residential wood combustion emissions.
- Pave Existing Shoulders (area fugitive dust inventory sector) – the control is applied to road dust emissions.
- Pave Unpaved Roads (area fugitive dust inventory sector) – the control is applied to road dust emissions.

The three controls that result in the most emissions reductions for revised and alternative standard levels of 10/35 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$ are Fabric Filter- All Types, Electrostatic Precipitator, and Substitute Chipping for Burning. The three controls that result in the most emissions reductions for alternative standard levels of 10/30 $\mu g/m^3$ are Electrostatic Precipitator, Substitute Chipping for Burning, and Pave Unpaved Roads.

Table 3-6 Summary of Estimated Emissions Reductions from CoST by Inventory Sector and Control Technology for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Inventory Sector	Control Technology	10/35	10/30	9/35	8/35
Non-EGU Point	Electrostatic Precipitator-All Types	0	0	24	0
	Fabric Filter-All Types	923	1,222	3,444	10,748
	Install new drift eliminator	0	0	171	512
	Venturi Scrubber	5	47	638	1,274
Oil & Gas Point	Fabric Filter-All Types	5	5	5	21
Non-Point (Area)	Add-on Scrubber	0	0	0	4
	Annual tune-up	58	121	825	1,940
	Biennial tune-up	136	160	24	198
	Catalytic oxidizers	0	75	318	99
	Electrostatic Precipitator	1,154	1,362	3,633	8,721
	HEPA filters	0	0	1	0
	Smokeless Broiler	74	79	437	909
	Substitute chipping for burning	811	1,466	3,528	14,075
Residential Wood Combustion	Convert to Gas Logs	357	674	1,212	2,572
	EPA Phase 2 Qualified Units	0	78	13	197
	EPA-certified wood stove	1	1	0	0
	Install Cleaner Hydronic Heaters	10	65	178	654
	Install Retrofit Devices	0	0	52	33
	New gas stove or gas logs	9	55	180	733
Area Source Fugitive Dust	Chemical Stabilizer	0	610	234	4,737
	Pave Unpaved Roads	838	1,493	1,364	2,185
	Pave existing shoulders	468	734	1,655	4,056
	Watering	226	759	656	1,862
Total		5,078	9,006	18,592	55,532

By emissions inventory sector and by inventory source classification code (SCC) sector, Table 3-7 includes a summary of estimated $PM_{2.5}$ emissions reductions from control applications for the revised and alternative standard levels analyzed. As seen in Table 3-6, across standard levels analyzed, estimated $PM_{2.5}$ emissions reductions from control applications in the (i) non-EGU point and oil and gas point inventory sectors account for between 14 and 23 percent of estimated reductions; (ii) non-point (area) inventory sector account for between 36 and 47 percent of estimated reductions; (iii) residential wood combustion inventory sector account for between 7 and 10 percent; and (iv) area fugitive dust inventory sector account for between 21 and 40 percent.

Across standard levels analyzed, estimated $PM_{2.5}$ emissions reductions from control applications in the *Industrial Processes – Cement Manufacturing, Industrial Processes – Ferrous Metals*, *Industrial Processes – Not Elsewhere Classified*, and *Industrial Processes – Petroleum Refineries* inventory SCC sectors account for between 48 percent and 69 percent of reductions from the non-EGU point and oil and gas point inventory sectors. Estimated $PM_{2.5}$ emissions reductions from control applications in the *Commercial Cooking* and *Waste Disposal – All Categories* inventory SCC sectors account for between 82 percent and 90 percent of reductions from the non-point (area) inventory sector. Estimated $PM_{2.5}$ emissions reductions from control applications in the *Fuel Combustion – Residential – Wood* inventory SCC sector account for all of the reductions from the residential wood combustion inventory sector, and estimated $PM_{2.5}$ emissions reductions from control applications in the *Agriculture - Crops & Livestock Dust, Dust – Paved Road Dust,* and *Dust – Unpaved Road Dust* inventory SCC sectors account for all of the reductions from the area source fugitive dust inventory sector.

Table 3-7 Summary of Estimated $PM_{2.5}$ Emissions Reductions from CoST by Inventory Source Classification Code Sectors for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Sector	SCC Sector	10/35	10/30	9/35	8/35
Non-EGU Point	Fuel Combustion - Commercial/Institutional Boilers - Natural Gas	0	0	0	5.2
	Fuel Combustion - Commercial/Institutional Boilers - Other	47.6	47.6	47.6	47.6
	Fuel Combustion - Industrial Boilers, ICEs - Biomass	0	0	14.7	316.6
	Fuel Combustion - Industrial Boilers, ICEs - Natural Gas	0	0	23.8	109.0
	Fuel Combustion - Industrial Boilers, ICEs - Oil	0	0	0	11.5
	Fuel Combustion - Industrial Boilers, ICEs - Other	96.6	96.6	379.3	762.0
	Industrial Processes - Cement Manufacturing	149.1	149.1	469.1	581.9
	Industrial Processes - Chemical Manufacturing	74.6	80.0	222.7	576.1
	Industrial Processes - Ferrous Metals	0	0	532.2	1,675.4
	Industrial Processes - Mining	0	0	0	249.1
	Industrial Processes - Non-ferrous Metals	0	13.0	195.4	724.3

Sector	SCC Sector	10/35	10/30	9/35	8/35
	Industrial Processes - Not Elsewhere Classified	210.1	294.1	1,525.7	4,348.0
	Industrial Processes - Petroleum Refineries	164.1	164.1	409.2	1,615.5
	Industrial Processes - Pulp & Paper	5.3	182.8	124.6	850.4
	Industrial Processes - Storage and Transfer	111.4	172.4	182.9	506.4
	Solvent - Degreasing	0	0	17.2	17.2
	Solvent - Industrial Surface Coating & Solvent Use	62.9	62.9	125.8	125.8
	Waste Disposal - General Processes	6.7	6.7	6.7	11.8
Oil & Gas Point	Fuel Combustion - Commercial/Institutional Boilers - Natural Gas	0	0	0	16.1
	Industrial Processes - Oil & Gas Production	5.1	5.1	5.1	5.1
Non-Point (Area)	Commercial Cooking	1,228.3	1,516.6	4,388.4	9,733.5
	Fuel Combustion - Commercial/Institutional Boilers - Biomass	16.0	22.5	116.6	252.8
	Fuel Combustion - Commercial/Institutional Boilers - Natural Gas	17.0	24.1	73.6	109.3
	Fuel Combustion - Commercial/Institutional Boilers - Oil	6.7	9.7	14.6	18.5
	Fuel Combustion - Commercial/Institutional Boilers - Other	0.6	0.6	0.6	0.6
	Fuel Combustion - Industrial Boilers, ICEs - Biomass	120.4	184.7	567.6	1,629.9
	Fuel Combustion - Industrial Boilers, ICEs - Coal	0.1	2.6	2.5	14.0
	Fuel Combustion - Industrial Boilers, ICEs - Natural Gas	32.3	34.2	68.0	105.8
	Fuel Combustion - Industrial Boilers, ICEs - Oil	1.7	2.5	5.7	7.5
	Waste Disposal - All Categories	773.1	1,156.5	3,009.4	11,995.2
	Waste Disposal - Residential	38.0	309.8	519.0	2,080.2
Residential Wood Combustion	Fuel Combustion - Residential - Wood	377.9	871.9	1,635.6	4,189.5
Area Source Fugitive Dust	Agriculture - Crops & Livestock Dust	226.3	758.5	656.4	1,861.7
	Dust - Paved Road Dust	468.0	733.8	1,654.6	4,055.8
	Dust - Unpaved Road Dust	838.2	2,103.7	1,597.9	6,922.3
Total		5,078.1	9,006.1	18,592.5	55,531.7

3.2.4 Estimates of $PM_{2.5}$ Emissions Reductions Still Needed after Applying End-of-Pipe and Area Source Controls

The percent of total $PM_{2.5}$ emissions reductions *estimated* from CoST (shown in Table 3-4 above) relative to total $PM_{2.5}$ emissions reductions *needed* (shown in Table 3-2 above) varies by standard level and by area. Note that in the northeast and southeast when we applied the emissions reductions from adjacent counties, we used a $\mu g/m^3$ per ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions (i.e., we applied four tons of $PM_{2.5}$ emissions reductions from an adjacent county for one ton of emissions reduction needed in a given county). For the revised standards of 9/35 $\mu g/m^3$, for the northeast we were able to identify approximately 98 percent of the reductions needed. For the southeast we were able to identify approximately 68 percent of the reductions needed. For the west, we were able to identify approximately 44 percent of the reductions needed, and for California the percentage is approximately 26 percent. For the more stringent standard levels of 8/35 $\mu g/m^3$, for the northeast we were able to identify approximately 84 percent of the reductions needed. For the southeast we were able to identify approximately 81 percent of the reductions needed. For the west, we were able to identify approximately 52 percent of the reductions needed, and for California the percentage is approximately 23 percent.[9]

The higher percent of *estimated* emissions reductions relative to *needed* reductions in the northeast and southeast is likely because as the standard level becomes more stringent, more controls from counties projected to exceed and their adjacent counties are available and applied. See Appendix 3A, Table 3A-2 through Table 3A-7 for more detailed summaries of $PM_{2.5}$ emissions reductions by county for the revised and alternative standard levels for the northeast, the adjacent counties in the northeast, the southeast, the adjacent counties in the southeast, the west, and California. Table 3A-7 for California presents the counties organized by air districts.

[9] Compared to standard levels of 9/35 $\mu g/m^3$, the more stringent alternative standard levels of 8/35 $\mu g/m^3$ include more counties that need reductions, a different set of emission reduction targets, and in the NE and SE more neighbor/adjacent counties. When these additional counties are included and emissions reductions in these counties are identified, the percentages may increase, which is happening in the SE and W for the more stringent standard levels of 8/35 $\mu g/m^3$ compared to the revised standard levels of 9/35 $\mu g/m^3$.

As indicated, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. By area, Table 3-8 includes a summary of the estimated emissions reductions still needed after control applications for the revised and alternative standard levels analyzed. By area and by county, Table 3-9 includes a more detailed summary of the estimated emissions reductions still needed after control applications for the revised and alternative standard levels analyzed. As seen in Table 3-9, some counties need emissions reductions to meet a standard level of 10/30 $\mu g/m^3$ that did not need emissions reductions to meet a standard level of 10/35 $\mu g/m^3$. These counties are in the west and California, where there are small valleys with mountainous terrain and wintertime inversions, along with residential woodsmoke emissions and some wildfire influence, and need emissions reductions to meet the more stringent 24-hour standard level of 30 $\mu g/m^3$. Figure 3-5 through Figure 3-8 show the counties that still need emissions reductions after control applications for the revised and alternative standards analyzed.

The analysis indicates that counties in the northeast and southeast U.S. do not need additional emissions reductions to meet alternative standard levels of 10/35 $\mu g/m^3$ and 10/30 $\mu g/m^3$. For the northeast, 2 (out of 12) counties need additional emissions reductions to reach attainment of the revised alternative standard levels of 9/35 $\mu g/m^3$, and 5 (out of 31) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 8/35 $\mu g/m^3$. For the southeast, 2 (out of 7) counties need additional emissions reductions to reach attainment of the revised alternative standard levels of 9/35 $\mu g/m^3$, and 5 (out of 33) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 8/35 $\mu g/m^3$.

The analysis also indicates that counties in the west and California need additional emissions reductions after the application of controls to meet all of the standard levels. For the west, 2 (out of 2) counties need additional emissions reductions to reach attainment of the less stringent alternative standard levels of 10/35 $\mu g/m^3$, 10 (out of 19) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 10/30 μg/m³, 4 (out of 10) counties need additional emissions reductions to reach attainment of the revised standard levels of 9/35 μg/m³, and 10 (out of 21) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 8/35 μg/m³. For California, 12 (out of 13) counties need additional emissions reductions to reach attainment of the less stringent alternative standard levels of 10/35 μg/m³, 20 (out of 25) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 10/30 μg/m³, 17 (out of 23) counties need additional emissions reductions to reach attainment of the revised alternative standard levels of 9/35 μg/m³, and 24 (out of 32) counties need additional emissions reductions to reach attainment of the more stringent alternative standard levels of 8/35 μg/m³.

Table 3-8 Summary of $PM_{2.5}$ Emissions Reductions Still Needed by Area for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Area	10/35	10/30	9/35	8/35
Northeast	0	0	130	3,285
Southeast	0	0	1,038	3,519
West	516	3,959	1,747	4,982
CA	7,739	11,986	14,411	24,366
Total	8,255	15,945	17,327	36,152

Table 3-9 Summary of $PM_{2.5}$ Emissions Reductions Still Needed by Area and by County for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

Area	Area Name	10/35	10/30	9/35	8/35
Northeast	Marion County, IN	0	0	0	496
	Bergen County, NJ	0	0	75	807
	Camden County, NJ	0	0	0	535
	Hamilton County, OH	0	0	55	784
	Delaware County, PA	0	0	0	664
Southeast	District Of Columbia	0	0	0	69
	Caddo Parish, LA	0	0	0	374
	West Baton Rouge Parish, LA	0	0	0	0
	Cameron County, TX	0	0	351	1,168
	El Paso County, TX	0	0	0	402
	Hidalgo County, TX	0	0	687	1,505
West	Maricopa County, AZ	0	0	0	4
	Pinal County, AZ	0	162	0	0

Area	Area Name	10/35	10/30	9/35	8/35
	Santa Cruz County, AZ	0	0	0	274
	Adams County, CO	0	0	0	161
	Denver County, CO	0	0	0	353
	Benewah County, ID	0	238	0	0
	Lemhi County, ID	0	557	235	703
	Shoshone County, ID	90	410	558	1,026
	Lewis and Clark County, MT	0	523	0	173
	Lincoln County, MT	426	426	894	1,361
	Harney County, OR	0	0	0	398
	Klamath County, OR	0	449	60	528
	Lake County, OR	0	575	0	0
	Okanogan County, WA	0	44	0	0
	Yakima County, WA	0	575	0	0
CA	Alameda County, CA	0	0	34	351
	Calaveras County, CA	0	0	50	367
	Colusa County, CA	0	502	0	0
	Fresno County, CA	124	124	441	758
	Imperial County, CA	1,665	1,665	2,516	3,366
	Kern County, CA	409	409	726	1,043
	Kings County, CA	413	413	730	1,047
	Los Angeles County, CA	599	599	1,450	2,300
	Madera County, CA	0	0	38	355
	Mendocino County, CA	0	109	0	0
	Merced County, CA	22	22	339	656
	Mono County, CA	0	502	0	173
	Napa County, CA	0	0	0	203
	Orange County, CA	329	329	1,179	2,030
	Plumas County, CA	309	502	626	943
	Riverside County, CA	1,701	1,701	2,551	3,402
	Sacramento County, CA	0	0	0	204
	San Bernardino County, CA	1,625	1,625	2,475	3,326
	San Diego County, CA	0	0	0	326
	San Francisco County, CA	0	0	0	91
	San Joaquin County, CA	0	0	48	365
	Santa Barbara County, CA	0	1,082	0	0
	Siskiyou County, CA	0	138	0	0
	Solano County, CA	0	0	0	283
	Stanislaus County, CA	97	97	414	731
	Sutter County, CA	0	105	31	348
	Tehama County, CA	0	170	0	0
	Tulare County, CA	446	446	763	1,080
	Ventura County, CA	0	1,447	0	619
Total		8,255	15,945	17,327	36,152

Note: The table includes only those counties that still need reductions (e.g., in the Northeast there were 31 counties that needed emissions reductions, and only the 5 counties still need emissions reductions for an alternative standard level of 8/35 μg/m^3).

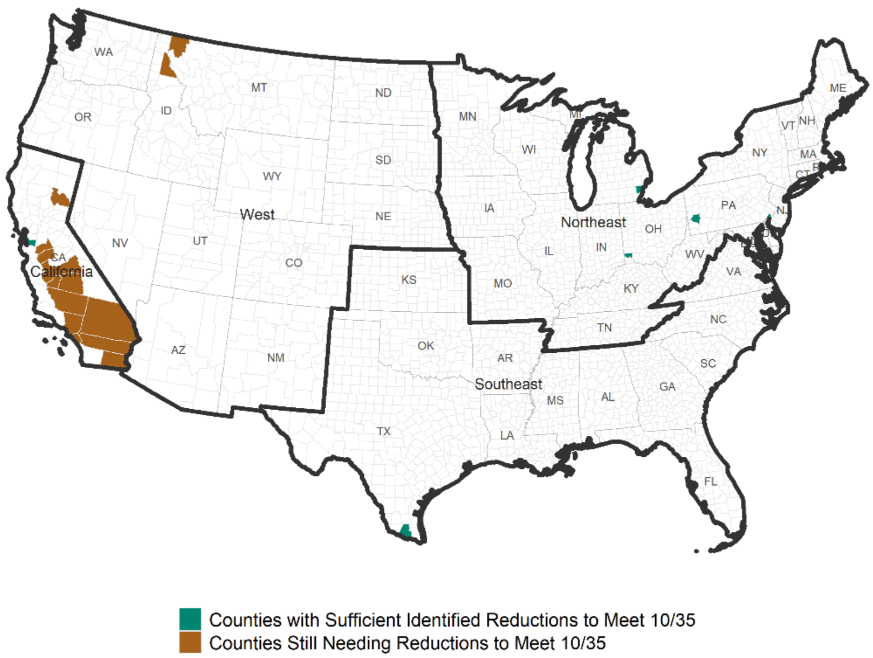

Figure 3-5 Counties that Still Need $PM_{2.5}$ Emissions Reductions for Less Stringent Alternative Standard Levels of 10/35 µg/m^3

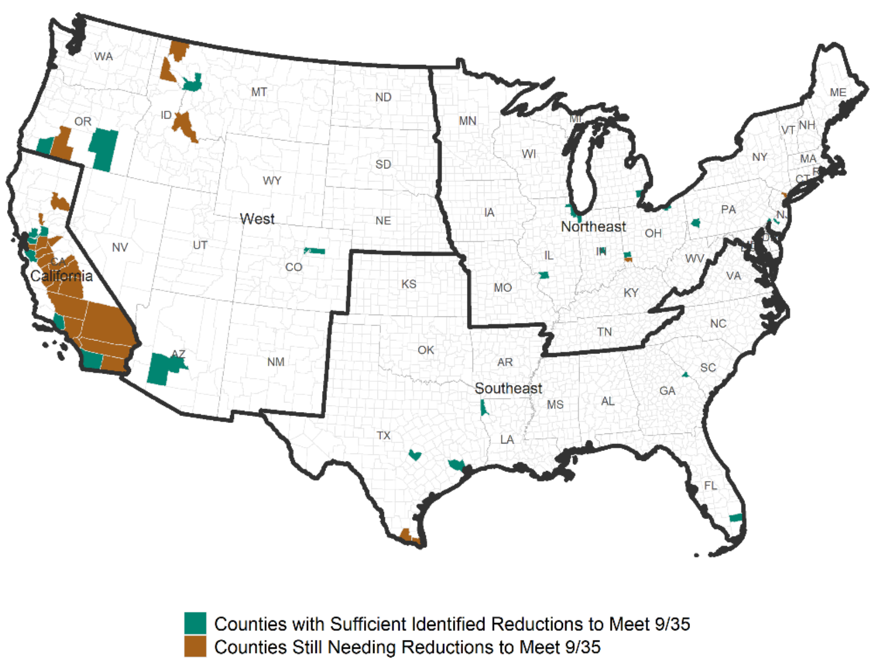

Figure 3-6 Counties that Still Need $PM_{2.5}$ Emissions Reductions for Revised Standard Levels of 9/35 µg/m^3

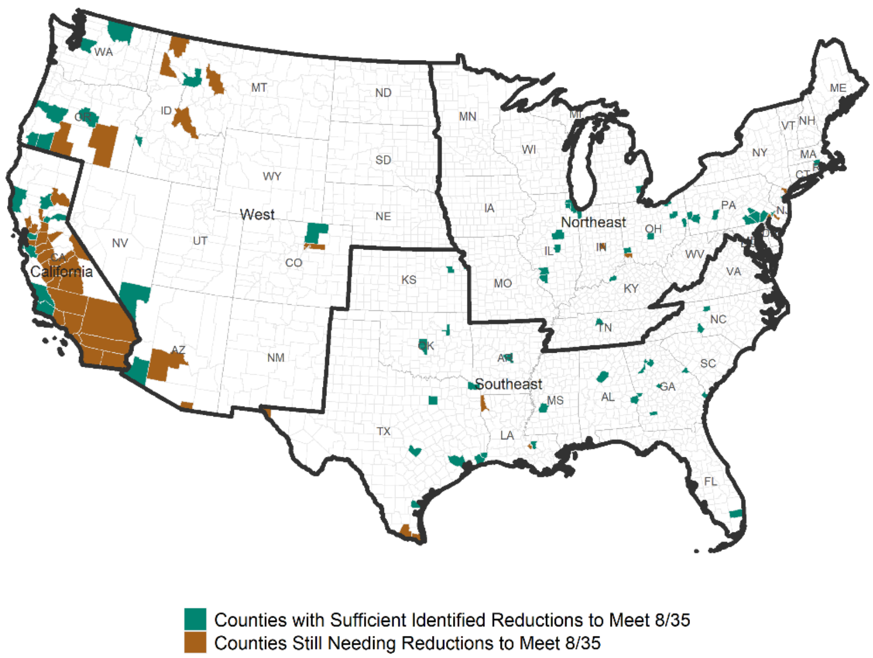

Figure 3-7 **Counties that Still Need PM2.5 Emissions Reductions for More Stringent Alternative Standard Levels of 8/35 μg/m³**

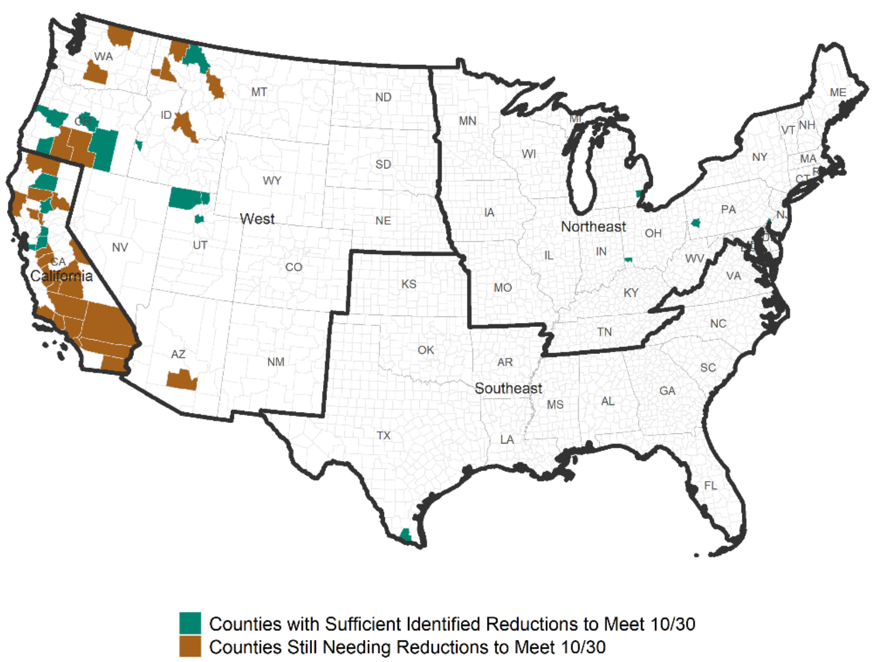

Figure 3-8 **Counties that Still Need PM2.5 Emissions Reductions for More Stringent Alternative Standard Levels of 10/30 μg/m³**

Table 3A-8 in Appendix 3A includes information on counties that still need emissions reductions and remaining $PM_{2.5}$ emissions by emissions inventory sector in those and adjacent counties. For some counties still needing emissions reductions, additional controls from the CMDB (listed below), rules listed in Table 3-10, or voluntary measures identified in Table 3-11 may provide information on potential additional area source controls or policies to consider that are beyond the scope of this analysis.

As noted, we did not apply some area source controls from the CMDB in the control strategy analyses. By emissions inventory sector, the controls include those identified below. Note that the X in the control measure abbreviation is the rule penetration rate.

- Residential Wood Combustion Emissions (Fireplaces, Hydronic Heaters, Wood Stoves)
  - Remove and destroy old wood stoves (control measure abbreviation: PBBFPHHWDSX)
  - Curtailment program, Burn bans for fireplaces, hydronic heaters, wood stoves (control measure abbreviation: PROWSWDSTVX)
- Construction Dust, Road Dust Controls
  - Apply gravel (control measure abbreviation: PGVUNPAVEDX)
  - Apply water (PWATUNPAVEDX)
  - Truck system for soil moisture (PTRCONSTX)
  - Trackout control devices (PTCDPAVEDX)
  - Gravel bed trackout (PGBTPAVEDX)
  - Dust control plan (control measure abbreviation: PDCPCONSTX)
  - Pave interior roads (control measure abbreviation: PPIPAVEDX)
  - Pipe grid trackout (control measure abbreviation: PPGTPAVEDX)
  - Sprinkler system for soil moisture (control measure abbreviation: PSPCONSTX)

Table 3-10 below lists current rules from several California air districts that could potentially address some of the remaining $PM_{2.5}$ emissions in some areas in some inventory sectors. Table 3-10 does not necessarily reflect additional measures. As shown in Table 3-3, in the control strategy analyses we apply some area source controls that may be required by or used to comply with some of the rules in Table 3-10 (e.g., catalytic oxidizers on charbroilers and residential wood combustion controls). However, because we do not know the portion of existing emissions sources that have already installed some non-point (area) source controls, the control strategy analyses limit the percent of the non-point (area), residential wood combustion, or area fugitive dust inventory emissions that the area source controls are applied to (e.g., EPA Phase 2 Qualified Units at 35% RP). Some of the non-point (area) source controls applied in the control strategy analyses could apply to a higher percentage of the applicable inventory.

In addition, Table 3-11 includes voluntary measures identified in the 2014 Houston-Galveston Area Council (H-GAC) Advance Plan for $PM_{2.5}$ that could potentially address some of the remaining $PM_{2.5}$ emissions in some areas (HGAC, 2014).[10]

Table 3-10 Current Rules from Several California Air Districts and City of Portola for Area Fugitive Dust Emissions, Non-point Source Emissions, and Residential Wood Combustion Emissions

Air District or City	Rule
	Area Fugitive Dust Emissions (Construction Activities, Unpaved Roads, Paved Roads)
San Joaquin Valley Air Pollution Control District	Regulation VIII: 8011 General Requirements; 8021 Construction, Demolition, Excavation, Extraction, and Other Earthmoving Activities; 8031 Bulk Materials; 8041 Carryout and Trackout; 8051 Open Areas; 8061 Paved and Unpaved Roads; 8071 Unpaved Vehicle/Equipment Traffic Areas; and 8081 Agricultural Sources
South Coast Air Quality Management District	Rule 403 Fugitive Dust --Applies to all construction activity sources listed in Table 1 of Rule, including but not limited to disturbed soil, road shoulder maintenance, truck loading, unpaved roads/parking lots, and vacant land. --Requires that no person conduct active operations without using the applicable best available control measures included in Table 1 of Rule to minimize fugitive dust emissions from each fugitive dust source type within the active operation.

[10] The H-GAC developed the Path Forward in partnership with the Regional Air Quality Planning Advisory Committee (RAQPAC), as part of H-GAC's participation in the voluntary EPA Particulate Matter (PM) Advance Program. H-GAC partnered with local and regional government agencies, citizen and environmental groups, business and industry-based organizations, and other stakeholders to proactively pursue air quality improvements within the region.

Air District or City	Rule
Ventura County Air Pollution Control District	Rule 55 Fugitive Dust --Applies to any operation, disturbed surface area, or man-made condition capable of generating fugitive dust, including bulk material handling, earth-moving, construction, demolition, storage piles, unpaved roads, track-out, or off-field agricultural operations. --Rule has visible dust beyond property line, opacity, and track-out requirements for the above operations.
	Non-point (Area) Source Emissions (Commercial Cooking, Waste Disposal, Cooling Towers, Small Boilers)
San Joaquin Valley Air Pollution Control District	Rule 4692 Commercial Charbroiling --Cannot operate a chain-driven charbroiler unless the chain-driven charbroiler is equipped and operated with a catalytic oxidizer. Requires a control efficiency of at least 83% for PM_{10} emissions and a control efficiency of at least 86% for VOC emissions. Chain-driven charbroiler/catalytic oxidizers combinations certified by the South Coast Air Quality Management District are considered compliant for the purposes of this section. Rule 4103 Open Burning --The Air Pollution Control Officer allocates burning based on the predicted meteorological conditions and whether total tonnage to be emitted would allow the volume of smoke and other contaminants to cause a public nuisance, impact smoke sensitive areas, or create or contribute to an exceedance of an ambient air quality standard. Except as otherwise provided, no person should set, permit, or use an open outdoor fire for the purpose of disposal or burning of petroleum wastes; demolition or construction debris; residential rubbish; garbage or vegetation; tires; tar; trees; wood waste; or other combustible or flammable solid, liquid or gaseous waste; or for metal salvage or burning of motor vehicle bodies.
South Coast Air Quality Management District	Rule 1138 Control of Emissions from Restaurant Operations --New and existing chain-driven charbroilers should be equipped and operated with a catalytic oxidizer control device. Rule 444 Open Burning --Cannot conduct open burning unless all of the following are met: (i) it is a permissive burn day or a marginal burn day on which burning is permitted in the applicable source/receptor area; (ii) the Executive Officer or the applicable fire protection agency has issued a written permit for the burn; (iii) the Executive Officer has authorized the burn by issuing a Burn Authorization Number for each day for each open burning event; and (iv) all site-specific permit conditions are met.
Ventura County Air Pollution Control District	Rule 74.25 Restaurant Cooking Operations --The owner or operator of a conveyorized charbroiler should reduce both reactive organic compound emissions and particulate matter emissions by at least 83 percent using an emission control device certified pursuant to rule. Rule 56 Open Burning --Requires a valid permit of specified substances for use on Burn Days.
Bay Area Air Quality Management District	Regulation 6 Rule 2 Commercial Cooking Equipment --For chain-driven charbroilers, no person should operate a chain-driven charbroiler unless it is equipped and operated with a certified catalytic oxidizer certified for use in combination with the specific model of chain-driven charbroiler by limiting the PM_{10} and organic compound emissions to no more than 1.3 pounds of PM_{10} and 0.32 pounds of organic compounds per 1,000 pounds of beef cooked. --For under-fired charbroilers, no person should operate an under-fired charbroiler in any restaurant that contains one or more underfired charbroilers with an aggregate grill surface area of 10 square feet or more, unless emissions from each under-fired charbroiler

Air District or City	Rule
	are exhausted through a certified control device certified as limiting the PM_{10} emissions of the under-fired charbroiler to no more than 1.0 pounds of PM_{10} per 1000 pounds of beef cooked. Regulation 5 Open Burning --Forbids open burning with certain exceptions.
	Residential Wood Combustion Emissions (Fireplaces, Hydronic Heaters, Wood Stoves)
San Joaquin Valley Air Pollution Control District	Rule 4901 Wood Burning Fireplaces, Wood Burning Heaters --Requirements for new wood burning heaters and used wood burning heaters. Requirements for property sales and certifications. Requirements for number of wood burning devices in new single or multi-family housing units.
South Coast Air Quality Management District	Rule 445 Wood-burning Devices --No person can permanently install a wood-burning device into any new development. --No person can sell, offer for sale, supply, or install, a new or used permanently installed indoor or outdoor wood-burning device or gaseous-fueled device unless it is one of the following: U.S. EPA Certified wood-burning heater; pellet-fueled wood-burning heater; masonry heater; or dedicated gaseous-fueled fireplace. --No person can burn any product not intended for use as fuel in a wood-burning device including, but not limited to, garbage, treated wood, particle board, plastic products, rubber products, waste petroleum products, paints, coatings or solvents, or coal. --No person can operate an indoor or outdoor wood-burning device, portable outdoor wood-burning device, or wood-fired cooking device on a calendar day during the woodburning season for $PM_{2.5}$ declared by the Executive Officer to be a mandatory wood-burning curtailment (No-Burn) day based on the specified geographic area below 3,000 feet above mean sea level and applicable daily $PM_{2.5}$ air quality forecast.
Bay Area Air Quality Management District	Regulation 6 Rule 3 Wood-burning Devices --Burning Prohibited During Mandatory Burn Ban --Requirements for Wood Heater Manufacturers and Retailers: no manufacturer or retailer should advertise, sell, offer for sale or resale, supply, install or transfer a new or used wood-burning device intended for use within District boundaries unless the device meets or exceeds the requirements of Title 40 Code of Federal Regulations, Part 60, Subpart AAA. --Sale, Resale, Transfer, or Installation of Wood-Burning Devices: no person should advertise, sell, offer for sale or resale, supply, install or transfer a new or used wood-burning device intended for use within District boundaries unless the device meets or exceeds the requirements of Title 40 Code of Federal Regulations, Part 60, Subpart AAA. Does not apply if a wood-burning device is an installed fixture included in the sale or transfer of any real property. --Disclosure Requirements for Real Property: any person selling, renting, or leasing real property should provide sale or rental disclosure documents that describe the health hazards of $PM_{2.5}$ from burning wood or any solid fuel as a source of heat. Disclosure documents must disclose $PM_{2.5}$ health hazards in accordance with guidance made available on the District's website. --Requirements for Rental Properties: all real property offered for lease or rent in areas with natural gas service should have a permanently-installed form of heat that does not burn solid fuel. --Requirements for New Building Construction: no person or builder should install a wood-burning device in a new building construction.

Air District or City	Rule
	--Requirements for Remodeling a Fireplace or Chimney: no person should remodel a fireplace or chimney unless a gas-fueled, electric, or EPA certified device is installed that meets requirements in Title 40 Code of Federal Regulations, Part 60, Subpart AAA.
City of Portola	Ordinance 359 – Regulation of Wood Stoves and Fireplaces and the Prohibition of the Open Burning of Yard Waste --Requirements for new devices (EPA-certified), existing devices (certificate or exemption before completing escrow for residential/commercial properties), permitted fuels, mandatory curtailments during stagnant conditions. Outdoor wood-fired boiler installation prohibited. --Prohibits burning of all yard waste and debris

Table 3-11 Voluntary Measures from the Houston-Galveston Area Advance Plan for PM

Initiative	Program or Measure
	Area Fugitive Dust Emissions
Dust Suppression	TCEQ, EPA Region 6, City of Houston, Harris County Precinct 2, Port of Houston Authority, Port Terminal Rail Authority, and local industry partnered to address $PM_{2.5}$ sources and implement dust suppression strategies to reduce $PM_{2.5}$ emissions. Strategies included: --Pave parking lot --Barriers to prevent trucks from driving on unpaved shoulder --Apply emulsified asphalt to reduce dust emissions at steel yards within the Terminal --Cease steel loading activities in dirt area --Implement new dust control best management practices
	Mobile Source Emissions (including Airports and Railroads)
H-GAC, Clean Vehicles and Clean School Bus Programs	Replace older diesel engines in public and private fleets; clean school bus projects
H-GAC, Clean Vessels for Texas Waters	Repower high-emitting tug vessels with new, cleaner engines
H-GAC, Commute Solutions: Vanpool Program	Regional vanpool and rideshare program
H-GAC, Regional TCEQ Emission Reduction Plan (TERP)	Established by the 77th Texas Legislature in 2001, through enactment of Senate Bill (SB) 5. TCEQ provides TERP funding for emission reduction projects to participants in Texas. Projects include a number of voluntary financial incentive programs to help improve the air quality in Texas. Between 2008 – 2013 TCEQ regional TERP has funded over 3,200 vehicle replacements.
City of Houston, EV Charging Stations	Participated in US Department of Energy's EV Project to secure additional charging stations
City of Houston, Anti-Idling Policy	Adopted anti-idling policy for municipal vehicles

Initiative	Program or Measure
City of Houston, Houston Airport System	--Improvements to airfield runways, taxiways, and gates/ramp reduced aircraft taxi and idle times -- Installed gate electrification equipment so parked aircraft forego the use of auxiliary power units
Harris County, Enhanced Enforcement Program Smoking Vehicles	Law enforcement personnel target high emitting vehicles, smoking vehicles, and suspicious vehicles to verify that the state inspection certificates attached to these vehicles are legitimate
Metropolitan Transit Authority of Harris County, Hybrid Bus Fleet	Converted over 1/3 of the METRO bus fleet to clean-running, diesel-electric hybrid technology
Port Authority of Houston, Cleaner Cranes	Replaced older cranes with new cranes. The increased efficiency associated with the cleaner, faster cranes reduces the truck idling and associated emissions at the Port.
Port Authority of Houston, Gate Automation, Idling Program	--Gate optical character recognition installation enabled Port to process trucks twice as fast and reduced idling time --Idling program in place for all landside engines at the port, including heavy duty diesel trucks and cargo handling equipment
H-GAC, Anti-Idling	Approximately 60 percent of Union Pacific switcher engines operating in the H-GAC area have anti-idling controls

3.2.5 Qualitative Assessment of the Remaining Air Quality Challenges and Emissions Reductions Potentially Still Needed

The sections below discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 $\mu g/m^3$; the areas include counties with near-road monitors, counties in border areas, counties in small western mountain valleys, and counties in California's air basins and districts. The characteristics of the air quality challenges for these areas include features of certain near-road sites with challenging local conditions, cross-border transport, effects of complex terrain in the west and California, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events (U.S. EPA, 2019b).

Consistent with Chapter 2, Section 2.4, to discuss the remaining air quality challenges for the revised standard levels of 9/35 $\mu g/m^3$, we group counties into the following "bins": near-road monitors, border areas, small mountain valleys, and California areas. By bin, Table 3-12 below summarizes the counties that need additional emissions reductions for the revised standard levels of 9/35 $\mu g/m^3$.

Table 3-12 Summary of Counties by Bin that Still Need Emissions Reductions for Revised Primary Standard Levels of 9/35 μg/m³

Bin	Area	Counties[a] for 9/35 mg/m³
Near-Road Monitors	Northeast	Bergen County, NJ Hamilton County, OH
Border Areas	Southeast	Cameron County, TX Hidalgo County, TX
	California	Imperial County, CA
Small Mountain Valleys	West	Plumas County, CA Lemhi County, ID Shoshone County, ID Lincoln County, MT Klamath County, OR
California Areas		Fresno County, CA (SJVAPCD) Kern County, CA (SJVAPCD) Kings County, CA (SJVAPCD) Los Angeles County, CA (SCAQMD) Madera County, CA (SJVAPCD) Merced County, CA (SJVAPCD) Orange County, CA (SCAQMD) Riverside County, CA (SCAQMD) San Bernardino County, CA (SCAQMD) Stanislaus County, CA (SJVAPCD) Tulare County, CA (SJVAPCD) San Joaquin County, CA (SJVAPCD) Alameda County, CA (BAAQMD) Calaveras County, CA Sutter County, CA

Note: For California counties that are part of multi-county air districts, the relevant district is indicated in parentheses; BAAQMD = Bay Area Air Quality Management District, SCAQMD = South Coast Air Quality Management District, and SJVAPCD= San Joaquin Valley Air Pollution Control District.

[a] The following counties had no identified $PM_{2.5}$ emissions reductions because available controls were applied for the current standard of 12/35 μg/m³ and additional controls were not available to apply for analyses of the revised and alternative standards: Colusa, Mono, Plumas, and Riverside, CA, Lake, OR, and Yakima, WA.

3.2.5.1 Near-Road Monitors (Northeast)

As shown in Table 3-9 above, the analysis indicates that Bergen County, New Jersey and Hamilton County, Ohio need additional emissions reductions for the revised standard levels of 9/35 μg/m³.

In analyzing the revised standard levels of 9/35 μg/m³, we estimated Bergen County would need 542 tons of $PM_{2.5}$ emissions reductions.[11] The control strategy analysis identified 338 tons of reductions within Bergen County from the application of several

[11] Appendix 2A, Table 2A-14 provides a summary of emissions reductions needed by county for the revised and less and more stringent alternative standard levels.

controls.[12] The control applications within Bergen County included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Pave Existing Shoulders applied to road dust emissions in the area fugitive dust inventory sector; and Convert to Gas Logs and New Gas Stove or Gas Logs applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

To analyze the 204 tons of $PM_{2.5}$ emissions reductions still needed, we identified 514 tons of $PM_{2.5}$ emissions reductions from adjacent counties[13], which is the equivalent of 129 tons of in-county emissions reductions after adjusting for the 4:1 ratio of adjacent county reductions identified to in-county reductions needed. This left 75 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Bergen County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, and residential wood combustion (*rwc*) emissions remaining in the inventory if additional controls beyond the scope of this analysis can be identified.

In Chapter 2, Section 2.4.1 we indicate that the Fort Lee, New Jersey (Bergen County) near-road monitor is close to the roadway interchange that leads to the George Washington Bridge, where six major highways converge in the area leading to the bridge and the location has been reported to be the most congested freight-significant highway location in the U.S. The monitor is also located near the urban activity of downtown Fort Lee. Understanding the nature of the local contributions and developing a plan to meet the revised standard levels under the complex conditions at this monitor would require a detailed local study beyond the scope of this RIA.

In analyzing the revised standard level of 9/35 $\mu g/m^3$, we estimated Hamilton County would need 1,025 tons of $PM_{2.5}$ emissions reductions.[14] The control strategy analysis identified 581 tons of reductions within Hamilton County from the application of

[12] Appendix 3A, Table 3A-2 provides a summary of in-county emissions reductions from control applications by county for the northeast.
[13] Appendix 3A, Table 3A-3 provides a summary of adjacent county emissions reductions from control applications in the northeast.
[14] Appendix 2A, Table 2A-14 provides a summary of emissions reductions needed by county for the revised and less and more stringent alternative standard levels.

several controls.[15] The control applications within Hamilton County included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions in the area fugitive dust inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers and industrial processes in the non-EGU point inventory sector; and Convert to Gas Logs and New Gas Stove or Gas Logs applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

To analyze the 444 tons of $PM_{2.5}$ emissions reductions still needed, we identified 1,275 tons of $PM_{2.5}$ emissions reductions from adjacent counties[16,17], which is the equivalent of 319 tons of in-county emissions reductions after adjusting for the 4:1 ratio of adjacent county reductions identified to in-county reductions needed. This left 55 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Hamilton County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, and residential wood combustion (*rwc*) emissions remaining in the inventory if additional controls beyond the scope of this analysis can be identified. In addition, Butler County, which is adjacent to Hamilton County, has emissions remaining in those inventory sectors if additional controls beyond the scope of this analysis can be identified.

In Chapter 2, Section 2.4.1 we indicate that the challenges in Hamilton County appear to be related to construction of a storage facility near the monitor during the monitoring period used in the air quality projections. However, a detailed local analysis beyond the scope of the national RIA would be needed to determine the full contribution of the construction and other local influences on the $PM_{2.5}$ DV at this monitor.

[15] Appendix 3A, Table 3A-2 provides a summary of in-county emissions reductions from control applications by county for the northeast.

[16] Hamilton County was both a core/home county and an adjacent/neighboring county. Before the second round of identifying emissions reductions, we adjusted any potential remaining reductions needed to account for reductions that were applied in the first round but for application in the neighboring county, resulting in slightly fewer remaining tons needed.

[17] Appendix 3A, Table 3A-3 provides a summary of adjacent county emissions reductions from control applications in the northeast.

3.2.5.2 Border Areas (Southeast, California)

As shown in Table 3-9 above, Cameron County and Hidalgo County, Texas need additional emissions reductions for the revised standard levels of 9/35 μg/m^3.

We estimated Cameron County would need 703 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 212 tons of reductions within Cameron County from the application of several controls.[18] The control applications within Cameron County included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions and Watering applied to crops and livestock dust in the area fugitive dust inventory sector; and Convert to Gas Logs applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

To analyze the 361 tons of $PM_{2.5}$ emissions reductions still needed, we identified 43 tons of $PM_{2.5}$ emissions reductions from adjacent counties[19,20], which was the equivalent of 10.75 tons of in-county emissions reductions after adjusting for the 4:1 ratio of adjacent county reductions identified to in-county reductions needed. This left 350 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Cameron County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, and residential wood combustion (*rwc*) emissions remaining in the inventory if additional controls beyond the scope of this analysis can be identified; the majority of the emissions remaining are area fugitive dust emissions.

In addition, we estimated Hidalgo County would need 1,349 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 521 tons of reductions within Hidalgo

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[18] Appendix 3A, Table 3A-4 provides a summary of in-county emissions reductions from control applications by county for the southeast.

[19] Cameron County was both a core/home county and an adjacent/neighboring county. Before the second round of identifying emissions reductions, we adjusted any potential remaining reductions needed to account for reductions that were applied in the first round but for application in the neighboring county, resulting in slightly fewer remaining tons needed.

[20] Appendix 3A, Table 3A-5 provides a summary of adjacent county emissions reductions from control applications in the southeast.

County from the application of several controls.[21] Some of the control applications within Hidalgo County included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers in the non-EGU point inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions and Watering applied to crops and livestock dust in the area fugitive dust inventory sector; and Convert to Gas Logs and New Gas Stove or Gas Logs RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

To analyze the 776 tons of $PM_{2.5}$ emissions reductions still needed, we identified 354 tons of $PM_{2.5}$ emissions reductions from adjacent counties[22,23], which was the equivalent of 88.5 tons of in-county emissions reductions after adjusting for the 4:1 ratio of adjacent county reductions identified to in-county reductions needed. This left 687.5 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Hidalgo County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-point source oil and gas (*np_oilgas*), non-electric generating unit point source (*ptnonipm)*, and residential wood combustion (*rwc*) emissions remaining in the inventory if additional controls beyond the scope of this analysis can be identified; the majority of the emissions remaining are area fugitive dust emissions.

In Chapter 2, Section 2.4.2.1 we note that the monitors in Cameron County and Hidalgo County are in the Lower Rio Grande Valley, which includes the northern portion of the state of Tamaulipas, Mexico. Addressing emissions reductions needed for the revised

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[21] Appendix 3A, Table 3A-4 provides a summary of in-county emissions reductions from control applications by county for the southeast.

[22] Hidalgo County was both a core/home county and an adjacent/neighboring county. Before the second round of identifying emissions reductions, we adjusted any potential remaining reductions needed to account for reductions that were applied in the first round but for application in the neighboring county, resulting in slightly fewer remaining tons needed.

[23] Appendix 3A, Table 3A-5 provides a summary of adjacent county emissions reductions from control applications in the southeast.

standard levels of 9/35 μg/m^3 at the monitors is challenging because of the location of these counties along the U.S.-Mexico border.

Area fugitive dust emissions make up the largest fraction of primary $PM_{2.5}$ emissions in Hidalgo County and Cameron County in the 2018 and 2032 air quality modeling cases (Chapter 2, Figure 2-16). Paved-road dust emissions (in the area fugitive dust inventory sector) are projected to increase in these counties between 2018 and 2032 as a result of projected increases in the vehicle miles travelled; non-point (area) sources emissions are also projected to increase as a result of population-based emissions projection factors. Increases in area fugitive dust and non-point (area) emissions from 2018 to 2032 offset the decreases in primary $PM_{2.5}$ emissions projected for EGUs and mobile sources in the counties. More detailed local analyses for these counties would be needed to better understand the potential growth in area fugitive dust and non-point (area) source emissions, as well as the potential contributions of international transport.

Further, for Imperial County, California the control strategy analysis identified 33 tons of $PM_{2.5}$ reductions from the application of controls for the revised standard levels of 9/35 μg/m^3. As shown in Table 3A-8, Imperial County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, and residential wood combustion (*rwc*) emissions remaining in the inventory if controls beyond the scope of this analysis can be identified; the majority of the emissions remaining are area fugitive dust emissions.

As discussed in Chapter 2, Section 2.4.2, Imperial County is located in the southeast corner of California and shares a southern border with Mexicali, Mexico. Imperial County includes three $PM_{2.5}$ monitoring sites, located in the cities of Calexico, El Centro, and Brawley (Chapter 2, Figure 2-12). While these three cities are of similar size and have similar emissions sources, the annual 2032 $PM_{2.5}$ DV at the Calexico monitor, which is the southern-most monitor and is less than a mile from the U.S.-Mexico border, is much greater than the other two monitors (12.36 μg/m^3, 9.70 μg/m^3, and 8.69 μg/m^3, respectively). In addition, substantially greater NOx, SO_2 and sulfate, and primary $PM_{2.5}$ emissions have been estimated for Mexicali, Mexico than for Calexico, California. For the revised standard levels, Imperial County may not need the additional emissions reductions estimated because of the potential influence of Mexicali emissions on $PM_{2.5}$ concentrations at the Calexico monitor and Section 179B of the Clean Air Act; however, a detailed local analysis would be needed.[24]

3.2.5.3 Small Mountain Valleys (West)

As shown in Table 3-9 above, the analysis also indicates that counties in the west need additional emissions reductions after the application of controls for all of the alternative standard levels analyzed. For the *small mountain valleys* bin, Table 3-13 below summarizes the estimated $PM_{2.5}$ emissions reductions needed and emissions reductions identified by CoST for each of these counties for the revised standard levels of 9/35 μg/m³.

Table 3-13 Summary of Estimated $PM_{2.5}$ Emissions Reductions Needed and Emissions Reductions Identified by CoST for the West for the Revised Primary Standard Levels of 9/35 μg/m³ in 2032 (tons/year)

County/State	$PM_{2.5}$ Emissions Reductions Needed	In-County $PM_{2.5}$ Emissions Reductions Identified by CoST
Plumas, CA	625.6	0
Lemhi, ID	242.8	7.6
Shoshone, ID	710.8	152.9
Lincoln, MT	1,211.2	317.4
Klamath, OR	185.5	125.1

Note: As shown in Table 3A-8, for Plumas, CA CoST identified controls to apply toward the current standard of 12/35 μg/m³. Additional controls were not available for the revised and less and more stringent alternative standard levels.

As shown in Table 3-13, the control strategy analysis identified emissions reductions for four of the counties. The controls applied included Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers in the non-EGU point inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions and Watering applied to crops and livestock dust in the area fugitive dust inventory sector; and Convert to Gas Logs and New

[24] Section 179B of the Clean Air Act (CAA) provides that a nonattainment area would be able to attain, or would have attained, the relevant National Ambient Air Quality Standard but for emissions emanating from outside the U.S.

Gas Stove or Gas Logs applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

As shown in Table 3A-8, these counties have area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, point oil and gas (*pt_oilgas*), and residential wood combustion (*rwc*) emissions remaining in the inventory if additional controls beyond the scope of this analysis can be identified; for each of the counties the majority of the emissions remaining are area fugitive dust emissions.

Meteorological temperature inversions often occur in small northwestern mountain valleys in winter and trap pollution emissions in a shallow atmospheric layer at the surface (Chapter 2, Section 2.1.2). As discussed in Chapter 2, Section 2.4.3, primary $PM_{2.5}$ emissions can build up in the surface layer and produce high $PM_{2.5}$ concentrations in winter (Chapter 2, Figure 2-18). These mountain valleys are often very small in size relative to the area of the surrounding county and far smaller than the resolution of photochemical air quality models (e.g., 12km grid cells). See Chapter 2, Figures 2-19 and 2-20 for maps of the Portola nonattainment area (2012 $PM_{2.5}$ NAAQS) relative to the city of Portola, California and the Libby nonattainment area (1997 $PM_{2.5}$ NAAQS) relative to the city of Libby, Montana. $PM_{2.5}$ concentrations in these small mountain valleys can be influenced by the temperature inversions, as well as by residential wood combustion and wildfire smoke.

Also as discussed in Chapter 2, Section 2.4.3, because of the small size of the urban areas within the northwestern mountain valleys, air quality planning is commonly based on linear rollback methods. To estimate emissions reductions needed for a standard level, the linear rollback method relates wood-smoke contribution estimates at an exceeding monitor to the local, or sub-county, wood combustion emissions totals. The $PM_{2.5}$ response factors from linear rollback methods estimate that relatively fewer residential wood combustion emissions reductions can greatly influence $PM_{2.5}$ concentrations in many of these small mountain valleys. We did not apply linear rollback-based response factors for the mountain valleys in this RIA because emissions inventory and area source control information are available at the county level, preventing us from targeting residential wood combustion controls in the local communities identified in the analyses. To better assess the emissions reductions needed for the revised and alternative standard levels, more detailed analyses that include local $PM_{2.5}$ response factors, emissions estimates, and controls for each local area would be needed.

In addition to air quality challenges related to meteorological temperature inversions and residential wood combustion, $PM_{2.5}$ concentrations in these small mountain valleys may also be influenced by wildfire emissions that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events.[25] We performed sensitivity projections to assess the potential for wildfire impacts. These projections indicate these sites may include an important contribution from wildfire. Detailed local analyses would be needed to fully characterize the wildfire influence in these areas. For more detailed discussions of the residential wood combustion and wildfire smoke air quality challenges, see Chapter 2, Section 2.4.3.

3.2.5.4 California Areas

As shown in Table 3-9 above, the analysis also indicates that counties in California need additional emissions reductions after the application of controls for the revised and alternative standard levels analyzed. The sections below discuss the air quality challenges by each air basin and/or district.

In the SJVAPCD, in analyzing the revised standard levels of 9/35 $\mu g/m^3$, the District needed 5,440 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 1,940 tons of reductions from the application of several controls.[26] Some of the control applications included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers and industrial processes in the non-EGU point inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions and Watering applied to crop and livestock dust in the area fugitive dust inventory sector; and Convert to Gas Logs applied to area source residential wood

[25] Some wildfire influence likely persists in the projected 2032 $PM_{2.5}$ DVs despite the exclusion of EPA-concurred exceptional events and the wildfire screening (Appendix 2A, Section 2A.2.1).
[26] Appendix 3A, Table 3A-7 provides a summary of in-county emissions reductions from control applications by county for California.

combustion emissions in the residential wood combustion inventory sector. As discussed above, we did not attempt to identify additional $PM_{2.5}$ emissions reductions in adjacent counties or air districts.

As discussed in more detail in Chapter 2, Section 2.4.4, the air quality in SJVAPCD is influenced by complex terrain and meteorological conditions that are best characterized with a high-resolution air quality modeling platform developed for the specific conditions of the valley. Air quality in the valley is influenced by emissions from large cities such as Bakersfield and Fresno, a productive agricultural region, dust exacerbated by drought, major goods transport corridors, and wildfires. The largest share of 2032 $PM_{2.5}$ emissions are from agricultural dust, the production of crops and livestock, agricultural burning, paved and unpaved road dust, and prescribed burning (Chapter 2, Figure 2-24); wildfire emissions also influence $PM_{2.5}$ concentrations.

Specific, local information on area source controls to reduce emissions from agricultural dust and burning and prescribed burning would be needed given the magnitude of emissions from these sources. In addition, more detailed analyses would be needed to characterize the influence of wildfires on $PM_{2.5}$ concentrations and the potential for some of these wildfires to be considered as atypical, extreme, or unrepresentative events. Note that wildfire screening is particularly complex in California because different parts of the state have different wildfire seasons.

In the SCAQMD, in analyzing the revised standard levels of 9/35 $\mu g/m^3$, the District needed 9,098 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 1,442 tons of reductions from the application of several controls.[27] Some of the control applications included: Electrostatic Precipitator applied to commercial cooking emissions in the non-point (area) inventory sector; Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers and industrial processes in the non-EGU point inventory sector; and Watering applied to crop and livestock dust in the

[27] Appendix 3A, Table 3A-7 provides a summary of in-county emissions reductions from control applications by county for California.

area fugitive dust inventory sector. We did not attempt to identify additional $PM_{2.5}$ emissions reductions in adjacent counties or air districts.

As discussed in more detail in Chapter 2, Section 2.4.4, the air quality in the SCAQMD is influenced by complex terrain and meteorological conditions that are best characterized with a high-resolution air quality modeling platform developed for the specific conditions of the air basin. Air quality is influenced by diverse emissions sources associated with the large population, the ports of Los Angeles and Long Beach, wildfires, and transportation of goods. The largest share of 2032 $PM_{2.5}$ emissions are from commercial and residential cooking, on-road mobile sources, and paved and unpaved road dust (Chapter 2, Figure 2-27).

Specific, local information on area source controls to reduce emissions from many of the non-point (area) emissions sources (e.g., commercial and residential cooking) would be needed given the magnitude of emissions from these sources. In addition, more detailed analyses would be needed to characterize the influence of wildfires on $PM_{2.5}$ concentrations and the potential for some of these wildfires to be considered as atypical, extreme, or unrepresentative events.

In the BAAQMD, in analyzing the revised standard levels of 9/35 $\mu g/m^3$, the District needed 948 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified sufficient tons of reductions from the application of several controls for all the counties in the District except Alameda County.[28] Some of the control applications included: Electrostatic Precipitator and Catalytic Oxidizer applied to commercial cooking emissions in the non-point (area) inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial, commercial, and institutional boilers and industrial processes in the non-EGU point inventory sector; Pave Existing Shoulders and Pave Unpaved Roads applied to road dust emissions and Watering applied to crop and livestock dust in the area fugitive dust inventory sector; and Convert to Gas Logs applied to area source residential wood combustion emissions in the residential wood combustion inventory sector. We did not

[28] Appendix 3A, Table 3A-7 provides a summary of in-county emissions reductions from control applications by county for California.

attempt to identify additional $PM_{2.5}$ emissions reductions in adjacent counties or air districts.

For the monitor in Alameda County, the ambient $PM_{2.5}$ DV for the 2020-2022 period at this monitor is 8.6 $\mu g/m^3$ and the ambient $PM_{2.5}$ DV for the 2019-2021 period is 8.5 $\mu g/m^3$. For the DV periods that overlap the 2016-2020 monitoring period reflected in the air quality modeling projections, higher ambient DVs of 12.0 $\mu g/m^3$, 11.7 $\mu g/m^3$, and 10.8 $\mu g/m^3$ were measured. Wildfire influence during this period may explain the much higher projected 2032 DV than the most recent ambient DV at the monitor. For example, the California Department of Forestry and Fire Protection reports (https://www.fire.ca.gov/incidents/) that 2017 was the most destructive wildfire year on record in California at the time in terms of property damage; the 2018 wildfire year included a total of over 7,500 fires burning an area of over 1.7 million acres; and the 2020 wildfire year had nearly 10,000 fires burning over 4.2 million acres, making 2020 the largest wildfire season recorded in California's modern history. Although detailed analysis of wildfire influence would be needed to determine the full extent of the fire impacts at the Alameda monitor, the existing evidence suggests that wildfire has an important contribution to the projected exceedances at this monitor.

In analyzing the revised standard levels of 9/35 $\mu g/m^3$, we identified remaining air quality challenges in two additional counties in California: Calaveras County and Sutter County. These air quality challenges in these counties may also have been influenced by wildfire during the 2016-2020 monitoring period used for air quality modeling projections. Table 2-3 in Chapter 2, Section 2.4.4 includes DVs for Alameda, Calaveras, and Sutter Counties, along with DVs using a more stringent wildfire screening threshold. At the Sutter and Calaveras monitors, the 2032 DVs decrease from above to below the revised annual standard of 9 $\mu g/m^3$ when the more stringent wildfire screening threshold is applied. This suggests the important influence of fires on the projected DVs, especially considering that the more stringent wildfire screening threshold is close to 4x the revised annual standard level of 9 $\mu g/m^3$. Although detailed analysis of wildfire influence would be needed to determine the full extent of the fire impacts at the Alameda, Calaveras, and Sutter monitors, the existing evidence suggests that wildfire has an important contribution to the projected exceedances at these monitors.

3.3 Limitations and Uncertainties

The EPA's analysis is based on the best available information from engineering studies of air pollution controls and a reasonable modeling framework for analyzing the cost, emissions changes, and other impacts of emissions controls. However, the control strategies above are subject to important limitations and uncertainties. Below we summarize the most significant limitations and uncertainties.

- **Control Strategies are Illustrative:** A control strategy is a set of end-of-pipe control technologies, area source controls, or policy actions that States may take to comply with a revised standard. The illustrative control strategy analyses in this RIA present only one potential pathway for controlling emissions, and we do not presume that these control strategies represent an exhaustive list of technologies, controls, or policy actions. Lastly, the illustrative control strategies are not recommendations for how a revised $PM_{2.5}$ NAAQS should be implemented, and States will make the final decisions regarding implementation of a revised NAAQS.
- **Limitations of Emissions Inventories and Air Quality Modeling:** Emissions inventories and air quality modeling serve as a foundation for the projected $PM_{2.5}$ DVs, control strategies, and estimated emissions reductions and costs in this analysis. The point source emissions inventories used may not accurately reflect existing controls on emissions units. The non-point emissions inventories – including inventories for non-point (area) sources, residential wood combustion, and area fugitive dust emissions – are emissions estimates at a county-level that reflect inventory-specific activity factors. These inventories do not reflect county-specific tabulations of emissions sources (e.g., the number of residential woodstoves or commercial cooking establishments in a county). As such, the non-point emissions inventories used may not accurately reflect the portion of existing emissions sources that have already installed some non-point (area) source controls. For example, Ventura

County Air Pollution Control District Rule 74.25 requires conveyorized charbroilers to reduce both reactive organic compound emissions and particulate matter emissions by at least 83 percent using an emissions control device; we do not know what portion of the commercial cooking emissions estimates for the county reflect those controls. The uncertainties introduced through the point and non-point (area) source inventories could result in the application of controls that are already on point sources or are reflected in non-point (area) source inventories (resulting in overestimating emissions reductions); these uncertainties could also result in not applying controls to a large enough portion of a non-point (area) source inventory (resulting in underestimating emissions reductions). The limitations and uncertainties associated with the inventories also impact the future year emissions projections and resulting estimated emissions reductions needed. Lastly, there are other factors not reflected that affect emissions estimates and introduce additional uncertainty, such as the economic base in a given area and economic growth.

- **Limits on Sizes of Sources Included**: We included emissions sources with greater than 5 tpy of $PM_{2.5}$ emissions because emissions sources with fewer tons are likely already controlled. We also limited the rule penetration rate when applying controls to non-point (area), residential wood combustion, and area fugitive emissions because the inventories used may not accurately reflect the portion of existing emissions sources that have already installed some non-point (area) source controls.
- **Assumptions About the Baseline**: There is significant uncertainty in the illustration of the impact of rules on the baseline.
- **Projecting the Level and Geographic Scope of Future Year Exceedances:** Estimates of the geographic areas that may exceed revised and alternative standard levels in a future year, and the level to which those areas may exceed, are approximations based on several factors. Any nonattainment

determinations that would result from a revised NAAQS will likely depend on the consideration of local air quality issues, changes in source operations between the time of this analysis and implementation of a new standard, and changes in control technologies over time.

- **Targeted Pollutants:** Local knowledge of atmospheric chemistry in each geographic area may result in a different prioritization of pollutants for potential control.
- **Applicability of Control Technologies:** The applicability of a control technology to a specific source varies depending on a number of process equipment factors such as age, design, capacity, fuel, and operating parameters. These can vary considerably from source to source and over time. While combinations of controls might be possible, we only select one control per source/SCC combination, and we have no way of assessing their appropriateness. This is especially limiting for area sources because we don't have county-specific tabulations of specific emissions sources and emissions are aggregated to the county level.
- **Limitations Related to Control Technologies Included**: Given the decades of progress in improving air quality, for many areas projected to exceed the alternative standards analyzed, analyzing only traditional end-of-pipe control technologies is limited. Future analyses should reflect changes in broader energy supply, demand, and use patterns, as well as other innovative technologies, policies, and strategies.
- **Advances in Control Technologies Over Time**: The control technologies applied do not reflect potential effects of technological change that may be available in future years. All estimates of impacts associated with control technologies applied reflect current knowledge, and not projections, of the technology's effectiveness or costs.

3.4 References

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APPENDIX 3A: CONTROL STRATEGIES AND $PM_{2.5}$ EMISSIONS REDUCTIONS

Overview

Chapter 3 describes the approach that EPA used in applying the illustrative control strategies for analyzing the following revised and less and more stringent alternative annual and 24-hour standard levels – 10/35 µg/m^3, 10/30 µg/m^3, 9/35 µg/m^3, and 8/35 µg/m^3. This Appendix contains additional information about the end-of-pipe and area source controls that were applied, as well as additional details on the estimated $PM_{2.5}$ emissions reductions.

3A.1 Types of Control Technologies

Several types of controls were applied in the analyses for the analytical baseline and revised and alternative standard levels. We identified controls using the EPA's Control Strategy Tool (CoST) (U.S. EPA, 2019) and the control measures database.[1] A brief description of several of the controls is below.

3A.1.1 PM Controls for Non-EGU Point Sources

Non-EGU point source categories covered in this analysis include industrial boilers, as well as industrial processes in the cement manufacturing, chemical manufacturing, pulp and paper, mining, ferrous and non-ferrous metals, and refining industries. Several types of end-of-pipe $PM_{2.5}$ controls were applied for these sources, including venturi scrubbers, fabric filters, and electrostatic precipitators, which are the primary controls analyzed for non-EGU point sources.

- Venturi scrubbers – Venturi scrubbers are one of several types of wet scrubbers that remove both acid gas and PM from waste gas streams of stationary point sources. The pollutants are removed primarily through the impaction, diffusion, interception and/or absorption of the pollutant onto droplets of liquid. The liquid containing the pollutant is then collected for disposal.

[1] More information about CoST and the control measures database can be found at the following link: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-analysis-modelstools-air-pollution.

- Fabric filters – A fabric filter unit consists of one or more isolated compartments containing rows of fabric bags in the form of round, flat, or shaped tubes, or pleated cartridges. Particle-laden gas usually passes up along the surface of the bags then radially through the fabric. Particles are retained on the upstream face of the bags, and the cleaned gas stream is vented to the atmosphere. Fabric filters collect particles with sizes ranging from submicron to several hundred microns in diameter at efficiencies generally in excess of 99 or 99.9 percent.
- Electrostatic precipitators – An ESP is a particle control device that uses electrical forces to move the particles out of the flowing gas stream and onto collector plates. The particles are given an electrical charge by forcing them to pass through a corona, a region in which gaseous ions flow. The electrical field that forces the charged particles to the walls comes from electrodes maintained at high voltage in the center of the flow lane. Once the particles are collected on the plates, they must be removed from the plates without re-entraining them into the gas stream. This is usually accomplished by knocking them loose from the plates, allowing the collected layer of particles to slide down into a hopper from which they are evacuated.

3A.1.2 PM Controls for Non-point (Area) Sources

The non-point sector of the emissions inventory includes emissions sources that are generally too small and/or numerous to estimate emissions for individual sources (e.g., commercial cooking, residential woodstoves, commercial or backyard waste burning). We estimate the emissions from these sources for each county overall, typically using an emissions factor that is applied to a surrogate of activity such as population or number of houses. Controls for non-point sources are applied to the county level emissions. Several area source controls were applied to $PM_{2.5}$ emissions from non-point sources, including catalytic oxidizers applied to charbroilers in commercial cooking, electrostatic precipitator applied to under-fire charbroilers in commercial cooking, substitute chipping for open burning in general and for households, converting to gas logs for residential wood combustion, chemical stabilizers to suppress unpaved road dust, paving existing shoulders to suppress paved road dust, and managing crop and livestock dust to suppress fugitive dust.

3A.2 EGU Trends Reflected in EPA's Integrated Planning Model (IPM) v6 Platform, Post-IRA 2022 Reference Case Projections

The EPA's Integrated Planning Model (IPM) v6 Platform Post-IRA 2022 Reference Case projections were used in the air quality modeling done for this RIA.[2] A high level summary of the input assumptions in the Post-IRA 2022 Reference Case is below. This version features several input data updates, in addition to reflecting Inflation Reduction Act (IRA) of 2022 provisions of tax incentives impacting electricity supply, other bottom-up input data, and assumption updates[3], including the following:

- Demand – Annual Energy Outlook (AEO) 2021 + Office of Transportation and Air Quality 2027 GHG Rule
- Gas and Coal Market Assumptions – Updated as of December 2021
- Cost and Performance of Fossil Generation Technologies – AEO 2021
- Cost and Performance of Renewable Energy Generation Technologies – National Renewable Energy Lab Annual Technology Baseline 2021 mid-case
- Environmental Rules and Regulations (On-the-Books) – 2023 Federal Good Neighbor Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standards (Final GNP), Revised Cross-State Air Pollution Rule, Mercury and Air Toxics Standards, BART, California Assembly Bill 32, Regional Greenhouse Gas Initiative, various renewable portfolio standards and clean energy standards, non-air rules (Cooling Water Intake, Steam Electric Power Generating Effluent Guidelines, Coal Combustion Residuals), and State Rules

[2] Documentation of the baseline run building on Post-IRA 2022 Reference Case, incorporating the Final GNP, and the corresponding results are available at https://www.epa.gov/power-sector-modeling/final-pm-naaqs.

[3] For a complete reference summary, see Chapter 1, Table 1-1 available at https://www.epa.gov/system/files/documents/2021-09/chapter-1-introduction.pdf

- Financial Assumptions – Based on 2016-2020 data, reflects tax credit extensions from Consolidated Appropriations Act of 2021
- Transmission – Updated data with build options
- Retrofits – Carbon capture and storage option for combined cycles
- Post-combustion control operation – Operate according to historical rates and/or to performance levels established in the IPM documentation
- Operating Reserves (in select runs) – Greater detail in representing interaction of load, wind, and solar, ensuring availability of quick response of resources at higher levels of renewable energy penetration
- Fleet – NEEDS for Post-IRA 022 Reference Case (rev:10-14-22)

The Post-IRA 2022 Reference Case projections show a significant decline in national-level annual SO_2, NOx, and primary PM emissions because of displacement of retired coal units with new natural gas generation and renewable energy. Greater near-term renewable energy penetration is due to an increase in actual projects reflected in NEEDS prior to the IPM projections; the long-term increase is largely driven by improved renewable energy technology costs, especially enhanced with the IRA tax incentives.

California sees a significant decrease in projected emissions for all pollutants by 2030 due to the state's Clean Energy Standards (CES). California's Senate Bill No. 100 requires expansion of the Renewable Portfolio Standard through 2030 where generation from qualifying renewables must achieve a 50 percent share of retail sales by 2026 and 60 percent by 2030.[4] California's legislation requires a transition from the RPS to CES where generation from qualifying "zero carbon resources" must equal 100 percent of retail sales by 2045. Our projections show a significant shift from fossil to renewable energy generation in California between 2025 and 2030 with the trend continuing thereafter.

[4] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100

3A.3 Applying End-of-Pipe and Area Source Controls

As mentioned in Chapter 3, Section 3.2.2, controls applied for the analyses of the existing standards of 12/35 μg/m^3 and the revised and less and more stringent annual and 24-hour $PM_{2.5}$ alternative standard levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 are listed in Table 3A-1 by geographic area and by emissions inventory sector, with an "X" indicating which controls were applied for each standard level.

Table 3A-2 through Table 3A-7 include detailed summaries of $PM_{2.5}$ emissions reductions by county for the revised and alternative standard levels for the northeast, the adjacent counties in the northeast, the southeast, the adjacent counties in the southeast, the west, and California. Table 3A-7 for California presents counties organized by air districts.

As shown in Table 3A-2 and Table 3A-3 for the northeast counties (31 counties) and the adjacent counties (51 counties), for the alternative standard levels of 10/35 μg/m^3 and 10/30 μg/m^3, controls were applied in four counties and no additional emissions reductions were needed in adjacent counties. For the revised standard levels of 9/35 μg/-m^3, we estimated a total of 9,825 tons of $PM_{2.5}$ emission reductions available from the application of controls – approximately 74 percent of that total is available from within a core county and 26 percent is from an adjacent county. For the alternative standard levels of 8/35 μg/m^3, we estimated a total of 25,947 tons of $PM_{2.5}$ emission reductions – approximately 54 percent of that total is available from within a core county and 46 percent is from an adjacent county.

As shown in Table 3A-4 and Table 3A-5 for the southeast counties (33 counties) and the adjacent counties (34 counties), for the alternative standard levels of 10/35 μg/m^3 and 10/30 μg/m^3, controls were applied in one county and additional emissions reductions were identified in three adjacent counties. For the revised standard levels of 9/35 μg/m^3, we estimated a total of 2,313 tons of $PM_{2.5}$ emission reductions – approximately 85 percent of that total is available from the application of controls from within a core county and 15 percent is from an adjacent county. For the alternative standard levels of 8/35 μg/m^3, we estimated a total of 17,080 tons of $PM_{2.5}$ emission reductions – approximately 82 percent of that total is available from within a core county and 18 percent is from an adjacent county.

As shown in Table 3A-6 for the west (29 counties), for the alternative standard level of 10/35 $\mu g/m^3$ controls were applied in two counties. For the alternative standard levels of 10/30 $\mu g/m^3$ controls were applied in 17 counties; for the revised standard levels of 9/35 $\mu g/m^3$ controls were applied in 10 counties; and for the alternative standard levels of 8/35 $\mu g/m^3$ controls were applied in 21 counties.

As shown in Table 3A-7 for California (36 counties) of the eight counties in the San Joaquin Valley Air Pollution Control District, we estimated that all eight need $PM_{2.5}$ emissions reductions. For six counties, we identified some emissions reductions available for alternative standard levels of 10/35 $\mu g/m^3$ and no additional emissions reductions for the revised and lower alternative standard levels analyzed. For one county, we identified some emissions reductions available for alternative standard levels of 10/30 $\mu g/m^3$ and additional reductions available for revised standard levels of 9/35 $\mu g/m^3$; for the remaining county we identified some emissions reductions available for revised standard levels of 9/35 $\mu g/m^3$. We estimated that the four counties in the South Coast Air Quality Management District need emissions reductions. For one county we did not identify any emissions reductions from the application of controls for any of the revised and alternative standard levels. For three counties, we identified some emissions reductions available for alternative standard levels of 10/35 $\mu g/m^3$.

Table 3A-8 includes information on $PM_{2.5}$ emissions by emissions inventory sector, on counties needing emissions reductions, and on estimated emissions reductions by the revised and alternative standard levels analyzed. The column labeled *Sector* uses abbreviations for emissions inventory sectors from the National Emissions Inventory. The abbreviations and related sectors include: *afdust* or area fugitive dust emissions; *nonpt* or non-point (area) source emissions; *np_oilgas* or non-point (area) source oil and gas emissions; *ptagfire* or point source agriculture fire emissions; *ptnonipm* or non-electric generating unit, point source emissions; *pt_oilgas* or point source oil and gas emissions; and *rwc* or residential wood combustions emissions.

The first column includes names of adjacent counties and counties still needing emissions reductions. The second column lists any counties that need emissions reductions. The columns with annual $PM_{2.5}$ emissions and the $PM_{2.5}$ emissions reductions are related to the county in the first column. If the second column is blank, then the annual $PM_{2.5}$ emissions serves as an indicator of the county's own $PM_{2.5}$ emissions that might be controllable if a state or local jurisdiction knew how to control those emissions; in these cases the maximum $PM_{2.5}$ emissions reductions should be equal to the selected $PM_{2.5}$ emissions reductions for one of the alternative standards being analyzed (e.g., Santa Cruz County, AZ).

The table is intended to present information about potential nearby emissions reductions that might be available to help counties attain a revised or alternative standard level. The list of $PM_{2.5}$ emissions is not exhaustive, as inventory sectors with reported emissions less than 5 tons per year are excluded in general, and emissions from rail, airports, and wildfires of all types are excluded regardless of their emissions because either we do not have information on potential controls for these sectors or the emissions from these sectors are not necessarily controllable (i.e., wildfires). While we considered emissions from adjacent counties in the east, we did not do so in the west and California due to uncertainty about the air quality impacts of emissions reductions from adjacent counties. For the west and California, in addition to finding ways of controlling remaining emissions within a county or adjacent counties (or within the same air district in California), it will be necessary to determine how much emissions reductions in adjacent counties may impact the DV at a monitor of interest.

Table 3A-1 By Area and Emissions Inventory Sector, Controls Applied in Analyses of the Current Standards, Revised, and Alternative Primary Standard Levels

Area	Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
Northeast	Non-EGU Point	Electrostatic Precipitator-All Types				x	
		Fabric Filter-All Types		x	x	x	x
		Install new drift eliminator				x	x
		Venturi Scrubber		x	x	x	x
	Non-Point (Area)	Annual tune-up		x	x	x	x
		Biennial tune-up		x	x	x	x
		Electrostatic Precipitator				x	x
		HEPA filters				x	x
		Smokeless Broiler		x	x	x	x
		Substitute chipping for burning		x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs				x	x
		EPA Phase 2 Qualified Units				x	x
		EPA-certified wood stove		x	x		
		Install Cleaner Hydronic Heaters		x	x	x	x
		Install Retrofit Devices				x	
		New gas stove or gas logs		x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer				x	x
		Pave Unpaved Roads				x	x
		Pave existing shoulders				x	x
		Watering				x	x
Northeast (Adjacent Counties)	Non-EGU Point	Fabric Filter-All Types				x	x
		Install new drift eliminator					x
		Venturi Scrubber				x	x
	Non-Point (Area)	Annual tune-up				x	x
		Biennial tune-up				x	x
		Electrostatic Precipitator				x	x
		Smokeless Broiler				x	x
		Substitute chipping for burning				x	x
	Residential Wood Combustion	Convert to Gas Logs				x	x
		Install Cleaner Hydronic Heaters				x	x
		New gas stove or gas logs				x	x
	Area Source Fugitive Dust	Chemical Stabilizer					x
		Pave Unpaved Roads				x	x
		Pave existing shoulders				x	x
		Watering				x	x
Southeast	Non-EGU Point	Fabric Filter-All Types		x	x	x	x
		Install new drift eliminator				x	x
		Venturi Scrubber					x
	Non-Point (Area)	Add-on Scrubber					x
		Annual tune-up				x	x
		Biennial tune-up				x	x
		Electrostatic Precipitator		x	x	x	x
		Smokeless Broiler				x	x

Area	Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
		Substitute chipping for burning		x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs		x	x	x	x
		EPA Phase 2 Qualified Units				x	x
		EPA-certified wood stove				x	
		Install Cleaner Hydronic Heaters				x	x
		Install Retrofit Devices				x	
		New gas stove or gas logs		x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer				x	x
		Pave Unpaved Roads		x	x	x	x
		Pave existing shoulders		x	x	x	x
		Watering		x	x	x	x
Southeast (Adjacent Counties)	Non-EGU Point	Fabric Filter-All Types					x
		Install new drift eliminator					x
		Venturi Scrubber					x
	Non-Point (Area)	Annual tune-up					x
		Biennial tune-up					x
		Electrostatic Precipitator				x	x
		Smokeless Broiler					x
		Substitute chipping for burning				x	x
	Residential Wood Combustion	Convert to Gas Logs					x
		Install Cleaner Hydronic Heaters					x
		New gas stove or gas logs					x
	Area Source Fugitive Dust	Chemical Stabilizer					x
		Pave Unpaved Roads				x	x
		Pave existing shoulders				x	x
		Watering		x	x	x	x
West	Non-EGU Point	Fabric Filter-All Types	x		x	x	x
		Install new drift eliminator				x	x
		Venturi Scrubber			x	x	x
	Oil & Gas Point	Fabric Filter-All Types					x
	Non-Point (Area)	Annual tune-up	x	x	x	x	x
		Biennial tune-up	x		x	x	x
		Electrostatic Precipitator	x		x	x	x
		Smokeless Broiler	x		x	x	x
		Substitute chipping for burning	x	x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs	x		x		x
		EPA Phase 2 Qualified Units	x		x		x
		Install Cleaner Hydronic Heaters	x	x	x	x	x
		Install Retrofit Devices				x	x
		New gas stove or gas logs	x	x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer	x		x	x	x
		Pave Unpaved Roads	x	x	x	x	x
		Pave existing shoulders	x		x	x	x
		Watering	x	x	x	x	x

Area	Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
CA	Non-EGU Point	Electrostatic Precipitator-All Types	x				
		Fabric Filter-All Types	x	x	x	x	x
		Install new drift eliminator	x			x	x
		Venturi Scrubber	x		x	x	x
	Oil & Gas Point	Fabric Filter-All Types		x	x	x	x
	Non-Point (Area)	Annual tune-up	x	x	x	x	x
		Biennial tune-up	x	x	x	x	x
		Catalytic oxidizers	x		x	x	x
		Electrostatic Precipitator	x	x	x	x	x
		Substitute chipping for burning	x	x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs	x	x	x	x	x
		EPA Phase 2 Qualified Units			x		x
		Install Retrofit Devices				x	x
	Area Source Fugitive Dust	Chemical Stabilizer	x		x	x	x
		Pave Unpaved Roads	x	x	x	x	x
		Pave existing shoulders	x	x	x	x	x
		Watering	x	x	x	x	x

Table 3A-2 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Northeast (31 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	10/35	10/30	9/35	8/35
Cook County, IL	0	0	534	785
DuPage County, IL	0	0	0	394
Macon County, IL	0	0	0	220
Madison County, IL	0	0	81	812
McLean County, IL	0	0	0	29
St. Clair County, IL	0	0	0	293
Lake County, IN	0	0	102	834
Marion County, IN	0	0	510	510
Jefferson County, KY	0	0	0	468
Wayne County, MI	220	220	951	1,048
Bergen County, NJ	0	0	338	338
Camden County, NJ	0	0	168	183
Union County, NJ	0	0	0	217
New York County, NY	0	0	0	593
Butler County, OH	0	0	784	794
Cuyahoga County, OH	0	0	607	840
Franklin County, OH	0	0	0	51
Hamilton County, OH	293	293	581	581
Jefferson County, OH	0	0	0	15
Stark County, OH	0	0	0	183
Allegheny County, PA	490	532	1,222	1,628
Beaver County, PA	0	0	0	117
Cambria County, PA	0	0	0	308

County	**10/35**	**10/30**	**9/35**	**8/35**
Chester County, PA	0	0	521	586
Delaware County, PA	29	29	384	384
Lancaster County, PA	0	0	0	491
Lebanon County, PA	0	0	0	168
Philadelphia County, PA	0	0	442	521
York County, PA	0	0	0	279
Providence County, RI	0	0	0	59
Davidson County, TN	0	0	0	307
Total	1,032	1,074	7,226	14,036

Table 3A-3 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Adjacent Counties in the Northeast (51 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	Adjacent Counties	10/35	10/30	9/35	8/35
Kane County, IL	Cook County, IL DuPage County, IL	0	0	0	450
Lake County, IL	Cook County, IL	0	0	0	326
McHenry County, IL	Cook County, IL	0	0	0	583
Will County, IL	Cook County, IL DuPage County, IL	0	0	0	169
Boone County, IN	Marion County, IN	0	0	48	89
Hamilton County, IN	Marion County, IN	0	0	179	344
Hancock County, IN	Marion County, IN	0	0	52	94
Hendricks County, IN	Marion County, IN	0	0	127	255
Johnson County, IN	Marion County, IN	0	0	117	203
Morgan County, IN	Marion County, IN	0	0	78	173
Shelby County, IN	Marion County, IN	0	0	168	554
Macomb County, MI	Wayne County, MI	0	0	0	571
Monroe County, MI	Wayne County, MI	0	0	0	397
Oakland County, MI	Wayne County, MI	0	0	0	1,171
Washtenaw County, MI	Wayne County, MI	0	0	0	399
Atlantic County, NJ	Camden County, NJ	0	0	0	155
Burlington County, NJ	Camden County, NJ	0	0	0	257
Essex County, NJ	Bergen County, NJ Union County, NJ	0	0	223	223
Gloucester County, NJ	Camden County, NJ	0	0	0	317
Hudson County, NJ	Bergen County, NJ Union County, NJ	0	0	148	148
Passaic County, NJ	Bergen County, NJ	0	0	144	144
Bronx County, NY	New York County, NY	0	0	0	72
Kings County, NY	New York County, NY	0	0	0	64
Queens County, NY	New York County, NY	0	0	0	126
Clermont County, OH	Hamilton County, OH	0	0	333	333
Geauga County, OH	Cuyahoga County, OH	0	0	0	297
Lake County, OH	Cuyahoga County, OH	0	0	0	208
Lorain County, OH	Cuyahoga County, OH	0	0	0	394
Medina County, OH	Cuyahoga County, OH	0	0	0	401
Portage County, OH	Cuyahoga County, OH Stark County, OH	0	0	0	308
Summit County, OH	Cuyahoga County, OH Stark County, OH	0	0	0	388
Warren County, OH	Butler County, OH Hamilton County, OH	0	0	437	437
Armstrong County, PA	Allegheny County, PA	0	0	0	88
Butler County, PA	Allegheny County, PA Beaver County, PA	0	0	0	364

County	Adjacent Counties	10/35	10/30	9/35	8/35
Montgomery County, PA	Chester County, PA Delaware County, PA Philadelphia County, PA	0	0	546	672
Washington County, PA	Allegheny County, PA Beaver County, PA	0	0	0	387
Westmoreland County, PA	Allegheny County, PA Cambria County, PA	0	0	0	348
Total		0	0	2,599	11,911

Table 3A-4 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Southeast (33 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	10/35	10/30	9/35	8/35
Jefferson County, AL	0	0	0	785
Russell County, AL	0	0	0	327
Pulaski County, AR	0	0	0	720
District of Columbia	0	0	0	200
Broward County, FL	0	0	16	834
Bibb County, GA	0	0	0	115
Chatham County, GA	0	0	0	82
Dougherty County, GA	0	0	0	240
Fulton County, GA	0	0	0	648
Gwinnett County, GA	0	0	0	442
Muscogee County, GA	0	0	0	204
Richmond County, GA	0	0	49	620
Shawnee County, KS	0	0	0	278
Wyandotte County, KS	0	0	0	303
Caddo Parish, LA	0	0	401	519
East Baton Rouge Parish, LA	0	0	0	381
West Baton Rouge Parish, LA	0	0	0	292
Hinds County, MS	0	0	0	311
Forsyth County, NC	0	0	0	25
Mecklenburg County, NC	0	0	0	254
Cleveland County, OK	0	0	0	482
Oklahoma County, OK	0	0	0	548
Tulsa County, OK	0	0	0	507
Bowie County, TX	0	0	0	188
Cameron County, TX	0	0	212	212
Dallas County, TX	0	0	0	172
El Paso County, TX	0	0	0	238
Harris County, TX	0	0	613	1,431
Hidalgo County, TX	521	521	521	521
Jefferson County, TX	0	0	0	343
Nueces County, TX	0	0	0	499
Orange County, TX	0	0	0	352
Travis County, TX	0	0	147	923
Total	521	521	1,959	13,995

Table 3A-5 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Adjacent Counties in the Southeast (34 counties) for Revised Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	Adjacent Counties	10/35	10/30	9/35	8/35
Burke County, GA	Richmond County, GA	0	0	0	487
Columbia County, GA	Richmond County, GA	0	0	0	91
Forsyth County, GA	Fulton County, GA Gwinnett County, GA	0	0	0	3
Jefferson County, GA	Richmond County, GA	0	0	0	308
McDuffie County, GA	Richmond County, GA	0	0	0	100
Bossier Parish, LA	Caddo Parish, LA	0	0	0	286
De Soto Parish, LA	Caddo Parish, LA	0	0	0	202
East Feliciana Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	0	0	0	38
Iberville Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	0	0	0	109
Pointe Coupee Parish, LA	West Baton Rouge Parish, LA	0	0	0	33
Red River Parish, LA	Caddo Parish, LA	0	0	0	813
West Feliciana Parish, LA	West Baton Rouge Parish, LA	0	0	0	38
Bastrop County, TX	Travis County, TX	0	0	0	70
Blanco County, TX	Travis County, TX	0	0	0	9
Brooks County, TX	Hidalgo County, TX	16	16	108	108
Burnet County, TX	Travis County, TX	0	0	0	15
Caldwell County, TX	Travis County, TX	0	0	0	28
Hays County, TX	Travis County, TX	0	0	0	14
Hudspeth County, TX	El Paso County, TX	0	0	0	56
Kenedy County, TX	Hidalgo County, TX	18	18	78	78
Starr County, TX	Hidalgo County, TX	0	0	125	125
Willacy County, TX	Cameron County, TX Hidalgo County, TX	11	11	43	43
Williamson County, TX	Travis County, TX	0	0	0	30
Total		45	45	354	3,086

Table 3A-6 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the West (29 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	10/35	10/30	9/35	8/35
Maricopa County, AZ	0	0	257	721
Pinal County, AZ	0	321	0	0
Santa Cruz County, AZ	0	0	0	39
Yuma County, AZ	0	0	0	122
Adams County, CO	0	0	43	348
Denver County, CO	0	0	9	124
Weld County, CO	0	0	0	373
Benewah County, ID	0	187	0	0
Canyon County, ID	0	264	0	290

County	**10/35**	**10/30**	**9/35**	**8/35**
Lemhi County, ID	0	8	8	8
Shoshone County, ID	153	153	153	153
Flathead County, MT	0	149	0	0
Lewis and Clark County, MT	0	51	0	51
Lincoln County, MT	317	317	317	317
Missoula County, MT	0	0	24	491
Clark County, NV	0	0	0	468
Crook County, OR	0	276	0	89
Harney County, OR	0	115	212	271
Jackson County, OR	0	12	239	706
Josephine County, OR	0	0	0	271
Klamath County, OR	0	125	125	125
Lake County, OR	0	0	0	0
Lane County, OR	0	196	0	206
Box Elder County, UT	0	159	0	0
Cache County, UT	0	115	0	0
Salt Lake County, UT	0	57	0	0
King County, WA	0	0	0	42
Okanogan County, WA	0	209	0	108
Yakima County, WA	0	0	0	0
Total	470	2,715	1,386	5,323

Table 3A-7 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for California (36 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 (tons/year)

County	Air District	10/35	10/30	9/35	8/35
Alameda County, CA	Bay Area AQMD	105	105	388	388
Contra Costa County, CA	Bay Area AQMD	0	0	127	444
Napa County, CA	Bay Area AQMD	0	0	0	69
San Francisco County, CA	Bay Area AQMD	0	0	0	93
San Mateo County, CA	Bay Area AQMD	0	0	0	114
Santa Clara County, CA	Bay Area AQMD	0	0	320	555
Solano County, CA	Bay Area AQMD	0	0	162	195
Butte County, CA	Butte County AQMD	0	301	0	248
Calaveras County, CA	Calaveras County APCD	0	0	128	128
Colusa County, CA	Colusa County APCD	0	0	0	0
Sutter County, CA	Feather River AQMD	0	86	86	86
Mono County, CA	Great Basin Unified APCD	0	0	0	0
Imperial County, CA	Imperial County APCD	33	33	33	33
Mendocino County, CA	Mendocino County AQMD	0	121	0	13
Plumas County, CA	Northern Sierra AQMD	0	0	0	0
Placer County, CA	Placer County APCD	0	0	0	24
Sacramento County, CA	Sacramento Metro AQMD	0	201	162	275
San Diego County, CA	San Diego County APCD	0	0	238	763
Fresno County, CA	San Joaquin Valley APCD	508	508	508	508
Kern County, CA	San Joaquin Valley APCD	225	225	225	225
Kings County, CA	San Joaquin Valley APCD	95	95	95	95
Madera County, CA	San Joaquin Valley APCD	0	0	255	255
Merced County, CA	San Joaquin Valley APCD	210	210	210	210
San Joaquin County, CA	San Joaquin Valley APCD	0	38	256	256
Stanislaus County, CA	San Joaquin Valley APCD	204	204	204	204
Tulare County, CA	San Joaquin Valley APCD	188	188	188	188
San Luis Obispo County, CA	San Luis Obispo County APCD	0	0	0	28
Santa Barbara County, CA	Santa Barbara County APCD	0	131	0	68
Shasta County, CA	Shasta County AQMD	0	30	0	0
Siskiyou County, CA	Siskiyou County APCD	0	339	0	0
Los Angeles County, CA	South Coast AQMD	1,102	1,102	1,102	1,102
Orange County, CA	South Coast AQMD	264	264	264	264
Riverside County, CA	South Coast AQMD	0	0	0	0
San Bernardino County, CA	South Coast AQMD	76	76	76	76
Tehama County, CA	Tehama County APCD	0	121	0	0
Ventura County, CA	Ventura County APCD	0	274	43	274
Total		3,010	4,652	5,069	7,181

Table 3A-8 Remaining $PM_{2.5}$ Emissions and Potential Additional Reduction Opportunities

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Maricopa County, AZ	Pinal County, AZ	afdust	5,257	68	-	-	-	68	68
		nonpt	2,299	457	-	-	-	166	457
		ptnonipm	163	18	-	-	-	18	18
		rwc	1,146	177	-	-	-	5	177
Pinal County, AZ	Maricopa County, AZ	afdust	3,337	118	-	-	118	-	-
		nonpt	377	191	-	-	191	-	-
		pt_oilgas	8	-	-	-	-	-	-
		ptnonipm	88	-	-	-	-	-	-
		rwc	99	11	-	-	11	-	-
Santa Cruz County, AZ	-	afdust	169	15	-	-	-	-	15
		nonpt	68	23	-	-	-	-	23
		rwc	13	-	-	-	-	-	-
Yuma County, AZ	Maricopa County, AZ	afdust	1,284	113	-	-	-	-	62
		nonpt	187	79	-	-	-	-	56
		ptnonipm	7	-	-	-	-	-	-
		rwc	42	4	-	-	-	-	4
Alameda County, CA	Napa County, CA San Francisco County, CA Solano County, CA	afdust	531	89	-	8	8	89	89
		nonpt	589	63	-	4	4	63	63
		ptnonipm	369	114	-	93	93	114	114
		rwc	356	122	-	-	-	122	122
Calaveras County, CA	-	afdust	189	49	-	-	-	49	49
		nonpt	144	67	-	-	-	67	67
		rwc	173	12	-	-	-	12	12
Colusa County, CA	-	afdust	346	56	56	-	-	-	-
		nonpt	102	15	15	-	-	-	-
		ptnonipm	19	-	-	-	-	-	-
		rwc	45	4	4	-	-	-	-

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Contra Costa County, CA	Alameda County, CA	afdust	392	71	-	-	-	8	8
	Napa County, CA	nonpt	502	55	-	-	-	-	3
	San Francisco County, CA	ptnonipm	1,611	897	-	-	-	118	433
	Solano County, CA	rwc	786	230	-	-	-	-	-
Fresno County, CA	Kern County, CA	afdust	2,240	373	67	306	306	306	306
	Kings County, CA	nonpt	643	135	27	109	109	109	109
	Madera County, CA	pt_oilgas	28	-	-	-	-	-	-
	Merced County, CA	ptnonipm	219	65	10	55	55	55	55
	San Joaquin County, CA	rwc	280	39	-	39	39	39	39
	Stanislaus County, CA								
	Tulare County, CA								
Imperial County, CA	-	afdust	3,610	275	275	-	-	-	-
		nonpt	190	14	-	14	14	14	14
		ptnonipm	47	15	-	15	15	15	15
		rwc	18	4	-	4	4	4	4
Kern County, CA	Fresno County, CA	afdust	1,377	53	53	-	-	-	-
	Kings County, CA	nonpt	936	325	303	7	7	7	7
	Madera County, CA	np_oilgas	5	-	-	-	-	-	-
	Merced County, CA	pt_oilgas	220	5	-	5	5	5	5
	San Joaquin County, CA	ptnonipm	684	351	169	177	177	177	177
	Stanislaus County, CA	rwc	217	36	-	36	36	36	36
	Tulare County, CA								
Kings County, CA	Fresno County, CA	afdust	845	74	-	74	74	74	74
	Kern County, CA	nonpt	74	16	-	16	16	16	16
	Madera County, CA	ptnonipm	50	-	-	-	-	-	-
	Merced County, CA	rwc	30	5	-	5	5	5	5
	San Joaquin County, CA								
	Stanislaus County, CA								
	Tulare County, CA								

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Los Angeles County, CA	Orange County, CA Riverside County, CA San Bernardino County, CA	afdust	2,193	6	6	-	-	-	-
		nonpt	4,599	785	83	702	702	702	702
		np_solvents	247	-	-	-	-	-	-
		pt_oilgas	11	-	-	-	-	-	-
		ptnonipm	1,720	583	334	249	249	249	249
		rwc	917	151	-	151	151	151	151
Madera County, CA	Fresno County, CA Kern County, CA Kings County, CA Merced County, CA San Joaquin County, CA Stanislaus County, CA Tulare County, CA	afdust	660	118	-	-	-	118	118
		nonpt	213	34	-	-	-	34	34
		ptnonipm	139	98	-	-	-	98	98
		rwc	50	6	-	-	-	6	6
Mendocino County, CA	-	afdust	244	55	-	-	55	-	13
		nonpt	158	36	-	-	36	-	-
		rwc	322	30	-	-	30	-	-
Merced County, CA	Fresno County, CA Kern County, CA Kings County, CA Madera County, CA San Joaquin County, CA Stanislaus County, CA Tulare County, CA	afdust	1,287	156	-	156	156	156	156
		nonpt	137	30	-	30	30	30	30
		ptnonipm	80	11	-	11	11	11	11
		rwc	110	13	-	13	13	13	13
Mono County, CA	-	afdust	174	34	34	-	-	-	-
		nonpt	12	-	-	-	-	-	-
		ptnonipm	6	-	-	-	-	-	-
		rwc	48	7	7	-	-	-	-
Napa County, CA	Alameda County, CA San Francisco County, CA Solano County, CA	afdust	111	20	-	-	-	-	20
		nonpt	45	4	-	-	-	-	4
		ptnonipm	46	24	-	-	-	-	24
		rwc	119	22	-	-	-	-	22

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Orange County, CA	Los Angeles County, CA Riverside County, CA San Bernardino County, CA	afdust	654	-	-	-	-	-	-
		nonpt	1,217	184	-	184	184	184	184
		np_solvents	95	-	-	-	-	-	-
		ptnonipm	180	8	-	8	8	8	8
		rwc	295	73	-	73	73	73	73
Plumas County, CA	-	afdust	489	149	149	-	-	-	-
		nonpt	70	3	3	-	-	-	-
		ptnonipm	5	-	-	-	-	-	-
		rwc	316	12	12	-	-	-	-
Riverside County, CA	Los Angeles County, CA Orange County, CA San Bernardino County, CA	afdust	2,525	23	23	-	-	-	-
		nonpt	765	119	119	-	-	-	-
		np_solvents	98	-	-	-	-	-	-
		pt_oilgas	18	-	-	-	-	-	-
		ptnonipm	177	33	33	-	-	-	-
		rwc	454	46	46	-	-	-	-
Sacramento County, CA	-	afdust	1,002	25	-	-	15	15	25
		nonpt	634	107	-	-	93	90	107
		ptnonipm	79	21	-	-	21	21	21
		rwc	1,734	122	-	-	73	37	122
San Bernardino County, CA	Los Angeles County, CA Orange County, CA Riverside County, CA	afdust	2,357	73	64	-	-	-	-
		nonpt	1,733	403	403	-	-	-	-
		np_solvents	43	-	-	-	-	-	-
		pt_oilgas	34	-	-	-	-	-	-
		ptnonipm	2,606	1,252	1,156	76	76	76	76
		rwc	456	42	42	-	-	-	-
San Diego County, CA	-	afdust	2,452	270	-	-	-	5	270
		nonpt	1,772	435	-	-	-	222	435
		ptnonipm	355	6	-	-	-	6	6
		rwc	657	52	-	-	-	5	52

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
San Francisco County, CA	Alameda County, CA	afdust	105	17	-	-	-	-	17
	Napa County, CA	nonpt	352	55	-	-	-	-	55
	Solano County, CA	ptnonipm	55	7	-	-	-	-	7
		rwc	47	14	-	-	-	-	14
San Joaquin County, CA	Fresno County, CA	afdust	1,090	138	-	-	29	138	138
	Kern County, CA	nonpt	350	70	-	-	-	70	70
	Kings County, CA	ptnonipm	185	10	-	-	9	10	10
	Madera County, CA	rwc	210	39	-	-	-	39	39
	Merced County, CA								
	Stanislaus County, CA								
	Tulare County, CA								
San Mateo County, CA	Alameda County, CA	afdust	242	42	-	-	-	-	6
	Napa County, CA	nonpt	299	32	-	-	-	-	25
	San Francisco County, CA	ptnonipm	145	64	-	-	-	-	58
	Solano County, CA	rwc	162	36	-	-	-	-	25
Santa Barbara County, CA	-	afdust	478	57	-	-	57	-	13
		nonpt	152	31	-	-	31	-	26
		pt_oilgas	12	-	-	-	-	-	-
		ptnonipm	40	-	-	-	-	-	-
		rwc	294	42	-	-	42	-	29
Santa Clara County, CA	Alameda County, CA	afdust	709	124	-	-	-	-	7
	Napa County, CA	nonpt	637	100	-	-	-	-	90
	San Francisco County, CA	ptnonipm	611	493	-	-	-	320	425
	Solano County, CA	rwc	594	166	-	-	-	-	33
Siskiyou County, CA	-	afdust	898	258	-	-	258	-	-
		nonpt	488	219	215	-	4	-	-
		ptnonipm	77	56	-	-	56	-	-
		rwc	210	20	-	-	20	-	-

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Solano County, CA	Alameda County, CA Napa County, CA San Francisco County, CA	afdust	408	68	-	-	-	38	68
		nonpt	209	31	-	-	-	29	31
		ptnonipm	169	40	-	-	-	38	40
		rwc	318	56	-	-	-	56	56
Stanislaus County, CA	Fresno County, CA Kern County, CA Kings County, CA Madera County, CA Merced County, CA San Joaquin County, CA Tulare County, CA	afdust	1,125	59	-	59	59	59	59
		nonpt	289	59	-	59	59	59	59
		ptnonipm	192	56	-	56	56	56	56
		rwc	183	30	-	30	30	30	30
Sutter County, CA	-	afdust	279	39	-	-	39	39	39
		nonpt	279	32	-	-	32	32	32
		ptnonipm	34	-	-	-	-	-	-
		rwc	193	15	-	-	15	15	15
Tehama County, CA	-	afdust	380	100	-	-	100	-	-
		nonpt	137	10	-	-	10	-	-
		ptnonipm	26	-	-	-	-	-	-
		rwc	154	12	-	-	12	-	-
Tulare County, CA	Fresno County, CA Kern County, CA Kings County, CA Madera County, CA Merced County, CA San Joaquin County, CA Stanislaus County, CA	afdust	2,078	288	101	188	188	188	188
		nonpt	282	50	49	-	-	-	-
		ptnonipm	95	-	-	-	-	-	-
		rwc	134	17	15	-	-	-	-
Ventura County, CA	-	afdust	519	73	-	-	73	3	73
		nonpt	256	47	-	-	47	39	47
		pt_oilgas	7	-	-	-	-	-	-
		ptnonipm	99	7	-	-	7	-	7
		rwc	655	147	-	-	147	-	147

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Adams County, CO	Denver County, CO	afdust	1,884	118	-	-	-	11	118
		nonpt	201	63	-	-	-	-	63
		np_oilgas	12	-	-	-	-	-	-
		pt_oilgas	36	16	-	-	-	-	16
		ptnonipm	357	103	-	-	-	17	103
		rwc	345	49	-	-	-	15	49
Denver County, CO	Adams County, CO	afdust	1,454	8	-	-	-	8	8
		nonpt	248	75	-	-	-	-	75
		ptnonipm	151	23	-	-	-	1	23
		rwc	169	18	-	-	-	-	18
Weld County, CO	Adams County, CO	afdust	4,283	748	-	-	-	-	373
		nonpt	181	67	-	-	-	-	-
		np_oilgas	283	-	-	-	-	-	-
		pt_oilgas	239	-	-	-	-	-	-
		ptnonipm	612	193	-	-	-	-	-
		rwc	270	42	-	-	-	-	-
District of Columbia, DC	-	afdust	447	49	-	-	-	-	49
		nonpt	476	151	-	-	-	-	151
		ptnonipm	36	-	-	-	-	-	-
		rwc	17	-	-	-	-	-	-
Benewah County, ID	Shoshone County, ID	afdust	860	184	-	-	184	-	-
		nonpt	33	3	-	-	3	-	-
		ptnonipm	9	-	-	-	-	-	-
		rwc	20	-	-	-	-	-	-
Lemhi County, ID	-	afdust	728	181	136	-	8	8	8
		nonpt	12	-	-	-	-	-	-
		rwc	19	-	-	-	-	-	-
Shoshone County, ID	Benewah County, ID	afdust	584	140	-	140	140	140	140
		nonpt	24	11	-	11	11	11	11
		rwc	27	2	-	2	2	2	2

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Boone County, IN	Marion County, IN	afdust	444	33	-	-	-	2	33
		nonpt	98	49	-	-	-	42	49
		rwc	70	7	-	-	-	3	7
Hamilton County, IN	Marion County, IN	afdust	789	90	-	-	-	2	90
		nonpt	398	223	-	-	-	167	223
		rwc	264	32	-	-	-	10	32
Hancock County, IN	Marion County, IN	afdust	315	32	-	-	-	2	32
		nonpt	103	51	-	-	-	46	51
		rwc	88	11	-	-	-	4	11
Hendricks County, IN	Marion County, IN	afdust	416	52	-	-	-	2	52
		nonpt	242	135	-	-	-	105	135
		ptnonipm	139	48	-	-	-	13	48
		rwc	162	20	-	-	-	8	20
Johnson County, IN	Marion County, IN	afdust	395	48	-	-	-	3	48
		nonpt	236	138	-	-	-	109	138
		rwc	133	17	-	-	-	6	17
Marion County, IN	-	afdust	1,535	204	-	-	-	204	204
		nonpt	697	182	-	-	-	182	182
		ptnonipm	176	80	-	-	-	80	80
		rwc	316	44	-	-	-	44	44
Morgan County, IN	Marion County, IN	afdust	369	41	-	-	-	3	41
		nonpt	133	75	-	-	-	70	75
		ptnonipm	49	45	-	-	-	-	45
		rwc	97	13	-	-	-	5	13
Shelby County, IN	Marion County, IN	afdust	271	20	-	-	-	2	20
		nonpt	76	33	-	-	-	30	33
		ptnonipm	565	495	-	-	-	134	495
		rwc	61	6	-	-	-	3	6

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Bossier Parish, LA	Caddo Parish, LA	afdust	430	90	-	-	-	-	90
		nonpt	445	189	-	-	-	-	189
		np_oilgas	34	-	-	-	-	-	-
		pt_oilgas	10	-	-	-	-	-	-
		ptnonipm	28	-	-	-	-	-	-
		rwc	50	7	-	-	-	-	7
Caddo Parish, LA	-	afdust	969	163	-	-	-	74	163
		nonpt	884	237	-	-	-	236	237
		np_oilgas	76	-	-	-	-	-	-
		pt_oilgas	15	-	-	-	-	-	-
		ptnonipm	219	106	-	-	-	80	106
		rwc	84	13	-	-	-	10	13
De Soto Parish, LA	Caddo Parish, LA	afdust	439	96	-	-	-	-	96
		nonpt	128	41	-	-	-	-	41
		np_oilgas	89	-	-	-	-	-	-
		pt_oilgas	44	-	-	-	-	-	-
		ptnonipm	348	65	-	-	-	-	65
		rwc	14	-	-	-	-	-	-
East Baton Rouge Parish, LA	West Baton Rouge Parish, LA	afdust	1,735	178	-	-	-	-	7
		nonpt	3,541	1,057	-	-	-	-	349
		pt_oilgas	8	-	-	-	-	-	-
		ptnonipm	1,652	1,049	-	-	-	-	24
		rwc	104	12	-	-	-	-	-
East Feliciana Parish, LA	West Baton Rouge Parish, LA	afdust	274	60	-	-	-	-	9
		nonpt	69	30	-	-	-	-	29
		pt_oilgas	24	-	-	-	-	-	-
		rwc	10	-	-	-	-	-	-

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Iberville Parish, LA	West Baton Rouge Parish, LA	afdust	326	39	-	-	-	-	4
		nonpt	375	113	-	-	-	-	86
		pt_oilgas	46	-	-	-	-	-	-
		ptnonipm	541	83	-	-	-	-	19
		rwc	13	-	-	-	-	-	-
Pointe Coupee Parish, LA	West Baton Rouge Parish, LA	afdust	533	80	-	-	-	-	11
		nonpt	66	21	-	-	-	-	19
		ptnonipm	256	3	-	-	-	-	3
		rwc	10	-	-	-	-	-	-
Red River Parish, LA	Caddo Parish, LA	afdust	201	45	-	-	-	-	45
		nonpt	55	11	-	-	-	-	11
		np_oilgas	21	-	-	-	-	-	-
		pt_oilgas	7	-	-	-	-	-	-
		ptnonipm	777	757	-	-	-	-	757
West Baton Rouge Parish, LA	-	afdust	249	48	-	-	-	-	48
		nonpt	282	77	-	-	-	-	77
		ptnonipm	398	166	-	-	-	-	166
		rwc	9	-	-	-	-	-	-
West Feliciana Parish, LA	West Baton Rouge Parish, LA	afdust	189	44	-	-	-	-	8
		nonpt	58	24	-	-	-	-	23
		ptnonipm	133	129	-	-	-	-	7
		rwc	5	-	-	-	-	-	-
Flathead County, MT	Lewis and Clark County, MT Lincoln County, MT	afdust	4,052	1,105	-	-	19	-	-
		nonpt	289	123	-	-	101	-	-
		ptnonipm	172	95	-	-	14	-	-
		rwc	173	28	-	-	14	-	-
Lewis and Clark County, MT	-	afdust	1,686	454	79	-	22	-	22
		nonpt	135	65	42	-	22	-	22
		rwc	82	13	6	-	7	-	7

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Lincoln County, MT	-	afdust	1,026	296	-	296	296	296	296
		nonpt	40	12	-	12	12	12	12
		rwc	64	9	-	9	9	9	9
Atlantic County, NJ	Camden County, NJ	afdust	278	70	-	-	-	-	70
		nonpt	175	44	-	-	-	-	44
		ptnonipm	18	-	-	-	-	-	-
		rwc	252	41	-	-	-	-	41
Bergen County, NJ	-	afdust	451	93	-	-	-	93	93
		nonpt	770	204	-	-	-	204	204
		ptnonipm	23	-	-	-	-	-	-
		rwc	333	41	-	-	-	41	41
Burlington County, NJ	Camden County, NJ	afdust	479	108	-	-	-	-	108
		nonpt	261	59	-	-	-	-	59
		ptnonipm	40	-	-	-	-	-	-
		rwc	539	90	-	-	-	-	90
Camden County, NJ	-	afdust	277	58	-	-	-	48	58
		nonpt	319	78	-	-	-	73	78
		ptnonipm	22	-	-	-	-	-	-
		rwc	231	47	-	-	-	47	47
Essex County, NJ	Bergen County, NJ	afdust	345	71	-	-	-	71	71
		nonpt	501	124	-	-	-	124	124
		ptnonipm	46	15	-	-	-	15	15
		rwc	148	14	-	-	-	14	14
Gloucester County, NJ	Camden County, NJ	afdust	269	52	-	-	-	-	52
		nonpt	150	33	-	-	-	-	33
		ptnonipm	265	189	-	-	-	-	189
		rwc	284	44	-	-	-	-	44
Hudson County, NJ	Bergen County, NJ	afdust	196	36	-	-	-	36	36
		nonpt	424	111	-	-	-	111	111
		ptnonipm	21	-	-	-	-	-	-
		rwc	11	-	-	-	-	-	-

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Passaic County, NJ	Bergen County, NJ	afdust	220	37	-	-	-	37	37
		nonpt	331	84	-	-	-	84	84
		rwc	164	23	-	-	-	23	23
Butler County, OH	Hamilton County, OH	afdust	645	102	-	-	-	102	102
		nonpt	460	199	-	-	-	193	199
		ptnonipm	683	451	-	-	-	451	451
		rwc	336	41	-	-	-	37	41
Clermont County, OH	Hamilton County, OH	afdust	513	95	-	-	-	95	95
		nonpt	351	207	-	-	-	207	207
		ptnonipm	13	-	-	-	-	-	-
		rwc	251	31	-	-	-	31	31
Hamilton County, OH	-	afdust	1,193	129	-	-	-	129	129
		nonpt	977	381	-	282	282	381	381
		ptnonipm	171	16	-	10	10	16	16
		rwc	357	55	-	-	-	55	55
Warren County, OH	Hamilton County, OH	afdust	533	87	-	-	-	87	87
		nonpt	495	308	-	-	-	308	308
		pt_oilgas	20	-	-	-	-	-	-
		ptnonipm	28	10	-	-	-	10	10
		rwc	242	31	-	-	-	31	31
Crook County, OR	Harney County, OR	afdust	1,134	326	-	-	246	-	65
		nonpt	37	18	-	-	18	-	17
		ptnonipm	6	-	-	-	-	-	-
		rwc	89	12	-	-	12	-	7
Harney County, OR	Lake County, OR	afdust	1,341	268	-	-	113	212	268
		nonpt	11	-	-	-	-	-	-
		rwc	31	3	-	-	2	-	3
Jackson County, OR	Klamath County, OR	afdust	1,916	568	-	-	12	12	336
		nonpt	379	233	-	-	-	206	230
		ptnonipm	167	134	-	-	-	-	63
		rwc	566	81	-	-	-	20	77

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Klamath County, OR	Lake County, OR	afdust	2,945	836	425	-	38	38	38
		nonpt	103	48	39	-	2	2	2
		pt_oilgas	9	-	-	-	-	-	-
		ptnonipm	217	184	99	-	85	85	85
		rwc	223	32	23	-	-	-	-
Lake County, OR	Harney County, OR Klamath County, OR	afdust	1,118	248	248	-	-	-	-
		nonpt	13	4	4	-	-	-	-
		rwc	35	5	5	-	-	-	-
Lane County, OR	Klamath County, OR	afdust	4,643	1,304	-	-	12	-	12
		nonpt	622	377	-	-	127	-	131
		ptnonipm	436	377	-	-	30	-	33
		rwc	852	120	-	-	26	-	30
Chester County, PA	Delaware County, PA	afdust	877	97	-	-	-	5	97
		nonpt	961	459	-	-	-	459	431
		pt_oilgas	12	-	-	-	-	-	-
		ptnonipm	84	9	-	-	-	-	9
		rwc	417	56	-	-	-	56	49
Delaware County, PA	-	afdust	368	51	-	-	-	51	51
		nonpt	554	110	-	28	28	110	110
		ptnonipm	314	199	-	-	-	199	199
		rwc	130	23	-	1	1	23	23
Montgomery County, PA	Delaware County, PA	afdust	985	103	-	-	-	2	103
		nonpt	1,376	389	-	-	-	389	389
		pt_oilgas	9	-	-	-	-	-	-
		ptnonipm	288	129	-	-	-	104	129
		rwc	415	52	-	-	-	52	52
Philadelphia County, PA	Delaware County, PA	afdust	596	78	-	-	-	-	11
		nonpt	1,349	330	-	-	-	330	330
		ptnonipm	439	176	-	-	-	109	176
		rwc	40	5	-	-	-	3	4

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Brooks County, TX	Hidalgo County, TX	afdust	466	108	-	16	16	108	108
		np_oilgas	7	-	-	-	-	-	-
Cameron County, TX	Hidalgo County, TX	afdust	915	128	-	-	-	128	128
		nonpt	217	80	-	-	-	80	80
		ptnonipm	43	-	-	-	-	-	-
		rwc	35	3	-	-	-	3	3
El Paso County, TX	-	afdust	1,605	78	-	-	-	-	78
		nonpt	258	124	-	-	-	-	124
		pt_oilgas	7	-	-	-	-	-	-
		ptnonipm	120	28	-	-	-	-	28
		rwc	58	8	-	-	-	-	8
Hidalgo County, TX	Cameron County, TX	afdust	1,755	261	-	261	261	261	261
		nonpt	462	192	-	192	192	192	192
		np_oilgas	19	-	-	-	-	-	-
		ptnonipm	85	60	-	60	60	60	60
		rwc	58	8	-	8	8	8	8
Hudspeth County, TX	El Paso County, TX	afdust	248	56	-	-	-	-	56
		pt_oilgas	18	-	-	-	-	-	-
Kenedy County, TX	Hidalgo County, TX	afdust	268	78	-	18	18	78	78
Starr County, TX	Hidalgo County, TX	afdust	489	107	-	-	-	107	107
		nonpt	50	18	-	-	-	18	18
		np_oilgas	16	-	-	-	-	-	-
		pt_oilgas	11	-	-	-	-	-	-
		rwc	8	-	-	-	-	-	-
Willacy County, TX	Cameron County, TX	afdust	357	43	-	11	11	43	43
	Hidalgo County, TX	nonpt	11	-	-	-	-	-	-
King County, WA	Yakima County, WA	afdust	3,808	154	-	-	-	-	9
		nonpt	2,503	632	-	-	-	-	28
		ptnonipm	90	51	-	-	-	-	5
		rwc	1,864	204	-	-	-	-	-

County	Adjacent Counties (NE,SE,W) or Counties in Same Air District (CA) Still Needing Reductions	Sector	Annual PM2.5 Emissions	Maximum PM2.5 Emissions Reduction	Selected PM2.5 Emissions Reductions				
					12/35	10/35	10/30	9/35	8/35
Okanogan County, WA	-	afdust	769	176	-	-	176	-	78
		nonpt	41	10	-	-	10	-	6
		rwc	149	23	-	-	23	-	23
Yakima County, WA	-	afdust	1,839	203	203	-	-	-	-
		nonpt	220	60	60	-	-	-	-
		ptnonipm	6	-	-	-	-	-	-
		rwc	335	53	53	-	-	-	-

CHAPTER 4: ENGINEERING COST ANALYSIS AND QUALITATIVE DISCUSSION OF SOCIAL COSTS

Overview

This chapter provides estimates of the engineering costs of the illustrative control strategies identified in Chapter 3 for the revised annual and current 24-hour alternative standard levels of 9/35 μg/m^3, as well as the following less and more stringent alternative standard levels 10/35 μg/m^3, 10/30 μg/m^3, and 8/35 μg/m^3. Because the EPA is retaining the current secondary PM standards, we did not evaluate alternative secondary standard levels in this RIA. The chapter summarizes the methods, tools, and data sources used to estimate the engineering costs presented. As discussed in Chapter 3, for the revised and alternative standards analyzed we applied end-of-pipe control technologies and area source controls to sources in the following emissions inventory sectors: non-electric generating unit (non-EGU) point, oil and gas point, non-point (area), residential wood combustion, and area fugitive dust.

The estimated costs for the revised and alternative standard levels are a function of (i) assumptions used in the analysis, including assumptions about which areas will require emissions controls and the sources and controls available in those areas; (ii) the level of sufficient, detailed information on emissions sources and end-of-pipe and area source controls needed to estimate engineering costs; and (iii) the future year baseline emissions from which the emissions reductions are measured.

For the less stringent alternative standard level of 10/35 μg/m^3, because 13 of the 20 counties that need emissions reductions are counties in California, the majority of the estimated costs are incurred in California. As the alternative standard levels become more stringent, more counties in the northeast and southeast need emissions reductions. For revised and more stringent standard levels of 9/35 μg/m^3 and 8/35 μg/m^3, more controls are available to apply in the northeast and their adjacent counties and the southeast and their adjacent counties. As additional controls are applied, those areas account for a relatively higher proportion of estimated costs compared to the west and California because availability of additional controls is limited for those areas. Note that in the northeast and southeast we identified controls and associated emissions reductions from adjacent counties and used a ppb/ton $PM_{2.5}$ air quality ratio that was four times less responsive than the ratio used when applying in-county emissions reductions (i.e., applied four tons of $PM_{2.5}$ emissions reductions from an adjacent county for one ton of emissions reduction needed in a given county); the cost of the additional reductions from adjacent counties contributes to the higher proportion of the estimated costs. Lastly, for the more stringent alternative standard levels of 8/35 $\mu g/m^3$, the largest share of estimated costs is from controls for area fugitive dust emissions across all areas.

The remainder of the chapter is organized as follows. Section 4.1 presents the engineering costs associated with the application of controls identified in EPA's national-scale analysis. Section 4.2 provides a discussion of the uncertainties and limitations associated with the engineering cost estimates. Section 4.3 includes a qualitative discussion on social costs. Section 4.4 includes references.

4.1 Estimating Engineering Costs

The engineering costs described in this chapter generally include the costs of purchasing, installing, operating, and maintaining the controls applied. The costs associated with monitoring, testing, reporting, and recordkeeping for potentially affected sources are not included in the annualized cost estimates. These cost estimates are presented for 2032 but reflect the annual cost that is expected to be incurred each year over a longer time horizon. We calculate the present value of these annual costs over 20 years in Chapter 8 using 3 and 7 percent discount rates.

This analysis focuses on emissions reductions needed for the revised and alternative standard levels. As discussed in this analysis, the end-of-pipe and area source controls and strategies selected for analysis were from information available in EPA's control measures database; these control strategies illustrate one way in which nonattainment areas could work toward meeting a revised standard. There are many ways to construct and evaluate potential control programs for a revised standard, and the EPA anticipates that state and local governments will consider programs best suited for local conditions.

The EPA understands that some states will incur costs both designing State Implementation Plans (SIPs) and implementing new control strategies to meet a revised standard. However, the EPA does not know what specific actions states will take to design their SIPs to meet a revised standard. Therefore, we do not present estimated costs that government agencies may incur for managing the requirement or implementing these (or other) control strategies.

4.1.1 Methods, Tools, and Data

The EPA uses the Control Strategy Tool (CoST) (U.S. EPA, 2019a) to estimate engineering control costs. CoST models emissions reductions and control costs associated with the application of end-of-pipe and area source controls by matching the controls in the control measures database (CMDB) to emissions sources in the future year projected emissions inventory by source classification code (SCC).[1,2] CoST was used in two ways in the analysis. First, CoST was used to identify controls and related potential $PM_{2.5}$ emissions reductions in counties projected to exceed the revised and alternative annual and 24-hour standard levels of 10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$ in the analytical baseline (see Chapter 3, Section 3.2.1 for a discussion of the counties and areas). Second, CoST was used to estimate the control costs for the technologies identified. As indicated in Chapter 3, Section 3.2.2, for the control strategy analyses in this RIA, to maximize the number of emissions sources included we applied controls to emissions sources with greater than 5 tons per year of $PM_{2.5}$ emissions at a marginal cost threshold of up to a $160,000/ton.

CoST calculates engineering costs using one of two different methods: (1) an equation that incorporates key operating unit information, such as unit design capacity or stack flow rate, or (2) an average annualized cost-per-ton factor multiplied by the total tons of reduction of a pollutant. Most control cost information within CoST was developed based on the cost-per-ton approach because (1) parameters used in the engineering equations are not readily available or broadly representative across emissions sources within the emissions inventory and (2) estimating engineering costs using an equation requires data from the emissions inventory, which may not be available. The cost equations used in CoST

[1] More information about CoST and the control measures database can be found at the following link: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-analysis-modelstools-air-pollution.

[2] We used a 2016-based modeling platform to project future-year emissions and air quality for 2032.

estimate annual, capital and/or operating and maintenance (O&M) costs and are used primarily for some larger emissions sources such as industrial, commercial, and institutional (ICI) boilers, glass manufacturing furnaces, and cement kilns.

CoST gets key operating unit information from the emissions inventory data submitted by state, local, and tribal air agencies (S/L/T), including detailed information by source on emissions, installed control devices, and control device efficiency. Much of this underlying emissions inventory data serves as key inputs into CoST and the control strategy analyses. The information on whether a source is currently controlled, by what control device, and control device efficiency is required under the Air Emissions Reporting Rule (AERR) used to collect the emissions inventory data. However, control information may not be fully reported by S/L/T agencies and would not be available for purposes of the control strategy analyses, introducing the possibility that CoST applies controls to already controlled emissions sources.

When sufficient information is available to estimate control costs using equations, the capital costs of the control equipment must be annualized. Capital costs are converted to annual costs using the capital recovery factor (CRF).[3] The engineering cost analysis uses the equivalent uniform annual costs (EUAC) method, in which annualized costs are calculated based on the equipment life for the control and the interest rate incorporated into the CRF. Annualized costs represent an equal stream of yearly costs over the period the control is expected to operate. For more information on the EUAC method, refer to the EPA Air Pollution Control Cost Manual (U.S. EPA, 2017a).

4.1.2 Cost Estimates for the Control Strategies

In this section, we provide engineering cost estimates for the end-of-pipe control technologies and area source controls presented in Chapter 3 that include end-of-pipe control technologies for non-EGU point sources, oil and gas point, non-point (area) sources, residential wood combustion sources, and area fugitive dust emissions. The cost estimates presented in Table 4-1 through Table 4-5 reflect the engineering costs annualized at 7

[3] The capital recovery factor incorporates the interest rate and equipment life (in years) of the control equipment. The capital recovery factor formula is expressed as $r*(1+r)^n/[(1+r)^n -1]$, where r is the real rate of interest and n is the number of time periods. The annualized costs assumed a 7 percent interest rate.

percent, to the extent possible.[4] When calculating the annualized costs we prefer to use the interest rates faced by firms; however, we do not know what those rates will be.

By area, Table 4-1 includes a summary of estimated control costs from control applications for the revised and alternative standard levels analyzed. Table 4A-1 through Table 4A-6 in Appendix 4A include detailed information on estimated costs by area and by county.

Table 4-1 By Area, Summary of Annualized Control Costs for Revised and Alternative Primary Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 for 2032 (millions of 2017$)

Area	10/35	10/30	9/35	8/35
Northeast	$5.3	$5.5	$203.6	$371.1
Northeast (Adjacent Counties)	$0	$0	$62.1	$364.2
Southeast	$35.8	$35.8	$60.4	$299.7
Southeast (Adjacent Counties)	$0.02	$0.02	$25.5	$69.2
West	$39.7	$112.4	$57.7	$140.6
CA	$121.8	$186.1	$184.4	$256.7
Total	$202.5	$339.8	$593.8	$1,501.5

Note: Costs associated with monitoring, testing, reporting, and recordkeeping for potentially affected sources are not included in these estimates.

For the less stringent alternative standard levels of 10/35 μg/m^3, the majority of the estimated costs are incurred in California because 13 of the 20 counties that need emissions reductions are located in California. Looking at the alternative standard levels of 10/30 μg/m^3 in the west, an additional 17 counties need emissions reductions, and the estimated costs increase; estimated costs for the revised alternative standard levels of 9/35 μg/m^3 are higher than for 10/35 μg/m^3 but lower than for 10/30 μg/m^3 in this area. For the revised and more stringent alternative standard levels of 9/35 μg/m^3 and 8/35 μg/m^3, more controls are available to apply in the northeast and the southeast as compared to in California and the west. Therefore, the estimated costs for the northeast and the southeast

[4] Because we obtain control cost data from many sources, we are not always able to obtain consistent data across original data sources. As a result, we do not know the interest rates used to calculate costs for some of the controls included in this analysis. If disaggregated control cost data is available (i.e., where capital, equipment life value, and O&M costs are separated out) we can calculate costs using a specified percent interest rate. EPA may not know the interest rates used to calculate costs when disaggregated control cost data is unavailable (i.e., where we only have a $/ton value and where capital, equipment life value, and O&M costs are not separated out).

are significantly higher for 9/35 μg/m^3 and 8/35 μg/m^3. See Table 3A-2 through Table 3A-7 for more details on emissions reductions available by area and county.

As discussed in Chapter 3, when we applied the emissions reductions from adjacent counties in the northeast and southeast, we applied a ratio of 4:1 in which four tons of $PM_{2.5}$ emissions reductions from an adjacent county are needed to produce the equivalent air quality change of one ton of emissions reduction if it had occurred within the county needing the reduction (see Appendix 2A, Section 2A.3.1 for a discussion of how the ratio was developed). Application of this ratio contributes to the higher cost estimates for revised and alternative standard levels of 9/35 μg/m^3 and 8/35 μg/m^3. It is anticipated that states will first attempt to find emissions reductions within the counties that need the reductions. To the extent that states are able to identify control opportunities within those counties beyond the reductions identified by CoST, the need for reductions from adjacent counties will be reduced. Also, depending on local air quality factors, the resulting air quality impact may be greater than a 4:1 ratio suggests. As a result, the estimate of costs for adjacent counties may be an overestimate.

By emissions inventory sector, Table 4-2 includes a summary of the estimated costs from control applications for the revised and alternative standard levels analyzed. For all of the standard levels analyzed, area source controls for area fugitive dust emissions comprise the largest share of the estimated costs, ranging from 65 to 79 percent of the cost estimates. Non-EGU point and non-point (area) controls represent the next largest shares of the cost estimates.

By area and by emissions inventory sector, Table 4-3 includes a summary of the estimated costs from control applications for the revised and alternative standard levels analyzed. For the more stringent alternative standard levels of 8/35 μg/m^3 across all areas the largest share of estimated costs is from controls for area fugitive dust emissions. In addition, as the standard levels become more stringent, more counties in the northeast and southeast need emissions reductions and controls are applied in those areas (and less so in the west and California because availability of additional controls is limited), resulting in a relatively higher proportion of estimated costs for those areas.

Table 4-2 By Emissions Inventory Sector, Summary of Annualized Control Costs for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

Sector	10/35	10/30	9/35	8/35
Non-EGU Point	$29.0	$35.6	$114.1	$275.5
Oil & Gas Point	$0.4	$0.4	$0.4	$0.8
Non-Point (Area)	$20.4	$27.4	$75.3	$203.0
Residential Wood Combustion	$4.3	$9.3	$16.6	$39.3
Area Source Fugitive Dust	$148.5	$267.1	$387.4	$983.0
Total	$202.5	$339.8	$593.8	$1,501.5

Table 4-3 By Area and by Emissions Inventory Sector, Summary of Annualized Control Costs for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

Area	Sector	10/35	10/30	9/35	8/35
Northeast	Non-EGU Point	$0.5	$0.5	$69.4	$144.2
	Non-Point (Area)	$4.7	$5.0	$33.0	$57.0
	Residential Wood Combustion	$0.03	$0.03	$7.1	$8.8
	Area Source Fugitive Dust	$0	$0	$94.1	$161.1
Northeast (Adjacent Counties)	Non-EGU Point	$0	$0	$2.4	$26.8
	Non-Point (Area)	$0	$0	$12.9	$45.7
	Residential Wood Combustion	$0	$0	$1.4	$8.9
	Area Source Fugitive Dust	$0	$0	$45.3	$282.7
Southeast	Non-EGU Point	$2.9	$2.9	$4.1	$52.0
	Non-Point (Area)	$1.8	$1.8	$8.0	$53.9
	Residential Wood Combustion	$0.08	$0.08	$0.5	$5.3
	Area Source Fugitive Dust	$31.0	$31.0	$47.9	$188.6
Southeast (Adjacent Counties)	Non-EGU Point	$0	$0	$0	$6.0
	Non-Point (Area)	$0	$0	$0.1	$6.5
	Residential Wood Combustion	$0	$0	$0	$0.2
	Area Source Fugitive Dust	$0.02	$0.02	$25.4	$56.6
West	Non-EGU Point	$0	$3.9	$3.9	$8.1
	Oil & Gas Point	$0	$0	$0	$0.4
	Non-Point (Area)	$0.1	$3.9	$2.4	$13.9
	Residential Wood Combustion	$0.05	$0.6	$0.1	$3.5
	Area Source Fugitive Dust	$39.5	$104.0	$51.4	$114.7
CA	Non-EGU Point	$25.6	$28.3	$34.2	$38.3
	Oil & Gas Point	$0.4	$0.4	$0.4	$0.4
	Non-Point (Area)	$13.7	$16.8	$18.9	$25.9
	Residential Wood Combustion	$4.2	$8.6	$7.6	$12.7
	Area Source Fugitive Dust	$77.9	$132.1	$123.4	$179.3
Total		$202.5	$339.8	$593.8	$1,501.5

By control technology, Table 4-4 includes a summary of the estimated costs from control applications for the revised and alternative standard levels analyzed. Across all of the standard levels analyzed, the end-of-pipe and area source controls that comprise more than 80 percent of the cost estimates include Pave Existing Shoulders and Pave Unpaved Roads (area fugitive dust inventory sector), Fabric Filter-All Types (non-EGU point inventory sector), and Electrostatic Precipitator (non-point (area) inventory sector).

By emissions inventory sector and by control technology, Table 4-5 includes a summary of the cost estimates. Across all of the standard levels analyzed, for the non-EGU point sector, the application of Fabric Filter-All Types results in the highest portion of estimated costs for that inventory sector; for the non-point (area) sector, the application of Electrostatic Precipitator and Substitute Chipping for Burning result in the highest portion of estimated costs for that inventory sector; for the residential wood combustion sector, the application of Convert to Gas Logs results in the highest portion of estimated costs for that inventory sector; and for the area fugitive dust sector, the application of Pave Existing Shoulders and Pave Unpaved Roads result in the highest portion of estimated costs for that inventory sector.

Table 4-4 By Control Technology, Summary of Annualized Control Costs for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

Control Technology	10/35	10/30	9/35	8/35
Add-on Scrubber	$0	$0	$0	$0.05
Annual tune-up	$0.4	$0.9	$6.2	$14.7
Biennial tune-up	$0.8	$0.9	$0.1	$1.2
Catalytic oxidizers	$0	$0.6	$2.4	$0.7
Chemical Stabilizer	$0	$18.7	$7.5	$152.5
Convert to Gas Logs	$4.2	$8.0	$14.4	$30.5
EPA Phase 2 Qualified Units	$0	$0.8	$0.1	$2.0
EPA-certified wood stove	$0.01	$0.01	$0.0	$0
Electrostatic Precipitator	$14.5	$17.2	$45.8	$109.9
Electrostatic Precipitator-All Types	$0	$0	$0.4	$0
Fabric Filter-All Types	$29.4	$35.9	$107.9	$266.0
HEPA filters	$0	$0	$0.01	$0.01
Install Cleaner Hydronic Heaters	$0.01	$0.05	$0.1	$0.5
Install Retrofit Devices	$0	$0	$0.5	$0.3
Install new drift eliminator	$0	$0	$0.7	$2.2
New gas stove or gas logs	$0.07	$0.4	$1.5	$5.9
Pave Unpaved Roads	$75.6	$133.9	$122.4	$199.2
Pave existing shoulders	$72.7	$114.1	$257.2	$630.4
Smokeless Broiler	$0.6	$0.6	$3.3	$6.9
Substitute chipping for burning	$4.0	$7.2	$17.4	$69.6
Venturi Scrubber	$0.01	$0.05	$5.5	$8.0
Watering	$0.1	$0.4	$0.3	$1.0
Total	$202.5	$339.8	$593.8	$1,501.5

Table 4-5 By Emissions Inventory Sector and Control Technology, Summary of Annualized Control Costs for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (millions of 2017$)

Inventory Sector	Control Technology	10/35	10/30	9/35	8/35
Non-EGU Point	Electrostatic Precipitator-All Types	$0	$0	$0.4	$0
	Fabric Filter-All Types	$29.0	$35.5	$107.5	$265.2
	Install new drift eliminator	$0	$0	$0.7	$2.2
	Venturi Scrubber	$0.01	$0.05	$5.5	$8.0
Oil & Gas Point	Fabric Filter-All Types	$0.4	$0.4	$0.4	$0.8
Non-Point (Area)	Add-on Scrubber	$0	$0	$0	$0.05
	Annual tune-up	$0.4	$0.9	$6.2	$14.7
	Biennial tune-up	$0.8	$0.9	$0.1	$1.2
	Catalytic oxidizers	$0	$0.6	$2.4	$0.7
	Electrostatic Precipitator	$14.5	$17.2	$45.8	$109.9
	HEPA filters	$0	$0	$0.01	$0.01
	Smokeless Broiler	$0.6	$0.6	$3.3	$6.9
	Substitute chipping for burning	$4.0	$7.2	$17.4	$69.6
Residential Wood Combustion	Convert to Gas Logs	$4.2	$8.0	$14.4	$30.5
	EPA Phase 2 Qualified Units	$0	$0.8	$0.1	$2.0
	EPA-certified wood stove	$0.01	$0.01	$0.0	$0
	Install Cleaner Hydronic Heaters	$0.01	$0.05	$0.1	$0.5
	Install Retrofit Devices	$0	$0	$0.5	$0.3
	New gas stove or gas logs	$0.07	$0.4	$1.5	$5.9
Area Source Fugitive Dust	Chemical Stabilizer	$0	$18.7	$7.5	$152.5
	Pave Unpaved Roads	$75.6	$133.9	$122.4	$199.2
	Pave existing shoulders	$72.7	$114.1	$257.2	$630.4
	Watering	$0.1	$0.4	$0.3	$1.0
Total		$202.5	$339.8	$593.8	$1,501.5

As discussed in Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5 for the revised standard levels of 9/35 μg/m³, there are remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California; the areas include 2 counties with near-road monitors, 3 counties in border areas, 5 counties in small western mountain valleys, and 15 additional counties in California's air districts and basins. The characteristics of the air quality challenges for these areas include features of certain near-road sites with challenging local conditions, cross-border transport, effects of complex terrain in the west and California, and identifying wildfire influence on projected $PM_{2.5}$ DVs that could qualify for exclusion as atypical, extreme, or unrepresentative events (U.S. EPA, 2019b). To the extent that state and local areas are able to find alternative lower-cost approaches to reducing emissions, the annualized control costs above may be overestimated. To the extent that additional $PM_{2.5}$ emissions reductions are required that were not identified in our analysis of these areas, the annualized control costs above may be underestimated.

4.2 Limitations and Uncertainties in Engineering Cost Estimates

The EPA acknowledges several important limitations of this analysis, including:

- **Exclusions from the Cost Analysis**: As indicated, recordkeeping, reporting, testing, and monitoring costs are not included. In addition, the costs some states will incur both designing SIPs and implementing new control strategies to meet a revised standard are not included.
- **Cost and Effectiveness of Controls**: We are not able to account for regional or local variation in capital and annual cost items such as energy, labor, or materials. The estimates of control efficiencies assume that the control devices are properly installed and maintained. The estimates of control efficiencies do not account for differences in individual applications because we use a single value for each control that does not account for differences in individual applications; a control may operate more or less effectively than the specified efficiency. In addition, variability in scale of control application is difficult to reflect for small area sources of emissions.
- **Interest Rate**: Because we obtain control cost data from many sources, we are not always able to obtain consistent data across original data sources. If disaggregated control cost data is available (i.e., where capital, equipment life value, and O&M costs are separated out) we can calculate costs using a specified percent interest rate. The EPA may not know the interest rates used to calculate costs if disaggregated control cost data is unavailable (i.e., where we only have a $/ton value and where capital, equipment life value, and O&M costs are not separated out). In general, we have some disaggregated data available for non-EGU point source controls, but we do not have any disaggregated control cost data for non-point (area) source controls.

- **Differences Between *ex ante* and *ex post* Compliance Cost Estimates:** In comparing regulatory cost estimates before and after regulation, *ex ante* cost estimate predictions may differ from actual costs. Harrington *et al.* (2000) surveyed the predicted and actual costs of 28 federal and state rules, including 21 issued by the U.S. Environmental Protection Agency and the Occupational Safety and Health Administration (OSHA). In 14 of the 28 rules, predicted total costs were overestimated, while analysts underestimated costs in three of the remaining rules. In EPA rules where per-unit costs were specifically evaluated, costs of regulations were overestimated in five cases, underestimated in four cases, and accurately estimated in four cases (Harrington et al., 2000). The collection of literature regarding the accuracy of cost estimates seems to reflect these splits. A recent EPA report, the "Retrospective Study of the Costs of EPA Regulations" that examined the compliance costs of five EPA regulations in four case studies,[5] found that several of the case studies suggested that cost estimates were over-estimated *ex ante* and did not find the evidence to be conclusive. The EPA stated in the report that the small number of regulatory actions covered, as well as significant data and analytical challenges associated with the case studies limited the certainty of this conclusion (U.S. EPA, 2014).

4.3 Social Costs

As discussed in EPA's *Guidelines for Preparing Economic Analyses*, social costs are the total economic burden of a regulatory action (U.S. EPA, 2016). This burden is the sum of all opportunity costs incurred due to the regulatory action, where an opportunity cost is the value lost to society of any goods and services that will not be produced and consumed as a result of reallocating some resources toward pollution mitigation. Estimates of social costs may be compared to the social benefits expected as a result of a regulation to assess

[5] The four case studies in the 2014 *Retrospective Study of the Costs of EPA Regulations* examine five EPA regulations: the 2001/2004 National Emission Standards for Hazardous Air Pollutants and Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards on the Pulp and Paper Industry; Critical Use Exemptions for Use of Methyl Bromide for Growing Open Field Fresh Strawberries in California for the 2004-2008 Seasons; the 2001 National Primary Drinking Water Regulations for Arsenic; and the 1998 Locomotive Emission Standards.

its net impact on society. Computable General Equilibrium (CGE) models are a class of economy-wide models that can be used to evaluate the broader impacts of a regulatory action and can therefore be used to estimate social costs. While CGE modeling was not conducted for this analysis, we include a qualitative discussion of its use in evaluating social costs and economic impact modeling.

Economic impacts focus on the behavioral response to the costs imposed by a policy being analyzed. The responses typically analyzed are market changes in prices, quantities produced and purchased, changes in international trade, changes in profitability, facility closures, and employment. Sometimes these behavioral changes can be used to estimate social costs if there is indication that the social costs differ from the estimate of control costs because behavioral change results in other ways of meeting the requirements (e.g., facilities choosing to reduce emissions by producing less rather than adding pollution control devices). Changes in production in a directly regulated sector may have indirect effects on a myriad of other markets when output from that sector is used as an input in the production of many other goods. It may also affect upstream industries that supply goods and services to the sector, along with labor and capital markets, as these suppliers alter production processes in response to changes in factor prices. In addition, households may change their demand for particular goods and services due to changes in the price of those goods.

When new regulatory requirements are expected to result in effects outside of regulated and closely related sectors, a key challenge is determining whether they are of sufficient magnitude to warrant explicit evaluation (Hahn and Hird 1990). It is not possible to estimate the magnitude and direction of all of these potential effects outside of the regulated sector(s) without an economy-wide modeling approach. For example, studies of air pollution regulations for the power sector have found that the social costs and benefits may be greater or lower than when secondary market impacts are taken into account, and that the direction of the estimates may depend on the form of the regulation (e.g., Goulder et al. 1999, Williams 2002, Goulder et al. 2016).

The revised and alternative standard levels analyzed are anticipated to impact multiple markets in many places over time. CGE models are a class of economy-wide models that could be used to evaluate the impacts of a regulation on the broader economy because they explicitly capture interactions between markets across the entire economy. While a CGE model captures the effects of behavioral responses on the part of consumers or other producers to changes in price that are missed by an engineering estimate of compliance costs, most CGE models do not model the environmental externality or the benefits that accrue to society from mitigating the externality. When benefits from a regulation are expected to be substantial, social cost cannot be interpreted as a complete characterization of economic welfare.[6] To the extent that the benefits affect behavioral responses in markets, the social cost measure may also be potentially biased.

A CGE-based approach to cost estimation concurrently considers the effect of a regulation across all sectors in the economy. It is structured around the assumption that, for some discrete period of time, an economy can be characterized by a set of equilibrium conditions in which supply equals demand in all markets. When the imposition of a regulation alters conditions in one market, a general equilibrium approach will determine a new set of prices for all markets that will return the economy to equilibrium. These prices in turn determine the outputs and consumption of goods and services in the new equilibrium. In addition, a new set of prices and demands for the factors of production (labor, capital, and land), the returns to which compose the income of businesses and households, will be determined in general equilibrium. The social cost of the regulation can then be estimated by comparing the value of variables in the pre-regulation "baseline" equilibrium with those in the post-regulation, simulated equilibrium.

In 2015, the EPA established a Science Advisory Board (SAB) panel to consider the technical merits and challenges of using economy-wide models to evaluate costs, benefits, and economic impacts in regulatory development. In its final report (U.S. EPA, 2017b), the SAB recommended that the EPA begin to integrate CGE modeling into regulatory analysis

[6] The EPA included specific types of health benefits in a CGE model for the prospective analysis -- The Benefits and Costs of the Clean Air Act from 1990 to 2020 (EPA 2011) -- and demonstrated the importance of their inclusion when evaluating the economic welfare effects of policy. However, while the external Council on Clean Air Compliance Analysis (Council) peer review of the EPA report (Hammitt, 2010) stated that inclusion of benefits in an economy-wide model, specifically adapted for use in that study, "represent[ed] a significant step forward in benefit-cost analysis", serious technical challenges remain when attempting to evaluate the benefits and costs of potential regulatory actions using economy-wide models.

to offer a more comprehensive assessment of the effects of air regulations. The SAB noted that CGE models can provide insight into the likely social costs of a regulation even when they do not typically include a characterization of the likely social benefits of the regulation. CGE models may also offer insights into the ways costs are distributed across regions, industry sectors, or households.

In response to the SAB's recommendations, the EPA built a new CGE model called SAGE. A second SAB panel performed a peer review of SAGE, and the review concluded in 2020. While the theory and inherent model structure, including key underlying assumptions and model parameterization, have been through rigorous peer review, applying SAGE to specific regulatory contexts requires the EPA to determine when and how the tool can best be leveraged to gain insights. U.S. EPA (2017b) noted that there is "no hard and fast rule" for deciding when an economy-wide modeling approach will add value beyond other tools typically utilized by the EPA to quantify costs, though they suggest several relevant factors, including strong cross-price effects between markets, pre-existing distortions present in those markets, and impacts that are not small relative to the precision of the model.

There are additional considerations that are equally important when considering whether a CGE model will add value, on net, beyond the set of tools already being leveraged to estimate costs. For example, care must be given when preparing engineering costs to be used as an input in an economy-wide model to avoid double counting taxes and transfers, translate capital costs to a consistent measure within the economy-wide model, and attribute engineering costs to specific inputs. Using SAGE or any other CGE model in a rulemaking requires significant time and resources to adapt engineering cost estimates for use in the model and to modify the model, as needed, to capture important sector-specific nuances in modeling the behavioral response to a regulation. Therefore, in deciding whether and how to utilize CGE models to analyze the social costs of regulations requires a weighing of the value added of additional insights that can be gained from an economy-wide analysis against the time and resource costs of developing a careful approach to accurately capture key compliance pathways and sector-specific behavioral responses within the CGE model. The EPA will continue to evaluate the appropriateness of conducting an economy-wide analysis using SAGE or another CGE model for rulemakings.

In May 2023, the EPA used SAGE for the first time to analyze the social costs of a proposed regulation, the Greenhouse Gas Standards and Guidelines for Fossil Fuel-fired Power Plants. The analysis appears in an appendix of the Regulatory Impact Analysis and outlines the approach taken to ensure careful calibration of compliance cost estimates from the EPA's electricity sector model, the Integrated Planning Model (IPM), for use in SAGE. Connecting the outputs from a sectoral partial equilibrium model to a CGE model required significant attention and resources. The EPA needed to develop an approach to linking the SAGE model and the results from IPM that could adequately represent the regulatory requirements and detailed compliance response information from the technologically rich partial equilibrium model of the power sector in the CGE model. The EPA requested public comment on the use of the SAGE model and presentation of results, which the Agency will review in developing the analysis for the final Greenhouse Gas Standards and Guidelines for Fossil Fuel-fired Power Plants rule.

The EPA does not currently have the capacity to estimate the social costs of this rule using the SAGE model and anticipates that significant modeling and data development would be needed to adequately characterize the economy-wide impacts of the rule. This rulemaking differentially affects sectors and regions across the economy in ways that make capturing the economy-wide impacts difficult. The SAB's 2017 report noted that, "The more spatially, sectorally, and/or temporally detailed the regulation, the more challenging it is to represent in a modeling framework. For example, the National Ambient Air Quality Standards (NAAQS) are determined at the national level, with implementation occurring at the state level in accordance with air basin-specific considerations. As a result, the implementation of the standard can vary widely across air basins, making it difficult to capture in an economy- wide model, which usually are too spatially and sectorally aggregated to capture air basin specific regulations. It is also difficult to predict what each state will do to comply with the NAAQS, particularly for those compliance actions states must take that are not attributable to specific control measures and which may cost more than EPA's upper-bound action. However, this difficulty is not unique to CGE analysis: other methodologies must confront it as well." (U.S. EPA, 2017b). We therefore did not conduct an economy-wide analysis using SAGE for this rulemaking.

4.4 References

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APPENDIX 4A: ENGINEERING COST ANALYSIS

Overview

Chapter 4 describes the engineering cost analysis approach that EPA used to analyze the following revised and alternative annual and 24-hour standard levels in this regulatory impact analysis (RIA) -- 10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$. This Appendix contains more detailed information about the estimated costs from application of controls by area and by county for the northeast and their adjacent counties, the southeast and their adjacent counties, the west, and California.

4A.1 Estimated Costs by County for Revised and Alternative Standard Levels

The cost estimates presented in Table 4A-1 through Table 4A-6 reflect the engineering costs annualized at 7 percent, to the extent possible.[1] When calculating the annualized costs we prefer to use the interest rates faced by firms; however, we do not know what those rates are.

Table 4A-1 and Table 4A-2 present the cost estimates for the northeast counties and their adjacent counties. Table 4A-3 and Table 4A-4 present the cost estimates for the southeast counties and their adjacent counties. Table 4A-5 presents the cost estimates for the counties in the west, and Table 4A-6 presents the cost estimates for the counties in California, organized by air district.

Table 4A-1 Summary of Estimated Annual Control Costs for the Northeast (31 counties) for Revised and Alternative Primary Standard Levels of 10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$ for 2032 (millions of 2017$)

County	10/35	10/30	9/35	8/35
Cook County, IL	$0	$0	$5.4	$12.8
DuPage County, IL	$0	$0	$0	$9.5
Macon County, IL	$0	$0	$0	$4.9
Madison County, IL	$0	$0	$0.4	$22.1
McLean County, IL	$0	$0	$0	$0.08

[1] Because we obtain control cost data from many sources, we are not always able to obtain consistent data across original data sources. As a result, we do not know the interest rates used to calculate costs for some of the controls included in this analysis. If disaggregated control cost data is available (i.e., where capital, equipment life value, and O&M costs are separated out) we can calculate costs using a specified percent interest rate. EPA may not know the interest rates used to calculate costs when disaggregated control cost data is unavailable (i.e., where we only have a $/ton value and where capital, equipment life value, and O&M costs are not separated out).

County	10/35	10/30	9/35	8/35
St. Clair County, IL	$0	$0	$0	$7.7
Lake County, IN	$0	$0	$0.1	$1.7
Marion County, IN	$0	$0	$39.3	$39.3
Jefferson County, KY	$0	$0	$0	$3.4
Wayne County, MI	$1.2	$1.2	$21.4	$31.1
Bergen County, NJ	$0	$0	$17.3	$17.3
Camden County, NJ	$0	$0	$8.9	$10.4
Union County, NJ	$0	$0	$0	$13.5
New York County, NY	$0	$0	$0	$7.2
Butler County, OH	$0	$0	$33.4	$33.5
Cuyahoga County, OH	$0	$0	$6.5	$15.6
Franklin County, OH	$0	$0	$0	$0.2
Hamilton County, OH	$1.6	$1.6	$23.6	$23.6
Jefferson County, OH	$0	$0	$0	$0.04
Stark County, OH	$0	$0	$0	$0.7
Allegheny County, PA	$2.3	$2.6	$18.4	$60.3
Beaver County, PA	$0	$0	$0	$0.5
Cambria County, PA	$0	$0	$0	$0.5
Chester County, PA	$0	$0	$3.3	$17.5
Delaware County, PA	$0.2	$0.2	$19.3	$19.3
Lancaster County, PA	$0	$0	$0	$1.9
Lebanon County, PA	$0	$0	$0	$0.9
Philadelphia County, PA	$0	$0	$6.2	$12.6
York County, PA	$0	$0	$0	$1.2
Providence County, RI	$0	$0	$0	$0.3
Davidson County, TN	$0	$0	$0	$1.5
Total	$5.3	$5.5	$203.6	$371.1

Table 4A-2 Summary of Estimated Annual Control Costs for Adjacent Counties in the Northeast (51 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (millions of 2017$)

County	Adjacent Counties	10/35	10/30	9/35	8/35
Kane County, IL	Cook County, IL DuPage County, IL	$0	$0	$0	$11.4
Lake County, IL	Cook County, IL	$0	$0	$0	$7.0
McHenry County, IL	Cook County, IL	$0	$0	$0	$15.5
Will County, IL	Cook County, IL DuPage County, IL	$0	$0	$0	$1.5
Boone County, IN	Marion County, IN	$0	$0	$0.2	$5.2
Hamilton County, IN	Marion County, IN	$0	$0	$0.8	$15.4
Hancock County, IN	Marion County, IN	$0	$0	$0.2	$5.1
Hendricks County, IN	Marion County, IN	$0	$0	$0.5	$13.3
Johnson County, IN	Marion County, IN	$0	$0	$0.5	$8.0
Morgan County, IN	Marion County, IN	$0	$0	$0.4	$7.5
Shelby County, IN	Marion County, IN	$0	$0	$0.9	$14.3
Macomb County, MI	Wayne County, MI	$0	$0	$0	$18.1
Monroe County, MI	Wayne County, MI	$0	$0	$0	$11.0

County	Adjacent Counties	10/35	10/30	9/35	8/35
Oakland County, MI	Wayne County, MI	$0	$0	$0	$36.3
Washtenaw County, MI	Wayne County, MI	$0	$0	$0	$7.3
Atlantic County, NJ	Camden County, NJ	$0	$0	$0	$9.5
Burlington County, NJ	Camden County, NJ	$0	$0	$0	$16.0
Essex County, NJ	Bergen County, NJ Union County, NJ	$0	$0	$13.0	$13.0
Gloucester County, NJ	Camden County, NJ	$0	$0	$0	$12.1
Hudson County, NJ	Bergen County, NJ Union County, NJ	$0	$0	$7.0	$7.0
Passaic County, NJ	Bergen County, NJ	$0	$0	$7.0	$7.0
Bronx County, NY	New York County, NY	$0	$0	$0	$0.5
Kings County, NY	New York County, NY	$0	$0	$0	$0.4
Queens County, NY	New York County, NY	$0	$0	$0	$0.9
Clermont County, OH	Hamilton County, OH	$0	$0	$13.1	$13.1
Geauga County, OH	Cuyahoga County, OH	$0	$0	$0	$10.8
Lake County, OH	Cuyahoga County, OH	$0	$0	$0	$4.7
Lorain County, OH	Cuyahoga County, OH	$0	$0	$0	$13.3
Medina County, OH	Cuyahoga County, OH	$0	$0	$0	$14.7
Portage County, OH	Cuyahoga County, OH Stark County, OH	$0	$0	$0	$7.6
Summit County, OH	Cuyahoga County, OH Stark County, OH	$0	$0	$0	$16.0
Warren County, OH	Butler County, OH Hamilton County, OH	$0	$0	$13.9	$13.9
Armstrong County, PA	Allegheny County, PA	$0	$0	$0	$0.2
Butler County, PA	Allegheny County, PA Beaver County, PA	$0	$0	$0	$1.7
Montgomery County, PA	Chester County, PA Delaware County, PA Philadelphia County, PA	$0	$0	$4.4	$21.5
Washington County, PA	Allegheny County, PA Beaver County, PA	$0	$0	$0	$1.8
Westmoreland County, PA	Allegheny County, PA Cambria County, PA	$0	$0	$0	$1.6
Total		$0	$0	$62.1	$364.2

Table 4A-3 Summary of Estimated Annual Control Costs for the Southeast (33 counties) for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

County	10/35	10/30	9/35	8/35
Jefferson County, AL	$0	$0	$0	$0.8
Russell County, AL	$0	$0	$0	$3.1
Pulaski County, AR	$0	$0	$0	$5.5
District of Columbia	$0	$0	$0	$9.6
Broward County, FL	$0	$0	$0.1	$12.1
Bibb County, GA	$0	$0	$0	$1.4

County	10/35	10/30	9/35	8/35
Chatham County, GA	$0	$0	$0	$0.3
Dougherty County, GA	$0	$0	$0	$1.2
Fulton County, GA	$0	$0	$0	$42.9
Gwinnett County, GA	$0	$0	$0	$32.0
Muscogee County, GA	$0	$0	$0	$13.5
Richmond County, GA	$0	$0	$0.1	$23.7
Shawnee County, KS	$0	$0	$0	$6.1
Wyandotte County, KS	$0	$0	$0	$4.3
Caddo Parish, LA	$0	$0	$4.2	$21.7
East Baton Rouge Parish, LA	$0	$0	$0	$1.8
West Baton Rouge Parish, LA	$0	$0	$0	$10.4
Hinds County, MS	$0	$0	$0	$3.0
Forsyth County, NC	$0	$0	$0	$0.1
Mecklenburg County, NC	$0	$0	$0	$2.5
Cleveland County, OK	$0	$0	$0	$9.0
Oklahoma County, OK	$0	$0	$0	$3.2
Tulsa County, OK	$0	$0	$0	$3.2
Bowie County, TX	$0	$0	$0	$2.7
Cameron County, TX	$0	$0	$15.8	$15.8
Dallas County, TX	$0	$0	$0	$0.9
El Paso County, TX	$0	$0	$0	$7.7
Harris County, TX	$0	$0	$2.9	$9.2
Hidalgo County, TX	$35.8	$35.8	$35.8	$35.8
Jefferson County, TX	$0	$0	$0	$1.6
Nueces County, TX	$0	$0	$0	$3.3
Orange County, TX	$0	$0	$0	$4.6
Travis County, TX	$0	$0	$1.6	$6.9
Total	$35.8	$35.8	$60.4	$299.7

Table 4A-4 Summary of Estimated Annual Control Costs for Adjacent Counties in the Southeast (34 counties) for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

County	Adjacent Counties	10/35	10/30	9/35	8/35
Burke County, GA	Richmond County, GA	$0	$0	$0	$4.0
Columbia County, GA	Richmond County, GA	$0	$0	$0	$1.3
Forsyth County, GA	Fulton County, GA Gwinnett County, GA	$0	$0	$0	$0.0
Jefferson County, GA	Richmond County, GA	$0	$0	$0	$4.1
McDuffie County, GA	Richmond County, GA	$0	$0	$0	$1.1
Bossier Parish, LA	Caddo Parish, LA	$0	$0	$0	$10.8
De Soto Parish, LA	Caddo Parish, LA	$0	$0	$0	$10.5
East Feliciana Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	$0	$0	$0	$0.1
Iberville Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	$0	$0	$0	$0.5
Pointe Coupee Parish, LA	West Baton Rouge Parish, LA	$0	$0	$0	$0.1
Red River Parish, LA	Caddo Parish, LA	$0	$0	$0	$6.2
West Feliciana Parish, LA	West Baton Rouge Parish, LA	$0	$0	$0	$0.1

County	Adjacent Counties	10/35	10/30	9/35	8/35
Bastrop County, TX	Travis County, TX	$0	$0	$0	$0.2
Blanco County, TX	Travis County, TX	$0	$0	$0	$0.01
Brooks County, TX	Hidalgo County, TX	$0.01	$0.01	$9.1	$9.1
Burnet County, TX	Travis County, TX	$0	$0	$0	$0.01
Caldwell County, TX	Travis County, TX	$0	$0	$0	$0.06
Hays County, TX	Travis County, TX	$0	$0	$0	$0.02
Hudspeth County, TX	El Paso County, TX	$0	$0	$0	$4.6
Kenedy County, TX	Hidalgo County, TX	$0.01	$0.01	$5.9	$5.9
Starr County, TX	Hidalgo County, TX	$0	$0	$7.4	$7.4
Willacy County, TX	Cameron County, TX Hidalgo County, TX	$0.01	$0.01	$3.2	$3.2
Williamson County, TX	Travis County, TX	$0	$0	$0	$0.02
Total		$0.02	$0.02	$25.5	$69.2

Table 4A-5 Summary of Estimated Annual Control Costs for the West (29 counties) for Revised and Alternative Primary Standard Levels of 10/35 µg/m³, 10/30 µg/m³, 9/35 µg/m³, and 8/35 µg/m³ for 2032 (millions of 2017$)

County	10/35	10/30	9/35	8/35
Maricopa County, AZ	$0	$0	$1.2	$7.2
Pinal County, AZ	$0	$1.5	$0	$0
Santa Cruz County, AZ	$0	$0	$0	$0.8
Yuma County, AZ	$0	$0	$0	$0.4
Adams County, CO	$0	$0	$0.04	$16.0
Denver County, CO	$0	$0	$0.01	$1.8
Weld County, CO	$0	$0	$0	$0.2
Benewah County, ID	$0	$17.0	$0	$0
Canyon County, ID	$0	$4.2	$0	$6.8
Lemhi County, ID	$0	$1.2	$1.2	$1.2
Shoshone County, ID	$12.8	$12.8	$12.8	$12.8
Flathead County, MT	$0	$0.6	$0	$0
Lewis and Clark County, MT	$0	$3.7	$0	$3.7
Lincoln County, MT	$26.9	$26.9	$26.9	$26.9
Missoula County, MT	$0	$0	$0.02	$9.6
Clark County, NV	$0	$0	$0	$2.3
Crook County, OR	$0	$7.1	$0	$1.2
Harney County, OR	$0	$1.9	$4.7	$19.0
Jackson County, OR	$0	$0.01	$1.1	$12.8
Josephine County, OR	$0	$0	$0	$5.1
Klamath County, OR	$0	$9.8	$9.8	$9.8
Lake County, OR	$0	$0	$0	$0
Lane County, OR	$0	$0.7	$0	$0.7
Box Elder County, UT	$0	$3.3	$0	$0
Cache County, UT	$0	$3.2	$0	$0
Salt Lake County, UT	$0	$0.06	$0	$0
King County, WA	$0	$0	$0	$0.2
Okanogan County, WA	$0	$18.4	$0	$2.0

County	10/35	10/30	9/35	8/35
Yakima County, WA	$0	$0	$0	$0
Total	$39.7	$112.4	$57.7	$140.6

Table 4A-6 Summary of Estimated Annual Control Costs for California (36 counties) for Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (millions of 2017$)

County	Air District	10/35	10/30	9/35	8/35
Alameda County, CA	Bay Area AQMD	$0.1	$0.1	$16.4	$16.4
Contra Costa County, CA	Bay Area AQMD	$0	$0	$0.2	$1.4
Napa County, CA	Bay Area AQMD	$0	$0	$0	$3.7
San Francisco County, CA	Bay Area AQMD	$0	$0	$0	$3.3
San Mateo County, CA	Bay Area AQMD	$0	$0	$0	$0.5
Santa Clara County, CA	Bay Area AQMD	$0	$0	$0.3	$1.7
Solano County, CA	Bay Area AQMD	$0	$0	$2.4	$8.1
Butte County, CA	Butte County AQMD	$0	$3.6	$0	$1.7
Calaveras County, CA	Calaveras County APCD	$0	$0	$4.0	$4.0
Colusa County, CA	Colusa County APCD	$0	$0	$0	$0
Sutter County, CA	Feather River AQMD	$0	$4.2	$4.2	$4.2
Mono County, CA	Great Basin Unified APCD	$0	$0	$0	$0
Imperial County, CA	Imperial County APCD	$1.8	$1.8	$1.8	$1.8
Mendocino County, CA	Mendocino County AQMD	$0	$5.1	$0	$0.01
Plumas County, CA	Northern Sierra AQMD	$0	$0	$0	$0
Placer County, CA	Placer County APCD	$0	$0	$0	$0.02
Sacramento County, CA	Sacramento Metro AQMD	$0	$1.4	$1.0	$4.2
San Diego County, CA	San Diego County APCD	$0	$0	$1.7	$40.2
Fresno County, CA	San Joaquin Valley APCD	$44.0	$44.0	$44.0	$44.0
Kern County, CA	San Joaquin Valley APCD	$10.1	$10.1	$10.1	$10.1
Kings County, CA	San Joaquin Valley APCD	$5.0	$5.0	$5.0	$5.0
Madera County, CA	San Joaquin Valley APCD	$0	$0	$16.8	$16.8
Merced County, CA	San Joaquin Valley APCD	$12.4	$12.4	$12.4	$12.4
San Joaquin County, CA	San Joaquin Valley APCD	$0	$0.02	$15.6	$15.6
Stanislaus County, CA	San Joaquin Valley APCD	$2.6	$2.6	$2.6	$2.6
Tulare County, CA	San Joaquin Valley APCD	$21.7	$21.7	$21.7	$21.7
San Luis Obispo County, CA	San Luis Obispo County APCD	$0	$0	$0	$0.01
Santa Barbara County, CA	Santa Barbara County APCD	$0	$6.6	$0	$0.6
Shasta County, CA	Shasta County AQMD	$0	$0.03	$0	$0
Siskiyou County, CA	Siskiyou County APCD	$0	$23.6	$0	$0
Los Angeles County, CA	South Coast AQMD	$12.5	$12.5	$12.5	$12.5
Orange County, CA	South Coast AQMD	$3.2	$3.2	$3.2	$3.2
Riverside County, CA	South Coast AQMD	$0	$0	$0	$0
San Bernardino County, CA	South Coast AQMD	$8.4	$8.4	$8.4	$8.4
Tehama County, CA	Tehama County APCD	$0	$7.3	$0	$0
Ventura County, CA	Ventura County APCD	$0	$12.5	$0.3	$12.5
Total		$121.8	$186.1	$184.4	$256.7

CHAPTER 5: BENEFITS ANALYSIS APPROACH AND RESULTS

Overview

This chapter presents the estimated human health-related and welfare benefits of the illustrative control strategies discussed in Chapter 3 for the revised annual and current 24-hour alternative standard levels of 9/35 μg/m^3, as well as the following less and more stringent alternative standard levels 10/35 μg/m^3, 10/30 μg/m^3, and 8/35 μg/m^3. Because the EPA is retaining the current secondary PM standards, we did not evaluate alternative secondary standard levels in this chapter. We quantify the number and economic value of the estimated avoided premature deaths and illnesses attributable to applying hypothetical national control strategies for the revised, less stringent, and more stringent annual $PM_{2.5}$ NAAQS standards with a sensitivity analysis for a more stringent 24-hour standard that reduces fine particulate matter ($PM_{2.5}$) concentrations in 2032. Reducing directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursor emissions would also improve environmental quality (U.S. EPA, 2019c, 2022a) and reduce the ecological effects of nitrogen and sulfur deposition. Because the EPA is retaining the current secondary PM NAAQS standards, we did not evaluate alternative secondary standard levels in this RIA, or any visibility-, climate change-, or materials-damage-related benefits of the final rule (Cox, 2019; U.S. EPA, 2019c).

The analysis in this chapter aims to characterize the benefits of the air quality changes resulting from the implementation of revised PM standard levels by answering two key questions:

1. What is the estimated number and geographic distribution of avoided $PM_{2.5}$-attributable premature deaths and illnesses expected to result from applying hypothetical national control strategies for the revised and alternative $PM_{2.5}$ NAAQS standards? This chapter presents these results. As discussed in Chapter 3, Section 3.2.4, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the revised, less, and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. In Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5, we discuss the remaining air quality challenges for

areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 μg/m^3.

2. What is the estimated number and geographic distribution of avoided $PM_{2.5}$-attributable premature deaths and illnesses expected to result if we assume that areas identify all of the controls needed for compliance with the revised and alternative $PM_{2.5}$ NAAQS standard levels? Appendix 5A presents these results.
3. What is the estimated economic value of these avoided impacts?

To answer these questions we perform a human health benefits analysis (NRC, 2002). Starting first with the Integrated Science Assessment (ISA) for Particulate Matter (U.S. EPA, 2019b) and the Supplement to the ISA for Particulate Matter (U.S. EPA, 2022a), we identify the human health effects associated with ambient particles, which include premature death and a variety of morbidity effects associated with acute (hours-long) and chronic (months- or years- long) exposures. Table 5-2 summarizes human health categories monetized and reflected in the total value of the benefits reported and those categories not monetized due to limited data or resources. The list of benefits categories is neither exhaustive nor completely quantified. We excluded effects not identified as having a causal or likely to be causal relationship with the affected pollutants in the most recent PM ISA (U.S. EPA, 2019b),(U.S. EPA, 2022a). In the Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits Technical Support Document (TSD) (U.S. EPA, 2023b), we specify in detail our approach for identifying, selecting, and parametrizing concentration-response relationships and economic unit values to support this benefits analysis.

This chapter contains a subset of the estimated health benefits of the revised and alternative $PM_{2.5}$ standard levels in 2032 that EPA was able to quantify, given available resources and methods. This benefits analysis relies on an array of data inputs—including air quality modeling, health impact functions and valuation estimates—which are themselves subject to uncertainty and may also in turn contribute to the overall uncertainty in this analysis. We employ several techniques to characterize this uncertainty, which are described in detail in Section 5.3.

As described in Chapter 1, the analytical objectives of the NAAQS RIA are unique as compared to other RIAs. The NAAQS RIAs illustrate the potential costs and benefits of attaining one or more revised air quality standard(s) nationwide; these estimated costs and benefits are estimated after we first assume the current standards have been attained. In this RIA, we illustrate the potential costs and benefits for the revised, less, and more stringent alternative standard levels nationwide. The NAAQS RIAs hypothesize the control strategies that States may choose to enact when implementing a revised NAAQS, but they cannot do so with perfect foresight; individual states will formulate air quality management plans whose mix of emissions controls may differ substantially from those we simulate here. Hence, NAAQS RIAs are illustrative. The benefits and costs estimated in a NAAQS RIA are not intended to be added to the costs and benefits of other regulations that result in specific costs of control and emissions reductions. By contrast, EPA is generally confident in the emissions projected to be reduced from rules affecting specific and well-characterized sources—such as mobile and Electric Generating Units (U.S. EPA, 2019a). Hence, the emissions reduced by final rules affecting such sources are accounted for when simulating attainment with the revised and alternative NAAQS.

In the following sections of this chapter, we estimate health benefits occurring as an increment to a 2032 baseline in which the nation fully attains the current primary $PM_{2.5}$ standards (i.e., an annual standard of 12 $\mu g/m^3$ and a 24-hour standard of 35 $\mu g/m^3$, hereafter referred to as "12/35"). This baseline accounts for: (1) promulgated regulations (Chapter 1, Section 1.3.); and (2) any additional illustrative emissions reductions needed to simulate attainment with 12/35 (Chapter 3, Section 3.1). We project $PM_{2.5}$ levels in 2032 in certain areas that would exceed 10/35, 10/30, 9/35 and 8/35, even after illustrative controls applied to simulate attainment with 12/35 and estimate emissions reductions needed to attain the revised and alternative standard levels (Chapter 3, Table 3-2). Table 5-1 summarizes the total national monetized benefits resulting from applying the control strategies in 2032. Because the analyses in the RIA are national-level assessments and the ambient air quality issues are complex and local in nature, we do not currently have sufficiently detailed local information for the areas being analyzed, including local inventory information on emissions sources, higher resolution air quality modeling, and local information on emissions controls to estimate the control strategies that might result in meeting the range of revised annual and 24-hour alternative standard levels.

Whereas the main analysis in this chapter presents the benefits of the applied control strategies for the revised and alternative standards levels (Table 5-5 through Table 5-9), in Appendix 5A, we present the potential health and monetized benefits of full compliance with the revised and alternative standard levels; the tables in Appendix 5A present potential health benefits regardless of whether the control technologies or strategies to achieve them are currently available or whether an agency submits information on cross-border transport or wildfire influence on projected $PM_{2.5}$ DVs that could potentially qualify for exclusion as atypical, extreme, or unrepresentative events, potentially affecting the amount of any additional control needed. The estimates reflect the value of the avoided $PM_{2.5}$-attributable deaths and the value of morbidity impacts, including, for example, hospital admissions and emergency department visits for cardiovascular and respiratory health issues.

Table 5-1 Estimated Monetized Benefits of the Applied Control Strategies for the Revised and Alternative Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	10 µg/m³ annual & 35 µg/m³ 24-hour	10 µg/m³ annual & 30 µg/m³ 24-hour	9 µg/m³ annual & 35 µg/m³ 24-hour	8 µg/m³ annual & 35 µg/m³ 24-hour
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Pope III et al., 2019				
3% discount rate	$17 + B	$21 + B	$46 + B	$99 + B
7% discount rate	$16 + B	$19 + B	$42 + B	$89 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Wu et al., 2020				
3% discount rate	$8.5 + B	$10 + B	$22 + B	$48 + B
7% discount rate	$7.6 + B	$9.2 + B	$20 + B	$43 + B

Note: Rounded to two significant figures. Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag. It was not possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

Because the method used in this analysis to simulate the control strategies does not also simulate changes in ambient concentrations of other pollutants, we were not able to quantify the additional benefits associated with reduced exposure to other pollutants. We also did not estimate the additional benefits from improvements in welfare effects, such as climate effects, ecosystem effects, and visibility (Cox, 2019; U.S. EPA, 2019c). With regard to potential climate benefits, we note that because the available evidence suggests direct PM controls will be most effective in reducing ambient $PM_{2.5}$ concentrations, and because we lack information on the CO_2-related emissions changes that may result from such controls, we do not quantitatively estimate CO_2-related climate benefits in this RIA.

5.1 Human Health Benefits Analysis Methods

We estimate the quantity and economic value of air pollution-related effects using a "damage-function." This approach quantifies counts of air pollution-attributable cases of adverse health outcomes and assigns dollar values to those counts, while assuming that each outcome is independent of one another. We construct this damage function by adapting primary research—specifically, air pollution epidemiology studies and economic value studies—from similar contexts. This approach is sometimes referred to as "benefits transfer." Below we describe the procedure we follow for: (1) selecting air pollution health endpoints to quantify; (2) calculating counts of air pollution effects using a health impact function; (3) calculating the economic value of the health impacts.

5.1.1 Selecting Air Pollution Health Endpoints to Quantify

As a first step in quantifying $PM_{2.5}$-related human health impacts, the Agency consults the most recent PM ISA and the Supplement to the ISA for Particulate Matter (U.S. EPA, 2019b, 2022a). This document synthesizes the toxicological, clinical and epidemiological evidence to determine whether PM is causally related to an array of adverse human health outcomes associated with either acute (i.e., hours or days-long) or chronic (i.e., years-long) exposure; for each outcome, the ISA reports this relationship to be causal, likely to be causal, suggestive of a causal relationship, inadequate to infer a causal relationship or not likely to be a causal relationship. Historically, the Agency estimates the incidence of air pollution effects for those health endpoints that the ISA classified as either causal or likely-to-be-causal.

Consistent with economic theory, the willingness-to-pay (WTP) for reductions in exposure to environmental hazard will depend on the expected impact of those reductions on human health and other outcomes. All else equal, WTP is expected to be higher when there is stronger evidence of a causal relationship between exposure to the contaminant and changes in a health outcome (McGartland et al., 2017). For example, in the case where there is no evidence of a potential relationship the WTP would be expected to be zero and the effect should be excluded from the analysis. Alternatively, when there is some evidence of a relationship between exposure and the health outcome, but that evidence is insufficient to definitively conclude that there is a causal relationship, individuals may have a positive WTP for a reduction in exposure to that hazard (U.S. EPA-SAB, 2020; Kivi and Shogren, 2010). Lastly, the WTP for reductions in exposure to pollutants with strong evidence of a relationship between exposure and effect are likely positive and larger than for endpoints where evidence is weak, all else equal. Unfortunately, the economic literature currently lacks a settled approach for accounting for how WTP may vary with uncertainty about causal relationships.

Given this challenge, the Agency draws its assessment of the strength of evidence on the relationship between exposure to $PM_{2.5}$ and potential health endpoints from the ISAs that are developed for the NAAQS process as discussed above. The focus on categories identified as having a "causal" or "likely to be causal" relationship with the pollutant of interest is to estimate the pollutant-attributable human health benefits in which we are most confident. All else equal, this approach may underestimate the benefits of $PM_{2.5}$ exposure reductions as individuals may be willing to pay to avoid specific risks where the evidence is insufficient to conclude they are "likely to be caus[ed]" by exposure to these pollutants.[6] At the same time, WTP may be lower for those health outcomes for which causality has not been definitively established. This approach treats relationships with ISA causality determinations of "likely to be causal" as if they were known to be causal, and therefore benefits could be overestimated. Table 5-2 reports the effects we quantified and those we did not quantify in this RIA. The list of benefit categories not quantified is not exhaustive. The table below omits welfare effects such as acidification and nutrient enrichment.

Table 5-2 Human Health Effects of Pollutants Potentially Affected by Attainment of the Primary $PM_{2.5}$ NAAQS

Pollutant	Effect (age)	Effect Quantified	Effect Monetized	More Information
$PM_{2.5}$	Adult premature mortality based on cohort study estimates (>17 or >64)	✓	✓	PM ISA
	Infant mortality (<1)	✓	✓	PM ISA
	Non-fatal heart attacks (>18)	✓	✓	PM ISA
	Hospital admissions - cardiovascular (all)	✓	✓	PM ISA
	Hospital admissions - respiratory (<19 and >64)	✓	✓	PM ISA
	Hospital admissions - Alzheimer's disease (>64)	✓	✓	PM ISA
	Hospital admissions - Parkinson's disease (>64)	✓	✓	PM ISA
	Emergency department visits – cardiovascular (all)	✓	✓	PM ISA
	Emergency department visits – respiratory (all)	✓	✓	PM ISA
	Emergency hospital admissions (>65)	✓	✓	PM ISA
	Non-fatal lung cancer (>29)	✓	✓	PM ISA
	Out-of-hospital cardiac arrest (all)	✓	—	PM ISA
	Stroke incidence (50-79)	✓	✓	PM ISA
	New onset asthma (<12)	✓	✓	PM ISA
	Exacerbated asthma – albuterol inhaler use (asthmatics, 6-13)	✓	✓	PM ISA
	Lost work days (18-64)	✓	✓	PM ISA
	Minor restricted-activity days (18-64)	✓	—	PM ISA
	Other cardiovascular effects (e.g., doctor's visits, prescription medication)	—	—	PM ISA[1]
	Other respiratory effects (e.g., pulmonary function, other ages)	—	—	PM ISA[1]
	Other cancer effects (e.g., mutagenicity, genotoxicity)	—	—	PM ISA[1]
	Other nervous system effects (e.g., dementia)	—	—	PM ISA[1]
	Metabolic effects (e.g., diabetes, metabolic syndrome)	—	—	PM ISA[1]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births)	—	—	PM ISA[1]

[1] We assess these benefits qualitatively due to epidemiological or economic data limitations.

5.1.2 Calculating Counts of Air Pollution Effects Using the Health Impact Function

We use the environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) software program to quantify counts of premature deaths and illnesses attributable to photochemical modeled changes in annual mean $PM_{2.5}$ for the year 2032 using a health impact function (Sacks et al., 2018).[1] A health impact function combines information regarding: the concentration-response relationship between air

[1] The 2032 air quality modeling surface input files, BenMAP configuration files and script to produce the health benefits analyses in Chapters 5 and Appendix 5A are in the docket and available upon request with the Docket Office.

quality changes and the risk of a given adverse outcome; the population exposed to the air quality change; the baseline rate of death or disease in that population; and, the air pollution concentration to which the population is exposed.

The following provides an example of a $PM_{2.5}$ mortality risk health impact function. We estimate counts of $PM_{2.5}$-related total deaths (y_{ij}) during each year i (i=2032) among adults aged 18 and older (a) in each county in the contiguous U.S. j (j=1,…,J where J is the total number of counties) as

$$y_{ij} = \Sigma_a y_{ija}$$

$$y_{ija} = mo_{ija} \times (e^{\beta \cdot \Delta C_{ij}} - 1) \times P_{ija}, \quad \text{Eq[1]}$$

where mo_{ija} is the baseline total mortality rate for adults aged a=18-99 in county j in year i stratified in 10-year age groups, β is the risk coefficient for total mortality for adults associated with annual average $PM_{2.5}$ exposure, C_{ij} is the annual mean $PM_{2.5}$ concentration in county j in year i, and P_{ija} is the number of county adult residents aged a=18-99 in county j in year i stratified into 5-year age groups.[2]

To assess economic value in a damage-function framework, the changes in environmental quality must be translated into effects on people or on the things that people value. In some cases, the changes in environmental quality can be directly valued. In other cases, such as for changes in ozone and PM, a health and welfare impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values. For the purposes of this RIA, the health impacts analysis is limited to those health effects that are directly and specifically linked to $PM_{2.5}$.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure directly either the health outcomes or their values for regulatory

[2] In this illustrative example, the air quality is resolved at the county level. For this RIA, we simulate air quality concentrations at 12 x 12km grids. The BenMAP-CE tool assigns the rates of baseline death and disease stored at the county level to the 12 x 12km grid cells using an area-weighted algorithm. This approach is described in greater detail in the appendices to the BenMAP-CE user manual appendices (U.S. EPA, 2023a).

analyses. Thus, similar to (Künzli et al., 2000) and other, more recent health impact analyses, our estimates are based on the best available methods of benefits transfer.

5.1.3 Calculating the Economic Valuation of Health Impacts

After quantifying the change in adverse health impacts, the final step is to estimate the economic value of these avoided impacts. The appropriate economic value for a change in a health effect depends on whether the health effect is viewed *ex ante* (before the effect has occurred) or *ex post* (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a small amount for a large population. The appropriate economic measure is therefore *ex ante* WTP for changes in risk. However, epidemiological studies generally provide estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use these data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a regulation reduces the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we instead use the cost of treating or mitigating the effect to economically value the health impact. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These cost-of-illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect.

5.2 Benefits Analysis Data Inputs

In Figure 5-1, we summarize the key data inputs to the health impact and economic valuation estimates, which were calculated using BenMAP-CE model version 1.5.1 (Sacks et al., 2018). In the sections below we summarize the data sources for each of these inputs, including demographic projections, incidence and prevalence rates, effect coefficients, and economic valuation.

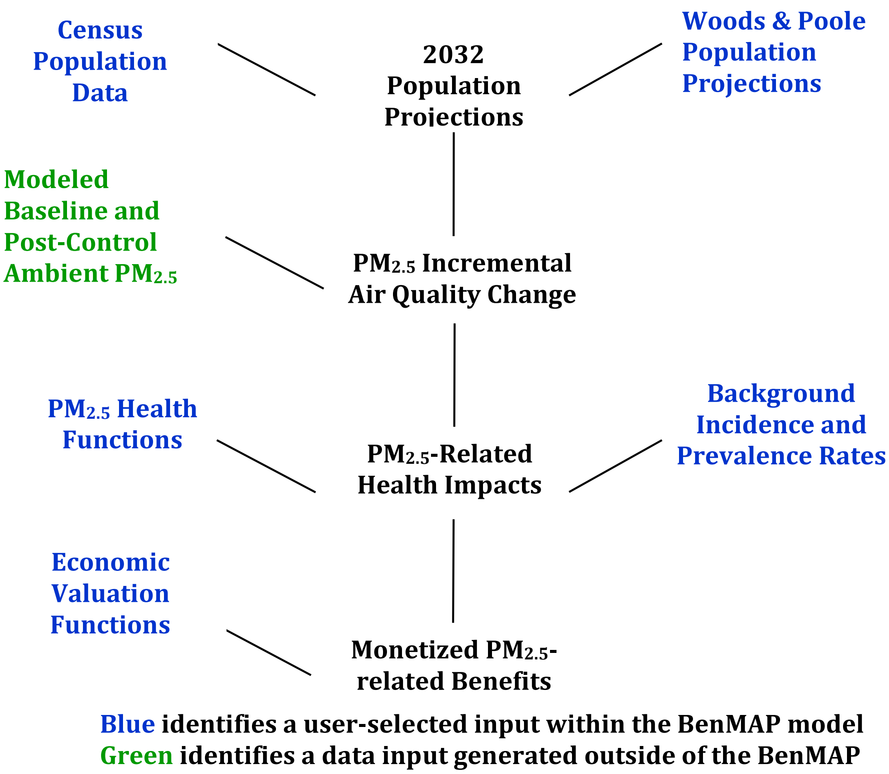

Figure 5-1 Data Inputs and Outputs for the BenMAP-CE Model

5.2.1 Demographic Data

Quantified and monetized human health impacts depend on the demographic characteristics of the population, including age, location, and income. We use projections based on economic forecasting models developed by Woods & Poole, Inc. (Woods & Poole, 2015). The Woods & Poole database contains county-level projections of population by age, sex, and race out to 2060, relative to a baseline using the 2010 Census data. Projections in each county are determined simultaneously with every other county in the U.S. to consider patterns of economic growth and migration. The sum of growth in county-level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates (Hollmann et al., 2000). According to Woods & Poole, linking county-level growth projections together and constraining the projected population to a national-level total growth avoids potential errors introduced by forecasting each county independently (for example, the projected sum of county-level populations cannot exceed the national total). County projections are developed in a four-stage process:

- First, national-level variables such as income, employment, and populations are forecasted.
- Second, employment projections are made for 179 economic areas defined by the Bureau of Economic Analysis (U.S. BEA, 2004)[3], using an "export-base" approach, which relies on linking industrial-sector production of non-locally consumed production items, such as outputs from mining, agriculture, and manufacturing with the national economy. The export-based approach requires estimation of demand equations or calculation of historical growth rates for output and employment by sector.
- Third, population is projected for each economic area based on net migration rates derived from employment opportunities and following a cohort-component method based on fertility and mortality in each area.
- Fourth, employment and population projections are repeated for counties, using the economic region totals as bounds. The age, sex, and race distributions for each region or county are determined by aging the population by single year by sex and race for each year through 2060 based on historical rates of mortality, fertility, and migration.

5.2.2 Baseline Incidence and Prevalence Estimates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 5 μg/m^3 decrease in daily $PM_{2.5}$ levels is associated with a decrease in hospital admissions of 3%. A baseline incidence rate, necessary to convert this relative change into a number of cases, is the estimate of the

[3] According to the Bureau of Economic Analysis (BEA) website, due to the impact of sequestration and reduced FY 2013 funding levels, statistics will not be updated or made available after November 21, 2013.

number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per million people, that number must be multiplied by the millions of people in the total population.

Table 12 (reproduced below as Table 5-3) from the Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits TSD (referred to as the TSD in rest of this chapter) summarizes the sources of baseline incidence rates and reports average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. National-level incidence rates were used for most morbidity endpoints[4], whereas county-level data are available for premature mortality. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level.

Table 5-3 Baseline Incidence Rates for Use in Impact Functions

Endpoint	Parameter	Rates	
		Value	**Source**
Mortality[1]	Daily or annual projected incidence to 2060 in 5-year increments (0--99)	Age-, cause-, race-, and county-stratified rates	CDC WONDER (2012–2014) (U.S. Census Bureau, 2012)
Hospitalizations[2]	Daily incidence rates for all ages	Age-, region/state/county-, and cause- stratified rates	2011-2014 HCUP data files and data requested from and supplied by individual states
Emergency Department Visits[2]	Daily emergency department visit incidence rates for all ages	Age-, region-, state-, county-, and cause-stratified rates	2011-2014 HCUP data files and data requested from and supplied by individual states

[4] Data availability from HCUP has changed since the 2012 PM NAAQS RIA, with state-level incidence data replacing regional-level data. As some states have low populations, many data points are unavailable, either because they are missing or have been censored to protect health record privacy. To avoid interpolating the missing values, we used national-level incidence data, which corresponds appropriately with the national-level epidemiology effect coefficients used in these analyses.

Endpoint	Parameter	Rates	
		Value	Source
Nonfatal Acute Myocardial Infarction	Daily nonfatal AMI incidence rate per person aged 18-99	Age-, region-, state-, and county- stratified rates	(AHRQ, 2016)
Asthma Symptoms	Daily incidence among asthmatic children Wheeze (ages 5-12) Cough (ages 5-12) Shortness of breath (ages 5-12) Albuterol use (ages 6-13)	Age- and race- stratified rates 2.2 puffs per day	(B. Ostro et al., 2001) (Rabinovitch et al., 2006)
Asthma Onset	Annual incidence 0 - 4 5 - 11 12 - 17	0.0234 0.0111 0.0044	(Winer et al., 2012)
Alzheimer's Disease	Daily incidence rates for all ages	Age-, region-, state-, and county- stratified rates	2011-2014 HCUP data files
Parkinson's Disease	Annual incidence 18 - 44 45 - 64 65 - 84 85 - 99	0.0000011 0.0000366 0.0002001 0.0002483	HCUPnet
Allergic Rhinitis	Respondents aged 3-17 experiencing allergic rhinitis/hay fever symptoms within the year prior to the survey	0.192	(Parker et al., 2009)
Cardiac Arrest	Daily nonfatal incidence rates 0 - 17 18 - 39 40 - 64 65 - 99	0.00000002 0.00000009 0.00000056 0.00000133	(Ensor et al., 2013; Rosenthal et al., 2008; Silverman et al., 2010)
Lung Cancer	Annual nonfatal incidence 25 - 34 35 - 44 45 - 54 55 - 64 65 - 74 75 - 84 95 - 99	0.000001746 0.000014919 0.000067463 0.000208053 0.000052370 0.000576950 0.000557130	(SEER, 2015) and (Gharibvand et al., 2017)
Stroke	Annual nonfatal incidence in ages 65-99	0.00446	(Kloog et al., 2012)
Work Loss Days	Daily incidence rate per person (18–64) Aged 18–24 Aged 25–44 Aged 45–64	0.00540 0.00678 0.00492	(Adams et al., 1999), Table 41; (U.S. Census Bureau, 2000)
School Loss Days	Rate per person per year, assuming 180 school days per year	9.9	(Adams et al., 1999), Table 47

Endpoint	Parameter	Rates	
		Value	Source
Minor Restricted-Activity Days	Daily MRAD incidence rate per person (18-64)	0.02137	(B. D. Ostro and Rothschild, 1989), p. 243

CDC-Centers for Disease Control; NHS-National Health Interview Survey. Detailed references associated with this table are located in the TSD.

[1]Mortality rates are only available in 5-year increments. The Healthcare Cost and Utilization Program (HCUP) database contains individual level, state and regional-level hospital and emergency department discharges for a variety of International Classification of Diseases (ICD) codes (AHRQ, 2016).

[2]Baseline incidence rates now include corrections from the states of Indiana and Montana.

We projected mortality rates such that future mortality rates are consistent with our projections of population growth (U.S. EPA, 2018). To perform this calculation, we began first with an average of 2007-2016 cause-specific mortality rates. Using Census Bureau projected national-level annual mortality rates stratified by age range, we projected these mortality rates to 2060 in 5-year increments (U.S. Census Bureau, 2009; U.S. EPA, 2023b). Further information regarding this procedure may be found in the TSD and the appendices to the BenMAP user manual (U.S. EPA, 2023a).

5.2.3 Effect Coefficients

Our approach for selecting and parametrizing effect coefficients for the benefits analysis is described fully in the TSD. Because of the substantial economic value associated with estimated counts of $PM_{2.5}$-attributable deaths, we describe our rationale for selecting among long-term exposure epidemiologic studies below; a detailed description of all remaining endpoints may be found in the TSD.

5.2.3.1 $PM_{2.5}$ Premature Mortality Effect Coefficients for Adults

A substantial body of published scientific literature documents the association between $PM_{2.5}$ concentrations and the risk of premature death (U.S. EPA, 2019b) (U.S. EPA, 2022a). This body of literature reflects thousands of epidemiology, toxicology, and clinical studies. The PM ISA, completed as part of this review of the PM standards and reviewed by the Clean Air Scientific Advisory Committee (CASAC) (Sheppard, 2022), concluded that there is a causal relationship between mortality and both long-term and short-term exposure to $PM_{2.5}$ based on the full body of scientific evidence (U.S. EPA, 2019b) (U.S. EPA, 2022a). The size of the mortality effect estimates from epidemiologic studies, the serious nature of the effect itself, and the high monetary value ascribed to reducing its risk, make premature mortality the most significant health endpoint quantified in this analysis. EPA selects Hazard Ratios from cohort studies to estimate counts of PM-related premature death, following a systematic approach detailed in the TSD that is generally consistent with previous (e.g., U.S. EPA, 2011a, U.S. EPA, 2011b, U.S. EPA, 2011c, U.S. EPA, 2012a, U.S. EPA, 2012b, U.S. EPA, 2015a, U.S. EPA, 2019a).

As premature mortality typically constitutes the vast majority of monetized benefits in a $PM_{2.5}$ benefits assessment, quantifying effects using risk estimates reported from multiple long-term exposure studies using different cohorts helps account for uncertainty in the estimated number of PM-related premature deaths. Below we summarize the two identified studies and hazard ratios used in this analysis and then describe our rationale for quantifying premature PM-attributable deaths using two of these studies.

Wu et al., 2020 evaluated the relationship between long-term $PM_{2.5}$ exposure and all-cause mortality in more than 68.5 million Medicare enrollees (over the age of 64), using Medicare claims data from 2000-2016 representing over 573 million person-years of follow up and over 27 million deaths. This cohort included over 20% of the U.S. population and was, at the time of publishing, the largest air pollution study cohort to date. The authors modeled $PM_{2.5}$ exposure at a 1-km^2 grid resolution using a hybrid ensemble-based prediction model that combined three machine learning models and relied on satellite data, land-use information, weather variables, chemical transport model simulation outputs, and monitor data. Wu et al., 2020 fit five different statistical models: a Cox proportional hazards model, a Poisson regression model, and three causal inference approaches (GPS estimation, GPS matching, and GPS weighting). All five statistical approaches provided consistent results; we report the results of the Cox proportional hazards model here. The authors adjusted for numerous individual-level and community-level confounders, and sensitivity analyses suggest that the results are robust to unmeasured confounding bias. In a single-pollutant model, the coefficient and standard error for $PM_{2.5}$ are estimated from the hazard ratio (1.066) and 95% confidence interval (1.058-1.074) associated with a change in annual mean $PM_{2.5}$ exposure of 10.0 ug/m^3 (Wu et al., 2020, Table S3, Main analysis, 2000-2016 Cohort, Cox PH). We use a risk estimate from this study in place of the risk estimate from Di et al., 2017. These two epidemiologic studies share many attributes, including the Medicare cohort and statistical model used to characterize population exposure to $PM_{2.5}$. As compared to Di et al., 2017, Wu et al., 2020 includes a longer follow-up period and reflects more recent $PM_{2.5}$ concentrations.

Pope III et al., 2019 examined the relationship between long-term $PM_{2.5}$ exposure and all-cause mortality in a cohort of 1,599,329 U.S. adults (aged 18-84 years) who were interviewed in the National Health Interview Surveys (NHIS) between 1986 and 2014 and linked to the National Death Index (NDI) through 2015. The authors also constructed a sub-cohort of 635,539 adults from the full cohort for whom body mass index (BMI) and smoking status data were available. The authors employed a hybrid modeling technique to estimate annual-average $PM_{2.5}$ concentrations derived from regulatory monitoring data and constructed in a universal kriging framework using geographic variables including land use, population, and satellite estimates. Pope III et al., 2019 assigned annual-average $PM_{2.5}$ exposure from 1999-2015 to each individual by census tract and used complex (accounting for NHIS's sample design) and simple Cox proportional hazards models for the full cohort and the sub-cohort. We select the Hazard Ratio calculated using the complex model for the sub-cohort, which controls for individual-level covariates including age, sex, race-ethnicity, inflation-adjusted income, education level, marital status, rural versus urban, region, survey year, BMI, and smoking status. In a single-pollutant model, the coefficient and standard error for $PM_{2.5}$ are estimated from the hazard ratio (1.12) and 95% confidence interval (1.08-1.15) associated with a change in annual mean $PM_{2.5}$ exposure of 10.0 ug/m^3 (Pope III et al., 2019, Table 2, Subcohort). This study exhibits two key strengths that makes it particularly well suited for a benefits analysis: (1) it includes a long follow-up period with recent (and thus relatively low) $PM_{2.5}$ concentrations; (2) the NHIS cohort is representative of the U.S. population, especially with respect to the distribution of individuals by race, ethnicity, income, and education.

5.2.4 Unquantified Human Health Benefits

Although we have quantified many of the health benefits associated with reducing exposure to $PM_{2.5}$, as shown in Table 5-2, we are unable to quantify the health benefits of implementing the illustrative control strategies described in Chapter 3 associated with reducing ozone exposure, SO_2 exposure, or NO_2 exposure. This is because we focused on reducing direct PM emissions and do not have air quality modeling data for these pollutants. Although we used air quality surfaces that reflect applying the control strategies for the impact of each combination of standard levels on ambient levels of $PM_{2.5}$, this method does not simulate how the illustrative emissions reductions would affect ambient levels of ozone, SO_2, or NO_2. Below we provide a qualitative description of these health benefits. In general, previous analyses have shown that the monetized value of these additional health benefits is much smaller than $PM_{2.5}$-related benefits (U.S. EPA, 2010, 2015a). The extent to which ozone, SO_2, and/or NOx would be reduced would depend on the specific control strategies used to reduce $PM_{2.5}$ in a given area.

Exposure to ambient ozone is associated with human health effects, including respiratory and metabolic morbidity (U.S. EPA, 2020a). Epidemiological researchers have associated ozone exposure with adverse health effects in numerous toxicological, clinical and epidemiological studies (U.S. EPA, 2020a). When adequate data and resources are available, EPA generally quantifies several health effects associated with exposure to ozone (e.g., U.S. EPA, 2014b, 2015a). These health effects include respiratory morbidity such as asthma attacks, hospital admissions, emergency department visits, and school loss days. The scientific literature suggests that exposure to ozone is also associated with chronic respiratory damage and premature aging of the lungs, but EPA has not quantified these effects in benefits analyses previously.

Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the *Integrated Science Assessment for Sulfur Dioxide—Health Criteria* (SO_2 ISA) concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2 (U.S. EPA, 2017). The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. A clear concentration-response relationship has been demonstrated in laboratory studies following exposures to SO_2, both in terms of increasing severity of effect and percentage of asthmatics adversely affected. Based on our review of this information, we identified three short-term morbidity endpoints that the SO_2 ISA identified as a "causal relationship":

asthma exacerbation, respiratory-related emergency department visits, and respiratory-related hospitalizations. The differing evidence and associated strength of the evidence for these different effects is described in detail in the SO_2 ISA (U.S. EPA, 2017). The SO_2 ISA also concluded that the relationship between short-term SO_2 exposure and premature mortality was "suggestive of a causal relationship" because it is difficult to attribute the mortality risk effects to SO_2 alone. Although the SO_2 ISA stated that studies are generally consistent in reporting a relationship between SO_2 exposure and premature mortality, the number of studies was limited. Because we focused on reducing primary PM emissions, we did not quantify these benefits.

Epidemiological researchers have associated NO_2 exposure with adverse health effects in numerous toxicological, clinical and epidemiological studies, as described in the *Integrated Science Assessment for Oxides of Nitrogen—Health Criteria* (NO_2 ISA) (U.S. EPA, 2016). The NO_2 ISA provides a comprehensive review of the current evidence of health and environmental effects of NO_2. The NO_2 ISA concluded that "evidence for asthma attacks supports a causal relationship between short-term NO_2 exposure and respiratory effects," and "evidence for development of asthma supports a likely to be causal relationship between long-term NO_2 exposure and respiratory effects." These are stronger conclusions than those determined in the 2008 NO_2 ISA (U.S. EPA, 2008).These epidemiologic and experimental studies encompass a number of endpoints including emergency department visits and hospitalizations, respiratory symptoms, airway hyperresponsiveness, airway inflammation, and lung function. Effect estimates from epidemiologic studies conducted in the United States and Canada generally indicate a 2–20% increase in risks for ED visits and hospital admissions and higher risks for respiratory symptoms. The NO_2 ISA concluded that the relationship between short-term NO_2 exposure and premature mortality was "suggestive but not sufficient to infer a causal relationship" because it is difficult to attribute the mortality risk effects to NO_2 alone. Although the NO_2 ISA stated that studies consistently reported a relationship between NO_2 exposure and mortality, the effect was generally smaller than that for other pollutants such as PM. Because we focused on reducing primary PM emissions, we did not quantify these benefits.

Illustrative controls to meet the revised and alternative standard levels are expected to reduce $PM_{2.5}$ emissions from fossil fuel and wood combustion, as well as industrial processes, and consequentially is expected to lead to reduced Hazardous Air Pollutant (HAP) emissions. HAP emissions from EGUs and other industrial sources may contribute to increased cancer risks and other serious health effects, including damage to the immune system, as well as neurological, reproductive (e.g., reduced fertility), developmental, respiratory and other health problems. These public health implications of exposure to HAPs can be particularly pronounced for segments of the population that are especially vulnerable to some of these effects (*e.g.*, children are especially vulnerable to neurological effects because their brains are still developing). Some HAPs can also detrimentally affect ecosystems used for recreational and commercial purposes.

5.2.5 Unquantified Welfare Benefits

The Clean Air Act definition of welfare effects includes, but is not limited to, effects on soils, water, wildlife, vegetation, visibility, weather, and climate, as well as effects on man-made materials, economic values, and personal comfort and well-being. Detailed information regarding the ecological effects of nitrogen and sulfur deposition is available in the Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter— Ecological Criteria (ISA) (U.S. EPA, 2020b).

Particulate matter (PM) is composed of some or all of the following components: nitrate (NO_3^-), sulfate (SO_4^{2-}), ammonium (NH_4^+), metals, minerals (dust), and organic and elemental carbon. Nitrate, sulfate, and ammonium contribute to nitrogen (N) and sulfur (S) deposition, which causes substantial ecological effects. The ecological effects of deposition are grouped into three main categories: acidification, N enrichment/N driven eutrophication, and S enrichment. Ecological effects are further subdivided into terrestrial, wetland, freshwater, and estuarine/near-coastal ecosystems. These ecosystems and effects are linked by the connectivity of terrestrial and aquatic habitats through biogeochemical pathways of N and S.

In the ISA, information on ecological effects from controlled exposure, field addition, ambient deposition, and toxicological studies, among others, are integrated to form conclusions about the causal relationships between NOy, SOx, and PM and ecological effects. A consistent and transparent framework (U.S. EPA, 2015b, Table II) is applied to classify the ecological effect evidence according to a five-level hierarchy:

1. Causal relationship
2. Likely to be a causal relationship
3. Suggestive of, but not sufficient to infer, a causal relationship
4. Inadequate to infer a causal relationship
5. Not likely to be a causal relationship

Table 5-4 summarizes the causal determinations for relationships between N and S deposition and ecological effects. Though not quantified in this RIA, it is reasonable to infer that reducing fine particle levels by controlling emissions of NOx and SOx will yield the ecological benefits detailed below.

Table 5-4 Causal Determinations Identified in Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter — Ecological Criteria 2020b

Effect Category	Causal Determination
N and acidifying deposition to terrestrial ecosystems	
N and S deposition and alteration of soil biogeochemistry in terrestrial ecosystems Section IS.5.1 and Appendix 4.1	Causal relationship
N deposition and the alteration of the physiology and growth of terrestrial organisms and the productivity of terrestrial ecosystems Section IS.5.2 and Appendix 6.6.1	Causal relationship
N deposition and the alteration of species richness, community composition, and biodiversity in terrestrial ecosystems Section IS.5.2 and Appendix 6.6.2	Causal relationship
Acidifying N and S deposition and the alteration of the physiology and growth of terrestrial organisms and the productivity of terrestrial ecosystems Section IS.5.3 and Appendix 5.7.1	Causal relationship
Acidifying N and S deposition and the alteration of species richness, community composition, and biodiversity in terrestrial ecosystems Section IS.5.3 and Appendix 5.7.2	Causal relationship
N and acidifying deposition to freshwater ecosystems	
N and S deposition and alteration of freshwater biogeochemistry Section IS.6.1 and Appendix 7.1.7	Causal relationship

Effect Category	Causal Determination
Acidifying N and S deposition and changes in biota, including physiological impairment and alteration of species richness, community composition, and biodiversity in freshwater ecosystems Section IS.6.3 and Appendix 8.6	Causal relationship
N deposition and changes in biota, including altered growth and productivity, species richness, community composition, and biodiversity due to N enrichment in freshwater ecosystems Section IS.6.2 and Appendix 9.6	Causal relationship
N deposition to estuarine ecosystems	
N deposition and alteration of biogeochemistry in estuarine and near-coastal marine systems Section IS.7.1 and Appendix 7.2.10	Causal relationship
N deposition and changes in biota, including altered growth, total primary production, total algal community biomass, species richness, community composition, and biodiversity due to N enrichment in estuarine environments Section IS.7.2 and Appendix 10.7	Causal relationship
N deposition to wetland ecosystems	
N deposition and the alteration of biogeochemical cycling in wetlands Section IS.8.1 and Appendix 11.10	Causal relationship
N deposition and the alteration of growth and productivity, species physiology, species richness, community composition, and biodiversity in wetlands Section IS.8.2 and Appendix 11.10	Causal relationship
S deposition to wetland and freshwater ecosystems	
S deposition and the alteration of mercury methylation in surface water, sediment, and soils in wetland and freshwater ecosystems Section IS.9.1 and Appendix 12.7	Causal relationship
S deposition and changes in biota due to sulfide phytotoxicity, including alteration of growth and productivity, species physiology, species richness, community composition, and biodiversity in wetland and freshwater ecosystems Section IS.9.2 and Appendix 12.7	Causal relationship

5.2.5.1 Visibility Impairment Benefits

Reducing $PM_{2.5}$ would improve levels of visibility in the U.S. because suspended particles and gases degrade visibility by scattering and absorbing light (U.S. EPA, 2009). Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil (Sisler, 1996). Visibility has direct significance to people's enjoyment of daily activities and their overall sense of wellbeing. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities. Particulate sulfate is the dominant source of regional haze in the eastern U.S. and particulate nitrate is an important contributor to light extinction in California and the upper Midwestern U.S., particularly during winter (U.S. EPA, 2009). Previous analyses (U.S. EPA, 2011d) show that visibility benefits can be a significant welfare benefit category. Without air quality modeling, we are unable to estimate visibility-related benefits, and we are also unable to determine whether the emission reductions would be likely to have a significant impact on visibility in urban areas or Class I areas.

5.2.6 Climate Effects of $PM_{2.5}$

Atmospheric particles influence climate in multiple ways: directly absorbing light, scattering light, changing the reflectivity ("albedo") of snow and ice through deposition, and interacting with clouds. The particle's composition, the timing of emissions, and where the particle is in the atmosphere determine if it contributes to cooling or warming. Pollutants that affect the energy balance of the earth are referred to as climate forcers. A pollutant that increases the amount of energy in the Earth's climate system is said to exert "positive radiative forcing," which leads to warming and climate change. In contrast, a pollutant that exerts negative radiative forcing reduces the amount of energy in the Earth's system and leads to cooling. The short atmospheric lifetime of particles, lasting from days to weeks, and the mechanisms by which particles affect climate, distinguish it from long-lived greenhouse gases like CO_2. This means that actions taken to reduce $PM_{2.5}$ will have near term effects on climate change. The Intergovernmental Panel on Climate Change Sixth Assessment Report concludes that for forcers with short lifetimes, "the response in surface temperature occurs strongly, as soon as a sustained change in emissions is implemented" (Naik et al., 2021). The potential to affect near-term climate change and the rate of climate change with policies to address these emissions is gaining attention nationally and internationally (e.g., *Black Carbon Report to Congress,* Arctic Council, Climate and Clean Air Coalition, and Convention on Long-Range Transboundary Air Pollution of the United Nations Economic Commission for Europe). Recent reports have concluded that short-lived compounds play a prominent role in keeping global warming below 1.5° C (IPCC, 2018), and are especially important in the rapidly warming Arctic (AMAP, 2021). While reducing long-lived GHGs such as CO_2 is necessary to protect against long-term climate change, reducing short-lived forcers and would slow the rate of climate change within the first half of this century (UNEP, 2011).

5.2.6.1 Climate Effects of Carbonaceous Particles

The illustrative control strategies are focused on emissions sources that are significant sources of carbonaceous particles, including black carbon and organic carbon. Black Carbon (BC), also called soot, is the most strongly light-absorbing component of $PM_{2.5}$, and is formed by incomplete combustion of fossil fuels, biofuels, and biomass. Another contributor to carbonaceous particles is organic carbon (OC), which in addition to carbon are also composed of oxygen and hydrogen. Organic carbon particles can be directly emitted from the same sources as black carbon or formed in the atmosphere from chemical reactions. They can be light-absorbing, but most have a larger light-scattering component.

Both BC and organic carbon in the atmosphere influence climate in multiple ways: directly absorbing or reflecting light, modifying the rate of vertical mixing, and interacting with clouds. Light-absorbing particles also have an additional climate effect when deposited on snow and ice. These particles darken the surface and decrease albedo, thereby increasing absorption and accelerating melting (Hock et al., 2019; Meredith et al., 2019). Regional climate impacts of BC are highly variable, and sensitive regions such as the Arctic are particularly vulnerable to the warming and melting effects of BC. Snow and ice cover in the western U.S. has also been affected by BC. Specifically, deposition of BC on mountain glaciers and snowpacks produces a positive snow and ice albedo effect, contributing to the melting of snowpack earlier in the spring and reducing the amount of snowmelt that normally would occur later in the spring and summer (Hadley et al. 2010). This has implications for freshwater resources in regions of the U.S. dependent on snow-fed or glacier-fed water systems. In the Sierra Nevada mountain range, Hadley et al. (2010) found BC at different depths in the snowpack, deposited over the winter months by snowfall. In the spring, the continuous uncovering of the BC contributed to the early melt. A model capturing the effects of soot on snow in the western U.S. shows significant decreases in snowpack between December and May (Qian et al., 2009). Snow water equivalent (the amount of water that would be produced by melting all the snow) is reduced 2-50 millimeters (mm) in mountainous areas, particularly over the Central Rockies, Sierra Nevadas, and western Canada. A study found that biomass burning emissions in Alaska and the Rocky Mountain region during the summer can enhance snowmelt (McKenzie, Skiles et al. 2018). Light-absorbing particles and especially BC can have an additional warming effect when deposited on snow and ice, and this effect is highly seasonal and regional.

Relative to greenhouse gases, the net effect of carbonaceous particles is both more regionally variable and more uncertain (Naik et al., 2021). Particles have a relatively short lifetime in the atmosphere, leading to spatial concentration differences, while greenhouse gases are more well mixed and have less global variability. The amount of light absorption by particles depends on the season, with different effects in the summer and winter. Lastly, even light-absorbing particles can also contribute to cooling (e.g., by shading the surface).

5.2.6.2 Climate Effects: Summary and Conclusions

The net climate change effect of carbonaceous aerosols in the illustrative control strategies depends on the location, timing, and type of the emissions controls. As described above, the black carbon emissions are more likely to contribute to warming and organic aerosols more likely to contribute to cooling. Emissions sources with larger amounts of light-absorbing aerosols, like diesel vehicles, or with emissions near snow or the Arctic, like residential wood combustion, are more likely to contribute to warming (Bond et al., 2013).

However, assessing the net effect is beyond the scope of this RIA and requires climate atmospheric modeling that has not been undertaken. Furthermore, there are uncertainties relevant to the assessment of the net climate change effects of $PM_{2.5}$, especially at a regional scale (U.S. EPA, 2019b). Strategies that could be implemented by State and Local governments that would likely provide climate change mitigation benefits include prioritizing (*i*) emissions control actions that also achieve emissions reductions for warming agents like carbon dioxide, methane, and ozone precursors (carbon monoxide and volatile organic compounds), and (*ii*) sources of light-absorbing carbonaceous aerosols, especially diesel engines and residential wood combustion.

5.2.7 Economic Valuation Estimates

To directly compare benefits estimates associated with a rulemaking to cost estimates, the number of instances of each air pollution-attributable health impact must be converted to a monetary value. This requires a valuation estimate for each unique health endpoint, and potentially also discounting if the benefits are expected to accrue over more than a single year, as recommended by the *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2016a).

5.3 Characterizing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. The TSD details our approach to characterizing uncertainty in both quantitative and qualitative terms. The TSD describes the sources of uncertainty associated with key input parameters including emissions inventories, air quality data from models (with their associated parameters and inputs), population data, population estimates, health effect estimates from epidemiology studies, economic data for monetizing benefits, and assumptions regarding the future state of the country (i.e., regulations, technology, and human behavior). Each of these inputs is uncertain and affects the size and distribution of the estimated benefits. When the uncertainties from each stage of the analysis are compounded, even small uncertainties can have large effects on the total quantified benefits.

To characterize uncertainty and variability into this assessment, we incorporate three quantitative analyses described below and in greater detail within the TSD (Section 7.1):

1. A Monte Carlo assessment that accounts for random sampling error and between study variability in the epidemiological and economic valuation studies;
2. The quantification of PM-related mortality using alternative $PM_{2.5}$ mortality effect estimates drawn from two long-term cohort studies; and
3. Presentation of 95th percentile confidence interval around each risk estimate.

Quantitative characterization of other sources of $PM_{2.5}$ uncertainties are discussed only in Section 7.1 of the TSD:

1. For adult all-cause mortality:

a. The distributions of air quality concentrations experienced by the original cohort population (TSD Section 7.1.2.1);

b. Methods of estimating and assigning exposures in epidemiologic studies (TSD Section 7.1.2.2);

c. Confounding by ozone (TSD Section 7.1.2.3); and

d. The statistical technique used to generate hazard ratios in the epidemiologic study (TSD Section 7.1.2.4).

2. Plausible alternative risk estimates for asthma onset in children (TSD Section 7.1.3), cardiovascular hospital admissions (TSD Section 7.1.4,), and respiratory hospital admissions (TSD Section 7.1.5);

3. Effect modification of $PM_{2.5}$-attributable health effects in at-risk populations (TSD Section 7.1.6).

Quantitative consideration of baseline incidence rates and economic valuation estimates are provided in Section 7.3 and 7.4 of the TSD, respectively. Qualitative discussions of various sources of uncertainty can be found in Section 7.5 of the TSD.

5.3.1 Monte Carlo Assessment

Similar to other recent RIAs, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and random effects modeling to characterize both sampling error and variability across the economic valuation functions. The Monte Carlo simulation in the BenMAP-CE software randomly samples from a distribution of incidence and valuation estimates to characterize the effects of uncertainty on output variables. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and monetized benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates for endpoints derived from a single study. For endpoints estimated using a pooled estimate of multiple studies, the confidence intervals reflect both the standard errors and the variance across studies. The confidence intervals around the monetized benefits incorporate the epidemiology standard errors as well as the distribution of the valuation function. These confidence intervals do not reflect other sources of uncertainty inherent within the estimates, such as baseline incidence rates, populations exposed, and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the benefits estimates.

5.3.2 Sources of Uncertainty Treated Qualitatively

Although we strive to incorporate as many quantitative assessments of uncertainty as possible, there are several aspects we are only able to address qualitatively. These attributes are summarized below and described more fully in the TSD.

Key assumptions underlying the estimates for premature mortality, which account for over 98% of the total monetized benefits in this analysis, include the following:

1. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ varies considerably in composition across sources, but the scientific evidence is not yet sufficient to allow differentiation of effect estimates by particle type. The PM ISA, which was reviewed by CASAC, concluded that "across exposure durations and health effects categories … the evidence does not indicate that any one source or component is consistently more strongly related with health effects than $PM_{2.5}$ mass" (U.S. EPA, 2019b).

2. We assume that the health impact function for fine particles is log-linear down to the lowest air quality levels modeled in this analysis. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including both regions that are in attainment with the fine particle standard and those that do not meet the standard down to the lowest modeled concentrations. The PM ISA concluded that "the majority of evidence continues to indicate a linear, no-threshold concentration-response relationship for long-term exposure to $PM_{2.5}$ and total (nonaccidental) mortality" (U.S. EPA, 2019b) .

3. We assume that there is a “cessation” lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure based on the advice of the SAB-HES (Cameron, 2004), which affects the valuation of mortality benefits at different discount rates. Similarly, we assume there is a cessation lag between the change in PM exposures and both the development and diagnosis of lung cancer.

5.4 Benefits Results

5.4.1 Benefits of the Applied Control Strategies for the Revised and Alternative Combinations of Primary $PM_{2.5}$ Standard Levels

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ yields estimates of the changes in physical damages (e.g., premature mortalities, cases of hospital admissions and emergency department visits) and the associated monetary values for those changes. Not all known PM health effects could be quantified or monetized.

We present two sets of tables – one set in this chapter and one set in Appendix 5A. First, Table 5-5 through Table 5-9 present benefits associated with the illustrative control strategies identified in Chapter 3. More specifically, for the revised standard levels of 9/35 $\mu g/m^3$, for the northeast we were able to identify approximately 98 percent of the reductions needed. For the southeast we were able to identify approximately 68 percent of the reductions needed. For the west, we were able to identify approximately 44 percent of the reductions needed, and for California the percentage is approximately 26 percent. As such, these tables present the benefits associated with the illustrative control strategies and reflect the remaining air quality challenges (discussed in Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5). For a more detailed description of the geographic distribution of the emissions reductions needed for the revised and alternative standard levels, see the discussion in Chapter 3, Section 3.2.4. Second, Table 5A-1 through 5A-5 in Appendix 5A present the potential benefits associated with fully meeting the revised and alternative standards.

Table 5-5 through Table 5-9 present the benefits results of applying the control strategies for the revised annual and current 24-hour alternative standard levels of 9/35 $\mu g/m^3$, as well as the less stringent alternative standard levels of 10/35 $\mu g/m^3$ and the following two more stringent alternative standard levels: (1) an alternative annual standard level of 8 $\mu g/m^3$ in combination with the current 24-hour standard (i.e., 8/35 $\mu g/m^3$), and (2) an alternative 24-hour standard level of 30 $\mu g/m^3$ in combination with an annual standard level of 10 $\mu g/m^3$ (i.e., 10/30 $\mu g/m^3$).

Table 5-5 presents the estimated avoided incidences of PM-related illnesses and premature mortality resulting from the control strategies applied to the revised and alternative standard levels in 2032. Table 5-6 and Table 5-7 present the monetized valuation benefits (discounted at a 3% and 7% discount rate, respectively) of the avoided health outcomes presented in Table 5-5.

Table 5-8 and Table 5-9 present a summary of the monetized benefits associated with the revised and the alternative standard levels, both nationally and by area. The monetized benefits in Table 5-8 are presented in four areas: California (CA), the Northeastern (NE) states, the Southeastern (SE) states, and the Western (W) states. For Table 5-8 and Table 5-9, the monetized value of unquantified effects is represented by adding an unknown "B" to the aggregate total. This B represents both uncertainty and a bias in this analysis, as it reflects health and welfare benefits that we are unable to quantify.[5]

[5] The health and monetized benefits of fully attaining the revised and alternative standard levels in all areas can be found in Appendix 5A.

Table 5-5 Estimated Avoided PM-Related Premature Mortalities and Illnesses of the Applied Control Strategies for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (95% Confidence Interval)

Avoided Mortality[a]	**10/35**	**10/30**	**9/35**	**8/35**
(Pope III et al., 2019) (adult mortality ages 18-99 years)	1,700 (1,200 to 2,100)	2,000 (1,400 to 2,600)	4,500 (3,200 to 5,700)	9,500 (6,800 to 12,000)
(Wu et al., 2020) (adult mortality ages 65-99 years)	810 (710 to 900)	970 (850 to 1,100)	2,100 (1,900 to 2,400)	4,500 (4,000 to 5,100)
(Woodruff et al., 2008) (infant mortality)	1.7 (-1.0 to 4.3)	2.0 (-1.2 to 5.1)	5.0 (-3.1 to 13)	11 (-7.2 to 29)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	140 (100 to 180)	160 (120 to 200)	330 (240 to 420)	690 (500 to 870)
Hospital admissions—respiratory	90 (31 to 150)	100 (35 to 170)	230 (79 to 370)	480 (170 to 780)
ED visits--cardiovascular	260 (-98 to 600)	300 (-110 to 690)	660 (-250 to 1,500)	1,400 (-550 to 3,300)
ED visits—respiratory	470 (93 to 990)	560 (110 to 1,200)	1,300 (250 to 2,700)	2,900 (570 to 6,000)
Acute Myocardial Infarction	30 (17 to 42)	35 (20 to 49)	72 (42 to 100)	150 (86 to 210)
Cardiac arrest	14 (-5.9 to 33)	17 (-6.9 to 38)	36 (-15 to 81)	75 (-31 to 170)
Hospital admissions--Alzheimer's Disease	360 (270 to 440)	400 (300 to 500)	910 (690 to 1,100)	2,000 (1,500 to 2,400)
Hospital admissions--Parkinson's Disease	47 (24 to 69)	56 (29 to 81)	130 (67 to 190)	280 (140 to 400)
Stroke	54 (14 to 93)	65 (17 to 110)	140 (35 to 230)	290 (74 to 490)
Lung cancer	65 (20 to 110)	77 (23 to 130)	160 (49 to 270)	340 (100 to 560)
Hay Fever/Rhinitis	15,000 (3,600 to 26,000)	17,000 (4,200 to 30,000)	38,000 (9,100 to 65,000)	79,000 (19,000 to 140,000)
Asthma Onset	2,300 (2,200 to 2,300)	2,600 (2,500 to 2,700)	5,700 (5,500 to 6,000)	12,000 (12,000 to 13,000)
Asthma symptoms – Albuterol use	310,000 (-150,000 to 760,000)	370,000 (-180,000 to 900,000)	800,000 (-390,000 to 1,900,000)	1,700,000 (-820,000 to 4,100,000)
Lost work days	110,000 (96,000 to 130,000)	130,000 (110,000 to 150,000)	290,000 (240,000 to 330,000)	610,000 (510,000 to 700,000)
Minor restricted-activity days	670,000 (540,000 to 790,000)	780,000 (630,000 to 920,000)	1,700,000 (1,400,000 to 2,000,000)	3,500,000 (2,900,000 to 4,200,000)

Note: Values rounded to two significant figures.
[a] Reported here are two alternative estimates of the number of premature deaths among adults due to long-term exposure to $PM_{2.5}$. These values should not be added to one another.

Table 5-6 Monetized PM-Related Premature Mortalities and Illnesses of the Applied Control Strategies for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (Millions of 2017$, 3% discount rate; 95% Confidence Interval)

Avoided Mortality[a]	**10/35**	**10/30**	**9/35**	**8/35**
(Pope III et al., 2019) (adult mortality ages 18-99 years)	17,000 (1,600 to 47,000)	21,000 (1,900 and 56,000)	46,000 (4,100 to 120,000)	98,000 (8,900 to 260,000)
(Wu et al., 2020) (adult mortality ages 65-99 years)	8,300 (760 to 22,000)	9,900 (920 to 26,000)	22,000 (2,000 to 58,000)	47,000 (4,300 to 120,000)
(Woodruff et al., 2008) (infant mortality)	19 (-11 and 75)	22 (-12 and 89)	56 (-31 and 220)	130 (-72 and 510)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	2.3 (1.7 to 2.9)	2.7 (1.9 and 3.4)	5.5 (4 and 7)	11 (8.2 and 14)
Hospital admissions—respiratory	1.5 (0.34 and 2.7)	1.8 (0.39 and 3.1)	3.8 (0.87 and 6.6)	7.9 (1.8 and 14)
ED visits--cardiovascular	0.32 (-0.12 and 0.74)	0.37 (-0.14 and 0.86)	0.82 (-0.31 and 1.9)	1.8 (-0.68 and 4.1)
ED visits—respiratory	0.44 (0.087 and 0.92)	0.52 (0.1 and 1.1)	1.2 (0.24 and 2.5)	2.7 (0.53 and 5.6)
Acute Myocardial Infarction	1.5 (0.9 and 2.2)	1.8 (1 and 2.5)	3.7 (2.2 and 5.2)	7.7 (4.5 and 11)
Cardiac arrest	0.55 (-0.22 and 1.2)	0.64 (-0.26 and 1.5)	1.4 (-0.56 and 3.1)	2.9 (-1.2 and 6.5)
Hospital admissions--Alzheimer's Disease	4.6 (3.5 and 5.6)	5.2 (3.9 and 6.3)	12 (8.8 and 14)	25 (19 and 31)
Hospital admissions--Parkinson's Disease	0.65 (0.33 and 0.94)	0.77 (0.39 and 1.1)	1.8 (0.92 and 2.6)	3.8 (2 and 5.5)
Stroke	2 (0.51 and 3.4)	2.3 (0.6 and 4)	4.9 (1.3 and 8.4)	10 (2.7 and 18)
Lung cancer	1.8 (0.55 and 3)	2.1 (0.65 and 3.5)	4.5 (1.4 and 7.4)	9.3 (2.9 and 15)
Hay Fever/Rhinitis	9.5 (2.3 and 16)	11 (2.7 and 19)	24 (5.8 and 41)	50 (12 and 87)
Asthma Onset	110 (99 and 110)	120 (120 and 130)	270 (250 and 290)	570 (530 and 610)
Asthma symptoms – Albuterol use	0.12 (-0.056 and 0.28)	0.14 (-0.066 and 0.33)	0.29 (-0.14 and 0.71)	0.62 (-0.3 and 1.5)
Lost work days	20 (17 and 24)	24 (20 and 27)	51 (43 and 59)	110 (92 and 130)
Minor restricted-activity days	52 (27 and 79)	61 (32 and 92)	130 (69 and 200)	280 (150 and 420)

Note: Values rounded to two significant figures.

[a] Reported here are two alternative estimates of the number of premature deaths among adults due to long-term exposure to $PM_{2.5}$. These values should not be added to one another.

Table 5-7 Monetized PM-Related Premature Mortalities and Illnesses of the Applied Control Strategies for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032 (Millions of 2017$, 7% discount rate; 95% Confidence Interval)

Avoided Mortality[a]	**10/35**	**10/30**	**9/35**	**8/35**
(Pope III et al., 2019) (adult mortality ages 18-99 years)	16,000 (1,400 and 42,000)	19,000 (1,700 and 50,000)	41,000 (3,700 and 110,000)	88,000 (8,000 and 240,000)
(Wu et al., 2020) (adult mortality ages 65-99 years)	7400 (690 and 20000)	8900 (830 and 24000)	20000 (1800 and 52000)	42000 (3900 and 110000)
(Woodruff et al., 2008) (infant mortality)	19 (-11 and 75)	22 (-12 and 89)	56 (-31 and 220)	130 (-72 and 510)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	2.3 (1.7 to 2.9)	2.7 (1.9 and 3.4)	5.5 (4 and 7)	11 (8.2 and 14)
Hospital admissions—respiratory	1.5 (0.34 and 2.7)	1.8 (0.39 and 3.1)	3.8 (0.87 and 6.6)	7.9 (1.8 and 14)
ED visits--cardiovascular	0.32 (-0.12 and 0.74)	0.37 (-0.14 and 0.86)	0.82 (-0.31 and 1.9)	1.8 (-0.68 and 4.1)
ED visits—respiratory	0.44 (0.087 and 0.92)	0.52 (0.1 and 1.1)	1.2 (0.24 and 2.5)	2.7 (0.53 and 5.6)
Acute Myocardial Infarction	1.5 (0.87 and 2.1)	1.8 (1 and 2.5)	3.6 (2.1 and 5.1)	7.5 (4.4 and 11)
Cardiac arrest	0.54 (-0.22 and 1.2)	0.64 (-0.26 and 1.4)	1.3 (-0.55 and 3)	2.8 (-1.2 and 6.4)
Hospital admissions--Alzheimer's Disease	4.6 (3.5 and 5.6)	5.2 (3.9 and 6.3)	12 (8.8 and 14)	25 (19 and 31)
Hospital admissions--Parkinson's Disease	0.65 (0.33 and 0.94)	0.77 (0.39 and 1.1)	1.8 (0.92 and 2.6)	3.8 (2 and 5.5)
Stroke	2 (0.51 and 3.4)	2.3 (0.6 and 4)	4.9 (1.3 and 8.4)	10 (2.7 and 18)
Lung cancer	1.3 (0.41 and 2.2)	1.6 (0.49 and 2.6)	3.3 (1 and 5.5)	7 (2.1 and 12)
Hay Fever/Rhinitis	9.5 (2.3 and 16)	11 (2.7 and 19)	24 (5.8 and 41)	50 (12 and 87)
Asthma Onset	66 (61 and 70)	77 (72 and 82)	170 (160 and 180)	350 (330 and 380)
Asthma symptoms – Albuterol use	0.12 (-0.056 and 0.28)	0.14 (-0.066 and 0.33)	0.29 (-0.14 and 0.71)	0.62 (-0.3 and 1.5)
Lost work days	20 (17 and 24)	24 (20 and 27)	51 (43 and 59)	110 (92 and 130)
Minor restricted-activity days	52 (27 and 79)	61 (32 and 92)	130 (69 and 200)	280 (150 and 420)

Note: Values rounded to two significant figures.

[a] Reported here are two alternative estimates of the number of premature deaths among adults due to long-term exposure to $PM_{2.5}$. These values should not be added to one another.

Table 5-8 Estimated Monetized Benefits of the Applied Control Strategies for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	10 μg/m³ annual & 35 μg/m³ 24-hour	10 μg/m³ annual & 30 μg/m³ 24-hour	9 μg/m³ annual & 35 μg/m³ 24-hour	8 μg/m³ annual & 35 μg/m³ 24-hour
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Pope III et al., 2019)				
3% discount rate	$17 + B	$21 + B	$46 + B	$99 + B
7% discount rate	$16 + B	$19 + B	$42 + B	$89 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Wu et al., 2020)				
3% discount rate	$8.5 + B	$10 + B	$22 + B	$48 + B
7% discount rate	$7.6 + B	$9.2 + B	$20 + B	$43 + B

Note: Rounded to two significant figures. Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag. It was not all possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

Table 5-9 is a summary of the monetized benefits associated with applying the control strategies for the revised and alternative standard levels by four areas: the Northeast, the Southeast, the West, and California. The monetized benefits differ by area and for each standard level. For the revised standard levels of 9/35 μg/m³, because 23 of the 52 counties that need emissions reductions are counties in California, a large share of the benefits is incurred in California (Table 5-9). For California, we were able to identify approximately 26 percent of the reductions needed. In addition, as the alternative standard levels become more stringent, more counties in the northeast and southeast need emissions reductions. As additional controls are applied in those areas, those areas account for a relatively higher proportion of the benefits. For example, for more alternative standard levels of 8/35 μg/m³, more controls are available to apply in the northeast and their adjacent counties and the southeast and their adjacent counties.[6] The benefits for those areas are higher than for the west and California.

[6] Note that in the northeast and southeast we identified controls and associated emissions reductions from adjacent counties and used a ppb/ton $PM_{2.5}$ air quality ratio that was four times less responsive than the

Table 5-9 Estimated Monetized Benefits by Area of the Applied Control Strategies for the Revised and Alternative Primary Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ for 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	Area	10 μg/m³ annual & 35 μg/m³ 24-hour	10 μg/m³ annual & 30 μg/m³ 24-hour	9 μg/m³ annual & 35 μg/m³ 24-hour	8 μg/m³ annual & 35 μg/m³ 24-hour
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Pope III et al., 2019)					
3% discount rate	**Northeast**	\$2.4 + B	\$2.5 + B	\$18 + B	\$37 + B
	Southeast	\$0.51 + B	\$0.51 + B	\$5.3 + B	\$25 + B
	West	\$0.059 + B	\$1.3 + B	\$2.3 + B	\$10 + B
	California	\$15 + B	\$17 + B	\$21 + B	\$27 + B
7% discount rate	**Northeast**	\$2.1 + B	\$2.2 + B	\$16 + B	\$34 + B
	Southeast	\$0.46 + B	\$0.46 + B	\$4.8 + B	\$22 + B
	West	\$0.053 + B	\$1.2 + B	\$2.1 + B	\$9.3 + B
	California	\$13 + B	\$15 + B	\$19 + B	\$24 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from (Wu et al., 2020)					
3% discount rate	**Northeast**	\$1.2 + B	\$1.2 + B	\$8.7 + B	\$18 + B
	Southeast	\$0.24 + B	\$0.24 + B	\$2.5 + B	\$12 + B
	West	\$0.03 + B	\$0.64 + B	\$1.1 + B	\$5.0 + B
	California	\$7.0+ B	\$8.1 + B	\$10 + B	\$13 + B
7% discount rate	**Northeast**	\$1.0 + B	\$1.1 + B	\$7.8 + B	\$16 + B
	Southeast	\$0.21 + B	\$0.21 + B	\$2.2 + B	\$10 + B
	West	\$0.027 + B	\$0.58 + B	\$1.0 + B	\$4.5 + B
	California	\$6.3 + B	\$7.3 + B	\$9.1 + B	\$12 + B

Note: Rounded to two significant figures. Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag. It was not possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

5.5 Discussion

The estimated benefits to human health and the environment of the revised and alternative $PM_{2.5}$ daily and annual standard levels are substantial. We estimate that by 2032 the emissions reduced by the applied control strategies for the revised and alternative annual primary standards would decrease the number of $PM_{2.5}$-related premature deaths and illnesses. The emissions reduction strategies will also yield

ratio used when applying in-county emissions reductions (i.e., applied four tons of $PM_{2.5}$ emissions reductions from an adjacent county for one ton of emissions reduction needed in a given county); the benefits of the additional reductions from adjacent counties also contributes to the higher proportion of the benefits.

significant welfare benefits (see Section 5.2.5), though this RIA does not quantify those endpoints.

Inherent to any complex analysis quantifying the benefits of improved air quality, such as this one, are multiple sources of uncertainty. Some of these we characterized through our use of Monte Carlo techniques to sample the statistical error reported in the epidemiologic and economic studies supplying concentration-response parameters and economic unit values. Other key sources of uncertainty that affect the size and distribution of the estimated benefits—including projected atmospheric conditions and source-level emissions, projected baseline rates of illness and disease, incomes and expected advances in healthcare—remain unquantified. When evaluated within the context of these uncertainties, the estimated health impacts and monetized benefits in this RIA provide important information regarding the public health benefits associated with a revised PM NAAQS.

There are two important differences worth noting in the design and analytical objectives of NAAQS RIAs compared to RIAs for implementation rules. First, the NAAQS RIAs illustrate the potential costs and benefits of a revised air quality standard nationwide based on an array of emission reduction strategies for different sources. Second, those costs and benefits are calculated incremental to implementation of existing regulations as well as additional controls applied to reach the current standards and create the analytical baseline for the analysis. In short, NAAQS RIAs hypothesize, but do not predict, the strategies that States may follow to reduce emissions when implementing previous and revised NAAQS options. Setting a NAAQS does not directly result in costs or benefits, and as such, NAAQS RIAs illustrate potential benefits and costs; these estimated values cannot be added, or directly compared, to the costs and benefits of regulations that require specific emissions control strategies to be implemented.

This latter type of regulatory action—often referred to as an implementation rule—reduces emissions for specific, well-characterized sources. In general, the EPA is more confident in the magnitude and location of the emissions reductions for these implementation rules. As such, emissions reductions achieved under promulgated implementation rules have been reflected in the baseline of this NAAQS analysis. For this reason, the benefits estimated in this RIA and all other NAAQS RIAs should not be added to the benefits estimated for implementation rules.

In setting the NAAQS, the EPA accounts for the variability in $PM_{2.5}$ concentrations over space and time. While the standard is designed to limit concentrations at the highest monitor in an area, EPA acknowledges that emissions controls implemented to meet the standard at the highest monitor will simultaneously result in lower $PM_{2.5}$ concentrations in neighboring areas. In fact, the Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter (U.S. EPA, 2022c) shows how different standard levels would affect the distribution of $PM_{2.5}$ concentrations, as well as people's risk, across urban areas. For this reason, it is inappropriate to use the NAAQS level as a bright line for health effects.

The NAAQS are not set at levels that eliminate the risk of air pollution completely. Instead, the Administrator sets the NAAQS at a level requisite to protect public health with an adequate margin of safety, taking into consideration effects on susceptible populations based on the scientific literature. The risk analysis prepared in support of this PM NAAQS reported risks below these levels, while acknowledging that the confidence in those effect estimates is higher at levels closer to the standard (U.S. EPA, 2022c). While benefits occurring below the standard may be somewhat more uncertain than those occurring above the standard, the EPA considers these to be legitimate components of the total benefits estimate. Though there are greater uncertainties at lower $PM_{2.5}$ concentrations, there is no evidence of a threshold in $PM_{2.5}$-related health effects in the epidemiology literature. Given that the epidemiological literature in most cases has not provided estimates based on threshold models, there would be additional uncertainties imposed by assuming thresholds or other non-linear concentration response functions for the purposes of benefits analysis.

5.6 References

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APPENDIX 5A: BENEFITS OF THE REVISED AND ALTERNATIVE STANDARD LEVELS

Overview

In this Appendix, we estimate the potential health benefits resulting from identifying controls and emissions reductions to comply fully with the revised and alternative standard levels, incremental to a 2032 baseline in which the nation fully attains the current primary $PM_{2.5}$ standards (i.e., an annual standard of 12 μg/m^3 and a 24-hour standard of 35 μg/m^3). In contrast, in the main analysis in Chapter 5, we present the national health impacts and monetized benefits resulting only from the applied control strategies identified in Chapter 3 for the revised and alternative $PM_{2.5}$ standard levels in 2032. After applying the control strategies for the main analysis, we estimated that $PM_{2.5}$ emissions reductions would still be needed in certain areas to meet the revised standard of 9/35 and the 10/35, 10/30, and 8/35 alternative standard levels. Additional information on estimating the emission reductions needed to meet the revised and alternative standards is available in section 2A.3.4.2 of Appendix 2A. Also, additional information on the emissions reductions still needed is available in Chapter 3, Section 3.2.4. Lastly, Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5 discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California that may still need emissions reductions. These challenges limit our ability to characterize how standard levels might be met given highly local influences that require more specific information beyond what is available for this type of national analysis. In this Appendix, we assume the remaining emissions reductions are identified to meet the revised, less, and more stringent alternative standard levels, and we present the resulting health and monetized benefits below. To the extent that the additional $PM_{2.5}$ emissions reductions are not achieved, the health benefits reported below may be overestimated.

For this appendix, the annual-mean $PM_{2.5}$ concentration fields where existing, revised, and alternative NAAQS standard levels are just met were developed to estimate the emission changes resulting from fully meeting the revised, less, and more stringent alternative standard levels. Using the methods described in Chapter 5 of this RIA and the Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits TSD (U.S. EPA, 2023b), we estimate health benefits from achieving the revised, less, and more stringent alternative standard levels occurring as an increment to a 12/35 baseline. These benefits reflect the value of the avoided $PM_{2.5}$-attributable deaths and the value of avoided morbidity impacts, including, for example, hospital admissions and emergency department visits for cardiovascular and respiratory health issues.

5A.1 Benefits of the Revised, Less, and More Stringent Alternative Standard Levels of Primary $PM_{2.5}$ Standards

Applying the impact and valuation functions described in Chapter 5 and the TSD to the projected changes in $PM_{2.5}$ yields estimates of the changes in physical damages (e.g., premature mortalities, cases of hospital admissions and emergency department visits) and the associated monetary values for those changes. Not all known PM health effects could be quantified or monetized. Tables 5A-1 through 5A-5 present the benefits results for the revised, less, and more stringent alternative annual primary $PM_{2.5}$ standard levels. Table 5A-1 presents the estimated avoided incidences of PM-related illnesses and premature mortality for achieving the revised and alternative standard levels in 2032. Tables 5A-2 and 5A-3 present the monetized valuation benefits of the avoided morbidity and premature mortality (at a 3% and 7% discount rate respectively) of the health outcomes in Table 5A-1 for the revised and alternative standard levels in 2032.

Tables 5A-4 and 5A-5 present a summary of the monetized benefits nationally and by area of achieving the revised and alternative standard levels. The monetized benefits in Table 5A-5 are presented in four areas: the Northeast, the Southeast, the West, and California. For Tables 5A-4 and 5A-5, the monetized value of unquantified effects is represented by adding an unknown "B" to the aggregate total. The estimate of total monetized health benefits is thus equal to the subset of monetized PM-related health benefits plus B, the sum of the non-monetized health and welfare benefits; this B represents both uncertainty and a bias in this analysis, as it reflects those benefits categories that we are unable to quantify in this analysis.

Table 5A-1 Estimated Avoided PM-Related Premature Mortalities and Illnesses of Meeting the Revised and Alternative Primary $PM_{2.5}$ Standard Levels for 2032 (95% Confidence Interval)

Avoided Mortality	**10/35**	**10/30**	**9/35**	**8/35**
Pope et al. (adult mortality ages 18-99 years)	3,100 (2,200 to 4,000)	3,800 (2,700 to 4,900)	7,400 (5,300 to 9,400)	15,000 (11,000 to 20,000)
Wu et al. (adult mortality ages 65-99 years)	1,500 (1,300 to 1,700)	1,800 (1,600 to 2,000)	3,500 (3,100 to 3,900)	7,400 (6,500 to 8,200)
Woodruff et al. (infant mortality)	3.3 (-2.1 to 8.4)	3.9 (-2.5 to 9.9)	8.2 (-5.2 to 21)	18 (-11 to 45)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	260 (190 to 320)	310 (220 to 390)	580 (420 to 730)	1,200 (840 to 1,500)
Hospital admissions—respiratory	170 (60 to 280)	200 (69 to 330)	400 (140 to 650)	820 (290 to 1,300)
ED visits--cardiovascular	490 (-190 to 1,100)	580 (-220 to 1,300)	1,100 (-440 to 2,600)	2,400 (-910 to 5,500)
ED visits—respiratory	950 (190 to 2,000)	1,100 (220 to 2,300)	2,200 (440 to 4,700)	4,700 (920 to 9,800)
Acute Myocardial Infarction	56 (33 to 79)	67 (39 to 94)	130 (73 to 180)	250 (150 to 350)
Cardiac arrest	27 (-11 to 61)	33 (-13 to 74)	62 (-25 to 140)	130 (-52 to 290)
Hospital admissions--Alzheimer's Disease	600 (460 to 730)	700 (530 to 850)	1,400 (1,100 to 1,700)	2,900 (2,300 to 3,600)
Hospital admissions--Parkinson's Disease	84 (44 to 120)	100 (53 to 150)	200 (110 to 290)	420 (220 to 600)
Stroke	100 (26 to 170)	120 (32 to 210)	230 (61 to 400)	480 (120 to 820)
Lung cancer	120 (37 to 200)	140 (45 to 240)	270 (85 to 450)	560 (170 to 900)
Hay Fever/Rhinitis	29,000 (7,100 to 50,000)	35,000 (8,500 to 60,000)	67,000 (16,000 to 110,000)	140,000 (33,000 to 230,000)
Asthma Onset	4,400 (4,300 to 4,600)	5,300 (5,100 to 5,500)	10,000 (9,700 to 11,000)	20,000 (20,000 to 21,000)
Asthma symptoms – Albuterol use	620,000 (-300,000 to 1,500,000)	740,000 (-360,000 to 1,800,000)	1,400,000 (-700,000 to 3,500,000)	2,900,000 (-1,400,000 to 7,000,000)
Lost work days	220,000 (190,000 to 250,000)	260,000 (220,000 to 300,000)	500,000 (430,000 to 580,000)	1,000,000 (870,000 to 1,200,000)
Minor restricted-activity days	1,300,000 (1,000,000 to 1,500,000)	1,500,000 (1,200,000 to 1,800,000)	3,000,000 (2,400,000 to 3,500,000)	6,000,000 (4,900,000 to 7,100,000)

Note: Values rounded to two significant figures.

Table 5A-2 Monetized Avoided PM-Related Premature Mortalities and Illnesses of Meeting the Revised and Alternative Primary $PM_{2.5}$ Standard Levels for 2032 (Millions of 2017$, 3% discount rate; 95% Confidence Interval)

Avoided Mortality	**10/35**	**10/30**	**9/35**	**8/35**
Pope et al. (adult mortality ages 18-99 years)	32,000 (2,900 and 86,000)	39,000 (3,600 and 110,000)	76,000 (6,900 and 200,000)	160,000 (14,000 and 430,000)
Wu et al. (adult mortality ages 65-99 years)	15,000 (1,400 and 40,000)	19,000 (1,700 and 50,000)	36,000 (3,300 and 96,000)	75,000 (7,000 and 200,000)
Woodruff et al. (infant mortality)	37 (-21 and 150)	44 (-25 and 170)	92 (-52 and 370)	200 (-110 and 790)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	4.2 (3.1 and 5.3)	5 (3.6 and 6.4)	9.5 (6.9 and 12)	19 (14 and 24)
Hospital admissions—respiratory	2.9 (0.66 and 5.1)	3.4 (0.76 and 5.9)	6.6 (1.5 and 12)	13 (3.1 and 23)
ED visits--cardiovascular	0.6 (-0.23 and 1.4)	0.71 (-0.27 and 1.7)	1.4 (-0.54 and 3.3)	2.9 (-1.1 and 6.8)
ED visits—respiratory	0.88 (0.17 and 1.8)	1 (0.2 and 2.2)	2.1 (0.41 and 4.3)	4.4 (0.86 and 9.1)
Acute Myocardial Infarction	2.9 (1.7 and 4.1)	3.5 (2 and 4.9)	6.6 (3.8 and 9.2)	13 (7.6 and 18)
Cardiac arrest	1 (-0.42 and 2.3)	1.2 (-0.51 and 2.8)	2.4 (-0.97 and 5.3)	4.8 (-2 and 11)
Hospital admissions—Alzheimer's Disease	7.7 (5.9 and 9.4)	8.9 (6.8 and 11)	18 (14 and 22)	38 (29 and 46)
Hospital admissions--Parkinson's Disease	1.1 (0.6 and 1.7)	1.4 (0.73 and 2)	2.8 (1.4 and 4)	5.8 (3 and 8.2)
Stroke	3.7 (0.95 and 6.2)	4.5 (1.2 and 7.6)	8.4 (2.2 and 14)	17 (4.5 and 30)
Lung cancer	3.3 (1 and 5.4)	4 (1.2 and 6.6)	7.5 (2.3 and 12)	15 (4.8 and 25)
Hay Fever/Rhinitis	19 (4.6 and 32)	22 (5.4 and 38)	43 (10 and 73)	86 (21 and 150)
Asthma Onset	210 (200 and 220)	250 (230 and 260)	480 (450 and 510)	960 (900 and 1000)
Asthma symptoms – Albuterol use	0.23 (-0.11 and 0.56)	0.27 (-0.13 and 0.66)	0.53 (-0.26 and 1.3)	1.1 (-0.52 and 2.6)
Lost work days	40 (33 and 46)	47 (40 and 54)	91 (77 and 100)	190 (160 and 210)
Minor restricted-activity days	100 (53 and 150)	120 (63 and 180)	230 (120 and 350)	470 (250 and 720)

Note: Values rounded to two significant figures.

Table 5A-3 Monetized Avoided PM-Related Premature Mortalities and Illnesses of Meeting the Revised and Alternative Primary $PM_{2.5}$ Standard Levels for 2032 (Millions of 2017$, 7% discount rate; 95% Confidence Interval)

Avoided Mortality	**10/35**	**10/30**	**9/35**	**8/35**
Pope et al. (adult mortality ages 18-99 years)	29,000 (2,600 and 78,000)	35,000 (3,200 and 95,000)	68,000 (6,200 and 180,000)	140,000 (13,000 and 380,000)
Wu et al. (adult mortality ages 65-99 years)	14,000 (1,300 and 36,000)	17,000 (1,600 and 45,000)	33,000 (3,000 and 86,000)	68,000 (6,300 and 180,000)
Woodruff et al. (infant mortality)	37 (-21 and 150)	44 (-25 and 170)	92 (-52 and 370)	200 (-110 and 790)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	4.2 (3.1 and 5.3)	5 (3.6 and 6.4)	9.5 (6.9 and 12)	19 (14 and 24)
Hospital admissions—respiratory	2.9 (0.66 and 5.1)	3.4 (0.76 and 5.9)	6.6 (1.5 and 12)	13 (3.1 and 23)
ED visits--cardiovascular	0.6 (-0.23 and 1.4)	0.71 (-0.27 and 1.7)	1.4 (-0.54 and 3.3)	2.9 (-1.1 and 6.8)
ED visits—respiratory	0.88 (0.17 and 1.8)	1 (0.2 and 2.2)	2.1 (0.41 and 4.3)	4.4 (0.86 and 9.1)
Acute Myocardial Infarction	2.9 (1.7 and 4)	3.4 (2 and 4.8)	6.4 (3.7 and 9)	13 (7.4 and 18)
Cardiac arrest	1 (-0.42 and 2.3)	1.2 (-0.5 and 2.8)	2.3 (-0.96 and 5.3)	4.8 (-2 and 11)
Hospital admissions--Alzheimer's Disease	7.7 (5.9 and 9.4)	8.9 (6.8 and 11)	18 (14 and 22)	38 (29 and 46)
Hospital admissions--Parkinson's Disease	1.1 (0.6 and 1.7)	1.4 (0.73 and 2)	2.8 (1.4 and 4)	5.8 (3 and 8.2)
Stroke	3.7 (0.95 and 6.2)	4.5 (1.2 and 7.6)	8.4 (2.2 and 14)	17 (4.5 and 30)
Lung cancer	2.5 (0.76 and 4)	3 (0.93 and 4.9)	5.6 (1.7 and 9.2)	11 (3.6 and 19)
Hay Fever/Rhinitis	19 (4.6 and 32)	22 (5.4 and 38)	43 (10 and 73)	86 (21 and 150)
Asthma Onset	130 (120 and 140)	150 (140 and 160)	300 (280 and 310)	600 (560 and 630)
Asthma symptoms – Albuterol use	0.23 (-0.11 and 0.56)	0.27 (-0.13 and 0.66)	0.53 (-0.26 and 1.3)	1.1 (-0.52 and 2.6)
Lost work days	40 (33 and 46)	47 (40 and 54)	91 (77 and 100)	190 (160 and 210)
Minor restricted-activity days	100 (53 and 150)	120 (63 and 180)	230 (120 and 350)	470 (250 and 720)

Note: Values rounded to two significant figures.

Table 5A-4 Total Estimated Monetized Benefits of Meeting the Revised and Alternative Primary Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	10 µg/m³ annual & 35 µg/m³ 24-hour	10 µg/m³ annual & 30 µg/m³ 24-hour	9 µg/m³ annual & 35 µg/m³ 24-hour	8 µg/m³ annual & 35 µg/m³ 24-hour
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Pope (2019)				
3% discount rate	\$32 + B	\$40 + B	\$77 + B	\$160 + B
7% discount rate	\$29 + B	\$36 + B	\$69 + B	\$140+ B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Wu et al. (2020)				
3% discount rate	\$16 + B	\$19 + B	\$37 + B	\$77 + B
7% discount rate	\$14 + B	\$17 + B	\$33 + B	\$70 + B

Note: Rounded to two significant figures. Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag. It was not possible to quantify all benefits due to data limitations in this analysis. "B" is the sum of all unquantified health and welfare benefits.

Table 5A-5 Total Estimated Monetized Benefits by Area of Meeting the Revised and Alternative Primary Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	Area	10 µg/m³ annual & 35 µg/m³ 24-hour	10 µg/m³ annual & 30 µg/m³ 24-hour	9 µg/m³ annual & 35 µg/m³ 24-hour	8 µg/m³ annual & 35 µg/m³ 24-hour
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Pope (2019)					
3% discount rate	**Northeast**	$2.4 + B	$2.5 + B	$15 + B	$39 + B
	Southeast	$0.51 + B	$0.51+ B	$6.2 + B	$27 + B
	West	$0.11 + B	$2.1 + B	$2.6 + B	$12 + B
	California	$29 + B	$35 + B	$53 + B	$82 + B
7% discount rate	**Northeast**	$2.1 + B	$2.2 + B	$14 + B	$35 + B
	Southeast	$0.46 + B	$0.46 + B	$5.6 + B	$24 + B
	West	$0.1 + B	$1.9 + B	$2.3 + B	$11 + B
	California	$26 + B	$31 + B	$47 + B	$74 + B
Economic value of avoided $PM_{2.5}$-related morbidities and premature deaths using $PM_{2.5}$ mortality estimate from Wu et al. (2020)					
3% discount rate	**Northeast**	$1.2 + B	$1.2 + B	$7.5 + B	$19 + B
	Southeast	$0.24 + B	$0.24 + B	$2.9 + B	$13 + B
	West	$0.059 + B	$1.1 + B	$1.3 + B	$5.8 + B
	California	$14 + B	$17 + B	$25 + B	$40 + B
7% discount rate	**Northeast**	$1.0 + B	$1.1 + B	$6.8 + B	$17 + B
	Southeast	$0.21 + B	$0.21 + B	$2.6 + B	$11 + B
	West	$0.053 + B	$0.95 + B	$1.1 + B	$5.2 + B
	California	$13 + B	$15 + B	$23 + B	$36 + B

Note: Rounded to two significant figures. Avoided premature deaths account for over 98% of monetized benefits here, which are discounted over the SAB-recommended 20-year segmented lag. It was not all possible to quantify all benefits due to data limitations in this analysis. “B” is the sum of all unquantified health and welfare benefits.

5A.2 References

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CHAPTER 6: ENVIRONMENTAL JUSTICE

6.1 Analyzing EJ Impacts in This Final Action

In addition to the benefits assessment (Chapter 5), the EPA considers potential EJ concerns of this rulemaking. An EJ concern is defined as the actual or potential lack of fair treatment or meaningful involvement on the basis of income, race, color, national origin, Tribal affiliation, or disability in the development, implementation and enforcement of environmental laws, regulations and policies. For analytic purposes, this concept refers more specifically to disproportionate and adverse impacts that may exist prior to or be created by the proposed regulatory action. (U.S. EPA, 2015). Although EJ concerns for each rulemaking are unique and should be considered on a case-by-case basis, the EPA's EJ Technical Guidance (U.S. EPA, 2015) states that "[t]he analysis of potential EJ concerns for regulatory actions should address three questions:

1. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline?
2. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern for the regulatory option(s) under consideration?
3. For the regulatory option(s) under consideration, are potential EJ concerns created [, exacerbated,] or mitigated compared to the baseline?"

To address these questions, the EPA developed an analytical approach that considers the purpose and specifics of this rulemaking, as well as the nature of known and potential exposures and health impacts. The purpose of this Regulatory Impact Analysis (RIA) is to provide estimates of the potential costs and benefits of the illustrative national control strategies in 2032 for the revised and alternative standard levels analyzed. As revised and alternative standard levels evaluated in the RIA are more stringent than the current standards, when reducing emissions to reach lower standard levels, some areas above or near the current standards are expected to experience greater air quality improvements, and thus health improvements, than other areas already at or below lower alternative standard levels. As differences in both exposure and susceptibility (i.e., intrinsic individual risk factors) contribute to environmental impacts, the analytical approach used here first determines whether exposure (Section 6.3) and health effect (Section 6.4) disparities exist under the baseline scenario. The approach then evaluates if and how disparities are impacted when illustrative emissions control strategies are analyzed. Both the exposure and health effects analyses were developed using available scientific evidence from the current PM NAAQS reconsideration, for the future year 2032, and are associated with various uncertainties. Consistent with the methods the EPA uses to fully characterize the benefits of a regulatory action, these EJ analyses evaluate the full set of exposure and health outcome distributions resulting from this action at the national scale.

Since NAAQS RIAs are national-level assessments and air quality issues are complex and local in nature, the RIA presents costs and benefits of $PM_{2.5}$ emission reductions associated with illustrative control strategies. Correspondingly, the main EJ analyses in this chapter also evaluate implications of air quality surfaces associated with the illustrative emission control strategies for current (i.e., baseline), revised, and alternative standard levels. However, the illustrative control strategies do not result in all counties identifying emissions reductions needed to meet the revised or alternative standard levels (Chapter 3). As such, the appendix to this chapter provides EJ implications of air quality scenarios associated with meeting the standard levels (labelled in some Section 6.6 figures as "Standards") and also repeats results associated with the illustrative emissions control strategies (labelled in some Section 6.6 figures as "Controls"), allowing for direct comparison across the two air quality adjustment methods.

As only some areas of the U.S. are projected to exceed alternative standard levels, in the proposal RIA the EPA conducted a case study examining the subset of areas in which air quality is projected to change after the application of controls. In this final RIA, instead of the case study analysis, we illustrate how air quality improvements in the areas with the highest starting concentrations might be distributed by enlarging the portions of the distributional exposure figures that cover relatively high $PM_{2.5}$ exposures.[1] This permits visualization of the sometimes-nuanced exposure disparities.

[1] Input data (e.g., air quality surfaces, configuration files, and command line scripts) used to prepare the EJ analysis described in this chapter are in the docket and available upon request with the Docket Office.

The EJ exposure assessment portion of the analysis focuses on associating ambient $PM_{2.5}$ concentrations with various demographic variables. Because this type of analysis requires less *a priori* information, we were able to include a broad array of demographic characteristics (e.g., race/ethnicity, poverty status, educational attainment, etc.). In contrast, estimating health outcomes modified by demographic population requires additional scientific information, which constrained the scope of the second portion of the assessment. We focused the EJ health effects analysis on populations and health outcomes with the strongest scientific support (U.S. EPA, 2019, 2020, 2022a). However, the EJ health effects analysis does not include information about differences in other factors that could affect the likelihood of adverse impacts (e.g., access to health care, body mass index, genetic susceptibilities, etc.) across groups, due to limitations in the underlying data.[2]

Complex analyses using estimated parameters and inputs from numerous models are likely to include multiple sources of uncertainty. As this analysis is based on the same $PM_{2.5}$ spatial fields as the benefits assessment (Appendix 2A), it is subject to similar types of uncertainty (Chapter 5, Section 5.3). A particularly germane limitation is the illustrative nature of the emission reductions in NAAQS RIAs; as a result, the EJ analyses in this chapter illustrate the estimated EJ impacts of the illustrative control strategies and may not reflect state-level implementation decisions. Relatedly, while proximity analyses can sometimes provide limited EJ information regarding the demographics of populations living near emissions sources, in this case state-level implementation decisions are unknown. Therefore, proximity analyses of populations living near individual sources that could potentially install controls would be highly uncertain and were not conducted in this EJ assessment. However, the EJ exposure and health analyses included in this chapter provide more relevant and high-confidence information than a proximity analysis, since these analyses relate actual $PM_{2.5}$ concentrations (not just emissions) to various demographic populations.

Both the EJ exposure and health effects analyses are subject to uncertainties related to input parameters and assumptions. For example, both analyses focus on annual $PM_{2.5}$

[2] We do not ascribe differential health effects to be caused by race or ethnicity. Instead, race and ethnicity likely serve as proxies for a variety of environmental and social stressors.

concentrations and do not evaluate whether concentrations experienced by different groups persist across the distribution of daily $PM_{2.5}$ exposures. Additionally, air quality simulation input information is at a 12 km grid resolution, population information is either at the Census tract- or county-level, and baseline mortality rates are mostly at the county-level. The resolution of the input data may potentially mask impacts at geographic scales more highly resolved than the input information. The EJ health effects analysis is also subject to additional uncertainties related to concentration-response relationships and baseline incidence data.

As with all EJ analyses, data limitations make it quite possible that there exist additional disparities unidentified in this analysis. This is especially relevant for potential EJ characteristics and more granular spatial resolutions that were not evaluated. For example, results are provided here at national-, regional- and tract-levels, potentially masking block group- or block-level EJ impacts. Additional uncertainties are briefly discussed in the summary of this analysis (Section 6.5).

6.2 Introduction

Executive Order 12898 directs the EPA to "achiev[e] environmental justice (EJ) by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects" (59 FR 7629, February 16, 1994), termed disproportionate impacts in this chapter. Additionally, Executive Order 13985 was signed to advance racial equity and support underserved communities through Federal government actions (86 FR 7009, January 20, 2021). Recently, Executive Order 14096 (88 FR 25251, April 26, 2023) strengthens the directives for achieving environmental justice that are set out in Executive Order 12898.

Executive Order 14096 defines EJ as the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment. The EPA further defines the term fair treatment to mean that "no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies".[3] Meaningful involvement means that: (1) potentially affected populations have an appropriate opportunity to participate in decisions about an activity that will affect their environment and/or health; (2) the public's contribution can influence the regulatory Agency's decision; (3) the concerns of all participants involved will be considered in the decision-making process; and (4) the rule-writers and decision-makers seek out and facilitate the involvement of those potentially affected.

The term "disproportionate impacts" refers to differences in impacts or risks that are extensive enough that they may merit Agency action.[4] In general, the determination of whether a disproportionate impact exists is ultimately a policy judgment which, while informed by analysis, is the responsibility of the decision-maker. The terms "difference" or "differential" indicate an analytically discernible distinction in impacts or risks across population groups. It is the role of the analyst to assess and present differences in anticipated impacts across population groups of concern for both the baseline and final regulatory options, using the best available information (both quantitative and qualitative) to inform the decision-maker and the public.

A regulatory action may involve potential EJ concerns if it could: (1) create new disproportionate impacts on populations or communities of concern based on income, race, color, national origin, Tribal affiliation, or disability; (2) exacerbate existing disproportionate impacts on populations or communities of concern; or (3) present opportunities to address existing disproportionate impacts on populations or communities of concern through the action under development.

Executive Order 14094 (88 FR 21879, April 11, 2023) directs Federal agencies to recognize distributive impacts and equity in regulatory analysis, to the extent permitted by law, as practicable and appropriate. For purposes of analyzing regulatory impacts, the EPA relies upon its June 2016 "Technical Guidance for Assessing Environmental Justice in

[3] See, e.g., "Environmental Justice." *Epa.gov*, U.S. Environmental Protection Agency, 4 Mar. 2021, https://www.epa.gov/environmentaljustice.
[4] See https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.

Regulatory Analysis,"[5] which provides recommendations that encourage analysts to conduct the highest quality analysis feasible, recognizing that data limitations, time, resource constraints, and analytical challenges will vary by media and circumstance.

A reasonable starting point for assessing the need for a more detailed EJ analysis is to review the available evidence from the published literature and from community input on what factors may make population groups of concern more vulnerable to adverse effects (e.g., underlying risk factors that may contribute to higher exposures and/or impacts). It is also important to evaluate the data and methods available for conducting an EJ analysis. EJ analyses can be grouped into two types, both of which are informative, but not always feasible for a given rulemaking:

1. Baseline: Describes the current (pre-control) distribution of exposures and risk under control strategies associated with the current standard, identifying potential disparities.
2. Policy: Describes the distribution of exposures and risk after the regulatory option(s) have been applied (post-control), identifying how potential disparities change in response to the rulemaking.

EPA's 2016 Technical Guidance does not prescribe or recommend a specific approach or methodology for conducting EJ analyses, though a key consideration is consistency with the assumptions underlying other parts of the regulatory analysis when evaluating the baseline and regulatory options.

6.3 EJ Analysis of Exposures Under Current, Revised, and Alternative Standard Levels

This EJ $PM_{2.5}$ exposure[6] analysis aims to evaluate the potential for EJ concerns related to $PM_{2.5}$ exposures[7] among potentially vulnerable populations[8] from three

[5] See https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.
[6] The term exposure is used here to describe estimated $PM_{2.5}$ concentrations and not individual dosage.
[7] Air quality surfaces used to estimate exposures are based on 12 x 12 km grids. Additional information on air quality modeling can be found in Chapter 2.
[8] Race, ethnicity, sex, and age population input information is at the tract level, whereas poverty status and educational attainment population input information is at the county level.

perspectives, which correspond to the three EJ questions listed in Section 6.1. Specifically, the following questions are addressed:

1) Are there disparate $PM_{2.5}$ exposures under baseline/current PM NAAQS standard levels (question 1)?
2) Are there disparate $PM_{2.5}$ health effects under illustrative alternative PM NAAQS standard levels (question 2)?
3) Are $PM_{2.5}$ exposure disparities created, exacerbated, or mitigated under illustrative alternative PM NAAQS standard levels as compared to the baseline (question 3)?

Population variables considered in this EJ exposure assessment are listed in Table 6-1).[9] EPA has expanded the populations evaluated in this exposure EJ assessment as compared to those included in the proposal RIA EJ assessment to evaluate potential exposure disparities more comprehensively, regardless of any pre-existing biases. Several populations added to this final action have been included in other rulemaking RIAs evaluating $PM_{2.5}$ emission changes (e.g., employment status, health insurance status, and linguistic isolation). Additionally, this RIA assesses exposure in communities with a legacy of discriminatory land use designations and siting decisions (i.e., historically redlined areas, using the Home Owners' Loan Corporation (HOLC) gradings A-D, with grade D areas being defined as "redlined"). EPA believes all population groups added to this exposure assessment provide additional insight into community-level vulnerability, as all of these factors can reasonably be understood to lead to increased susceptibility and vulnerability (U.S. EPA, 2023). Additional information on the populations can be found in Section 6.6.1.

There is substantial research demonstrating that structural or historic racism can have lasting effects. For example, examiners for the Home Owners' Loan Corporation (HOLC) rated neighborhoods in the 1930s and 1940s based on a long list of criteria, including the age and condition of housing, access to highways and other forms of transportation, proximity to parks and polluting industries, and residents' economic class, employment status, and ethnic and racial composition. Neighborhoods that received a D grade were designated hazardous or undesirable (so called "redlined'). On this basis,

[9] Information on the input population data used in the exposure EJ analysis is available in Section 6.6.1.

potential homeowners were denied access to credit or lent money at higher rates than residents of other neighborhoods. Redlining was in effect across 239 cities and, although illegal now for many decades, has had lasting effects on investments in these neighborhoods, where greater proportions of low income and people of color still reside. Residents of neighborhoods that were redlines also tend to have poorer health outcomes (Mitchell et al., 2018, Swope et al., 2022, Lee et al., 2022).

Table 6-1 Populations Included in the $PM_{2.5}$ Exposure Analysis

Population	Groups
Ethnicity	Hispanic; Non-Hispanic
Race	Asian; American Indian; Black; White
Educational Attainment	High school degree or more; No high school degree
Employment Status	Employed; Unemployed; Not in the labor force
Health Insurance Status	Insured; Uninsured
Linguistic Isolation	English "well or better"; English < "well"
Poverty Status	Above the poverty line; Below the poverty line
Redlined Areas	HOLC Grades A-C; HOLC Grade D; Not graded by HOLC
Age	Children (0-17); Adults (18-64); Older Adults (65-99)
Sex	Female; Male

Results presented in the main chapter are associated with identified emissions controls, whereas the EJ appendix, Section 6.6, includes results for air quality scenarios associated with identified emissions controls ("Controls") and with fully meeting the current and alternate standard levels ("Standards"). Additional air quality information regarding identified controls, as well as areas where air quality has been adjusted, is available in Chapters 2 and 3.

6.3.1 National

We begin by considering the first two questions from EPA's EJ Technical Guidance (i.e., are there potential EJ concerns 1) in the baseline, and 2) for the regulatory option(s) under consideration) with respect to $PM_{2.5}$ exposures across the contiguous U.S., which we term "national." We also consider the extent to which exposures *change* for each demographic population, to compare improvements in air quality among populations. We then address the third question from EPA's EJ Technical Guidance, how disparities observed between demographic groups in the baseline scenario (12/35) are impacted (e.g., exacerbated/mitigated/unchanged) under alternative standard levels.

6.3.1.1 Absolute Exposures Under Current and Alternative Standard Levels and Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

As NAAQS are national rules, we begin by evaluating annual average $PM_{2.5}$ concentrations in absolute terms projected to be experienced by various demographic groups that may be of EJ concern, averaged across the contiguous U.S. Figure 6-1 shows the national average annual $PM_{2.5}$ exposure concentration burdens of various population groups under current standard (i.e., baseline) and alternative, more stringent standard scenarios as a heat map. Each scenario is a combination of an annual standard, listed first, and a 24-hr standard, listed after the slash, both presented in micrograms per cubic meter ($\mu g/m^3$). Higher estimated annual total $PM_{2.5}$ concentrations are shown in darker shades of blue for convenience. Populations with potential EJ concerns can be compared to the reference/overall population and/or other populations (i.e., White, Non-Hispanic, above the poverty line, more educated, etc.). It is also noteworthy that the national average annual exposures for all demographic groups are well below the current annual NAAQS. Relatedly, to display these results as a heat map, only the national population-weighted average is provided, with distributional information provided subsequently.

Figure 6-1 also shows the average $PM_{2.5}$ concentration *reductions* for each population when moving from the current standard to alternative standard levels, in columns with a dash (e.g., 12/35-10/35). Please note that the magnitude of the $PM_{2.5}$ concentration reductions is small (i.e., tenths of a $\mu g/m^3$) because they are national averages and include individuals residing in the relatively small number of areas predicted to experience $PM_{2.5}$ concentration reductions when moving to lower alternative standards, as well as in the relatively large number of areas already below the lower alternative $PM_{2.5}$ standard levels where no $PM_{2.5}$ concentration reductions are predicted under more stringent standards.

On average, under the current and alternative scenarios evaluated, Asian, Black, Hispanic, less educated, unemployed, uninsured, linguistically isolated, below the poverty line populations live in areas with higher annual average $PM_{2.5}$ concentrations than the reference population. Residents of both HOLC Grade D (i.e., redlined) and HOLC Grades A, B, and C (A-C) neighborhoods in urban areas also have higher annual average $PM_{2.5}$ concentrations compared to populations living outside of these urban areas (i.e., not graded by HOLC). Linguistically isolated, Hispanic, and Asian populations are projected to experience the highest relative concentrations under each scenario for the demographic groups examined. While residents of neighborhoods with HOLC grades of A-C in urban areas also experience some of the highest relative concentrations, concentrations in neighborhoods with a HOLC grade of D are even higher.

Regarding $PM_{2.5}$ concentration reductions (columns showing average annual $PM_{2.5}$ concentration reductions when shifting from the current to alternative standards), most demographic groups are projected to experience similar reductions under more stringent standards, in absolute terms. While certain populations are predicted to experience slightly greater annual $PM_{2.5}$ concentration reductions, these populations also often began with higher baseline concentrations, making the absolute change alone insufficient to determine if disparities are being mitigated. EJ guiding question 3, regarding the impacts of baseline disparities, is directly evaluated in Section 6.4.1.2.

Population Group	Population (Ages)	Number of People	12/35	10/35	12/35-10/35	10/30	1235-10/30	9/35	12/35-9/35	8/35	12/35-8/35
Reference	All (0-99)	371M	7.2	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3
Race	White (0-99)	287M	7.1	7.0	0.1	7.0	0.1	6.9	0.1	6.8	0.3
	American Indian (0-99)	4M	6.8	6.7	0.1	6.7	0.1	6.6	0.1	6.5	0.3
	Asian (0-99)	27M	7.8	7.7	0.1	7.7	0.1	7.6	0.2	7.4	0.4
	Black (0-99)	52M	7.4	7.3	0.0	7.3	0.0	7.2	0.1	7.0	0.3
Ethnicity	Non-Hispanic (0-99)	287M	6.9	6.9	0.0	6.9	0.0	6.8	0.1	6.7	0.2
	Hispanic (0-99)	84M	7.9	7.8	0.1	7.8	0.1	7.7	0.2	7.5	0.4
Educational Attainment	More educated (25-99)	219M	7.1	7.0	0.0	7.0	0.1	7.0	0.1	6.8	0.3
	Less educated (25-99)	37M	7.5	7.4	0.1	7.4	0.1	7.3	0.2	7.1	0.3
Employment Status	Employed (0-99)	174M	7.2	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3
	Unemployed (0-99)	9M	7.3	7.2	0.1	7.2	0.1	7.1	0.2	7.0	0.3
	Not in the labor force (0-99)	188M	7.2	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3
Insurance Status	Insured (0-64)	264M	7.2	7.1	0.1	7.1	0.1	7.1	0.1	6.9	0.3
	Unisured (0-64)	32M	7.3	7.3	0.1	7.2	0.1	7.2	0.1	7.0	0.3
Linguistic Isolation	English "well or better" (0-99)	354M	7.1	7.1	0.0	7.1	0.1	7.0	0.1	6.8	0.3
	English < "well" (0-99)	17M	8.1	8.0	0.1	8.0	0.2	7.9	0.3	7.7	0.5
Poverty Status	Above the poverty line (0-99)	312M	7.1	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3
	Below poverty line (0-99)	58M	7.3	7.2	0.1	7.2	0.1	7.2	0.1	7.0	0.3
Redlined Areas	HOLC Grades A-C (0-99)	44M	8.0	7.8	0.1	7.8	0.2	7.7	0.3	7.5	0.5
	HOLC Grade D (0-99)	16M	8.2	8.1	0.1	8.1	0.1	7.9	0.3	7.7	0.5
	Ungraded by HOLC (0-99)	311M	7.0	7.0	0.0	7.0	0.0	6.9	0.1	6.8	0.2
Age	Adults (18-64)	212M	7.2	7.2	0.1	7.1	0.1	7.1	0.1	6.9	0.3
	Children (0-17)	84M	7.2	7.2	0.1	7.2	0.1	7.1	0.1	6.9	0.3
	Older Adults (65-99)	75M	7.0	6.9	0.0	6.9	0.1	6.9	0.1	6.7	0.3
Sex	Females (0-99)	188M	7.2	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3
	Males (0-99)	184M	7.2	7.1	0.1	7.1	0.1	7.0	0.1	6.9	0.3

Figure 6-1 Heat Map of National Average Annual $PM_{2.5}$ Concentrations and Concentration Reductions (µg/m³) by Demographic for Current, Revised, and Alternative PM NAAQS Levels (annual/24-hr) After Application of Controls in 2032

While average $PM_{2.5}$ concentrations can provide some insight when comparing across population impacts, information on the full distribution of concentrations affords a more comprehensive understanding. This is because both demographic groups and ambient concentrations can be unevenly distributed across the spectrum of exposures, meaning that average exposures may mask important disparities that occur on a more spatially localized basis. To evaluate how the distribution of annual exposures varies within and across demographic groups at the county level, we plot the full array of exposures (including very high and very low exposures) projected to be experienced by the entirety of each population. Distributional figures present the running sum of each population, converted to a percentage, on the y-axes (i.e., cumulative percent of population).

Conversion of each total population to a percent of the total permits direct comparison of annual $PM_{2.5}$ exposures across demographic populations with different absolute numbers. The x-axes show annual $PM_{2.5}$ concentrations (μg/m^3) from low to high. $PM_{2.5}$ concentrations are tract-level averages from all Census tracts in the contiguous U.S.[10] In other words, plots compare the running sum of each population against increasing annual $PM_{2.5}$ concentrations.

Information on the distribution of tract-level $PM_{2.5}$ concentrations associated with the illustrative control strategies for the current and alternative PM standard levels across and within populations can be found in Figure 6-2.[11] Information on the distribution of tract-level $PM_{2.5}$ concentration reductions associated with the illustrative control strategies for the current and alternative PM standard levels across and within populations can be found in Figure 6-4. The reference population including everyone ages 0-99 is in the top row of both figures. In Figure 6-2, the reference row shows that the emissions reductions associated with the current or alternative standard levels yields a fairly smooth S-curve, with the majority of the population experiencing annual $PM_{2.5}$ concentrations between 4 and 10 μg/m^3 under air quality scenarios associated with controls applied to meet the current standards (12/35). Lower $PM_{2.5}$ concentrations remain similar across lower alternative standard levels, while higher concentrations are reduced (Figure 6-24).

To evaluate differential exposure distributions under current, revised, and alternate standard levels, populations of potential EJ concern are shown with colored lines and can be compared to the respective reference population shown with a black line. Colored lines to the right of a black line in Figure 6-2 indicate that the potential EJ population is experiencing disproportionately higher $PM_{2.5}$ concentrations. Notably, at exposures below ~8.5 μg/m^3, Black population exposures are substantially higher than White population exposures. This could suggest that exposure disparities in the Black population occur in

[10] Distributional figures in the proposal RIA EJ exposure assessment were based on county-level averages. While tract-level averages are preferable due to the higher resolution, they required substantial additional computing power (~10-fold) and generate similar results. Therefore, EPA will select the geographic resolution that is most reasonable in future EJ assessments.

[11] Unemployed, uninsured, and the two sexes experience virtually identical distributions of exposure of all standard levels so were not included in these distributional figures.

more rural areas with lower $PM_{2.5}$ concentrations. Black population exposures above ~8.5 $\mu g/m^3$ are considered further in the discussion of Figure 6-3.

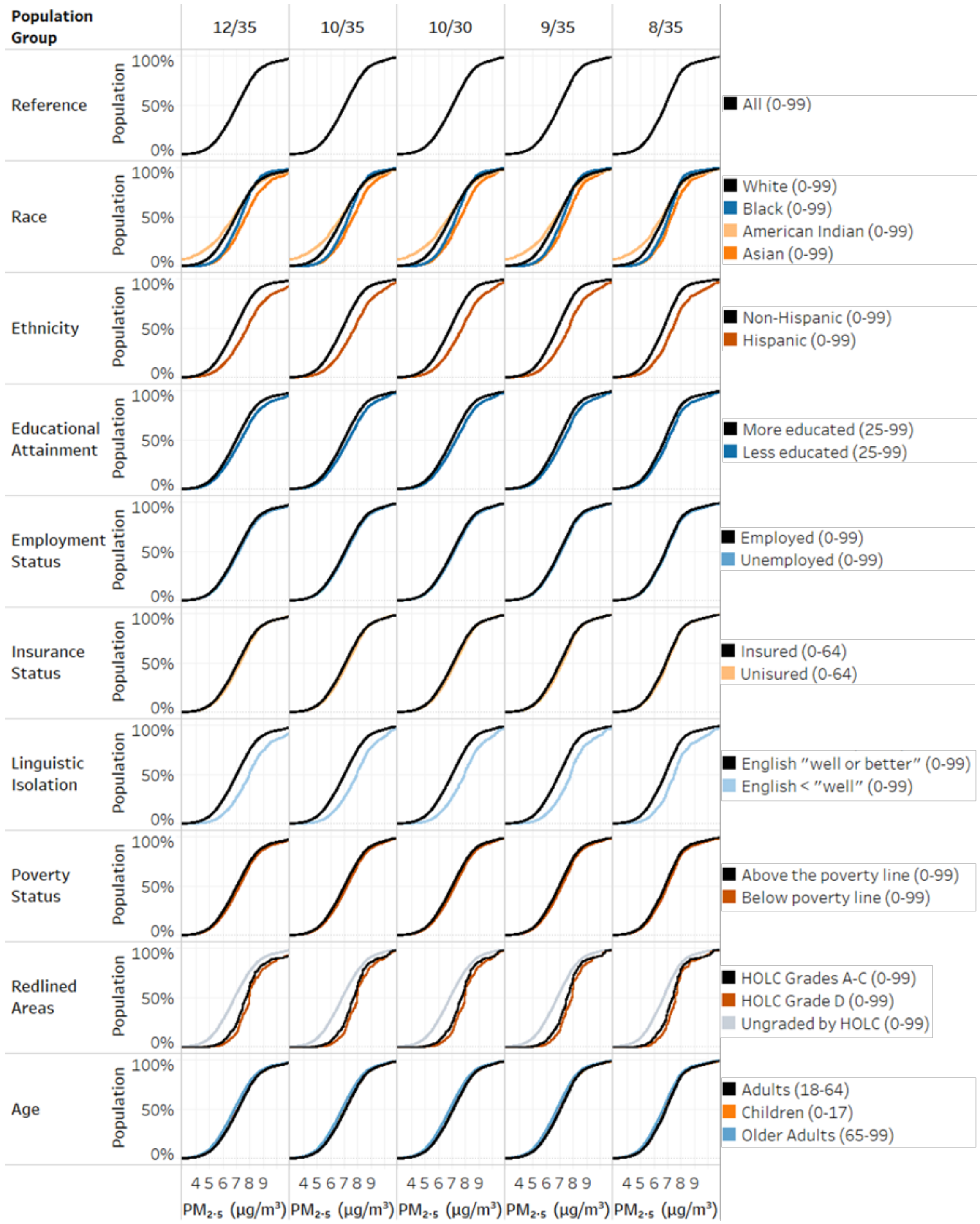

Figure 6-2 **National Distributions of Annual $PM_{2.5}$ Concentrations by Demographic for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032**

Figure 6-3 hones in on the distributional graphics for the portion of the population predicted to experience the highest exposures (>7 μg/m^3) for a subset of the population groups. This allows for improved visualization of tract-level exposure changes under emissions control strategies associated with the current, revised and alternative regulatory options at levels where changes are expected to occur. This figure replaces the case study included in the proposal RIA, which only provided average exposures in areas expected to experience changes when moving from 12/35-9/35. Figure 6-3 permits visualization of the sometimes-nuanced absolute disparities occuring at relatively high $PM_{2.5}$ exposures. For example, under all scenarios evaluated, there are proportionally more American Indian exposures than White exposures over 9 μg/m^3, whereas the proportion of the Black population experiencing exposures over 9 μg/m^3 is actually smaller than the proportion of White population exposures.

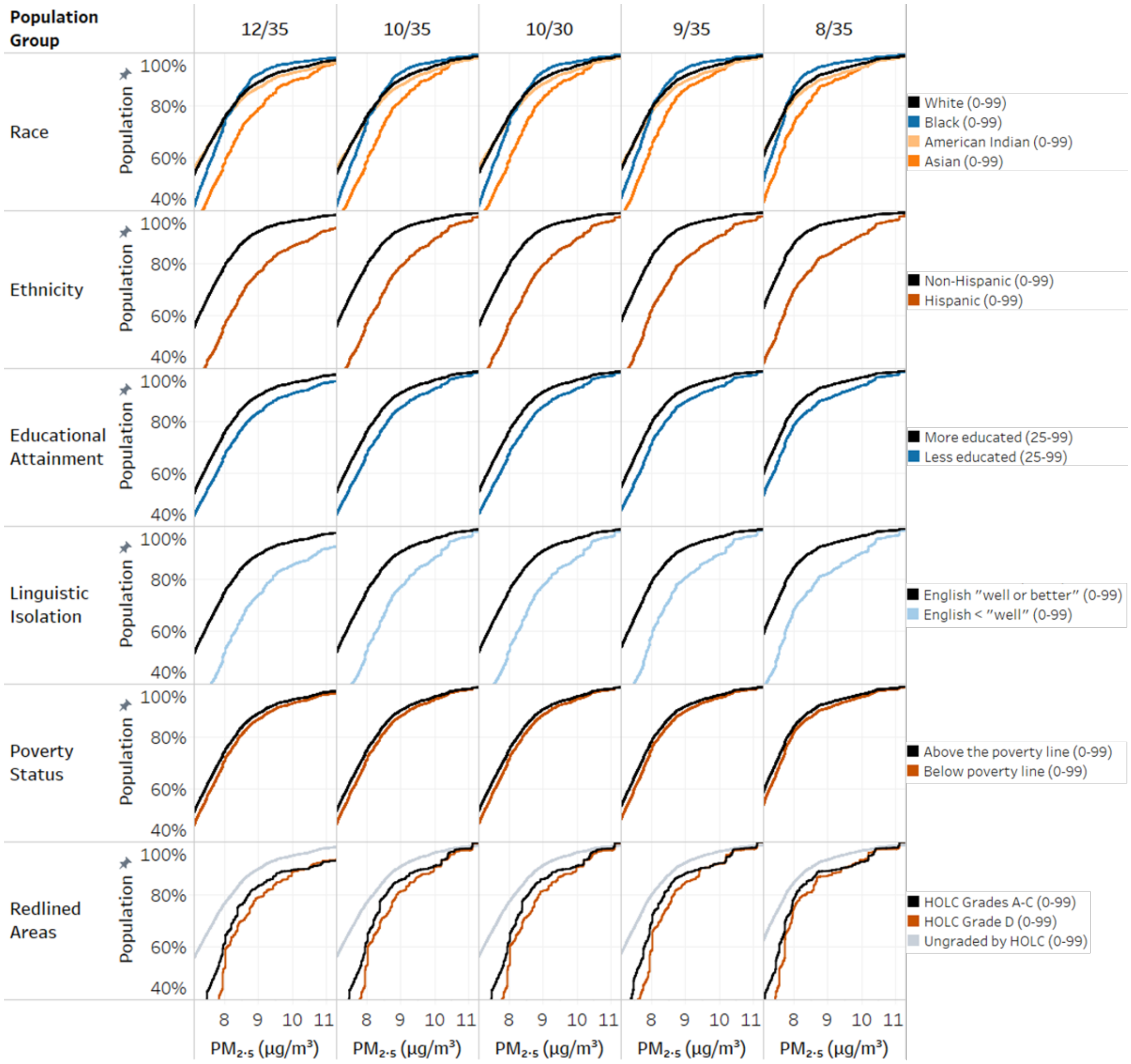

Figure 6-3 National Distributions of High Annual $PM_{2.5}$ Concentrations by Demographic for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032

When moving from controls associated with the current standards to controls associated with the alternative standards, most potential EJ populations of concern with higher baseline $PM_{2.5}$ concentrations are predicted to experience greater absolute $PM_{2.5}$ concentration reductions than the reference groups (e.g., Hispanic populations). Colored lines again represent potential populations of EJ concern and black lines the respective reference population; however, in these figures, colored lines to the right of the black line now indicate greater relative air quality improvements. For example, Figure 6-4 shows that ~25% of the non-Hispanic population are predicted to experience $PM_{2.5}$ concentration reductions when moving from the baseline of control strategies associated with the current standards (12/35) to control strategies associated with the revised standard levels of 9/35, whereas ~45% of the Hispanic population are predicted to experience $PM_{2.5}$ concentration reductions under control strategies when moving from 12/35-9/35. Figure 6-4 also shows that greater reductions are expected in the ~45% of the Hispanic population projected to experience $PM_{2.5}$ concentration reductions than the ~25% of the non-Hispanic population projected to experience $PM_{2.5}$ concentration reductions.

In general, populations with higher absolute national $PM_{2.5}$ exposures (Section 6.3.1) are also expected to see the greatest reductions in average $PM_{2.5}$ concentrations under the alternative standard levels. Populations of Asians, Hispanics, less educated, and linguistically isolated, are predicted to experience substantially greater $PM_{2.5}$ concentration reductions under air quality scenarios associated with control strategies for all alternative standard levels as compared to the reference population. However, Black populations are predicted to experience slightly smaller absolute $PM_{2.5}$ concentration reductions than White populations when moving to alternative standard levels of 10/35, 10/30, and the revised standards 9/35.

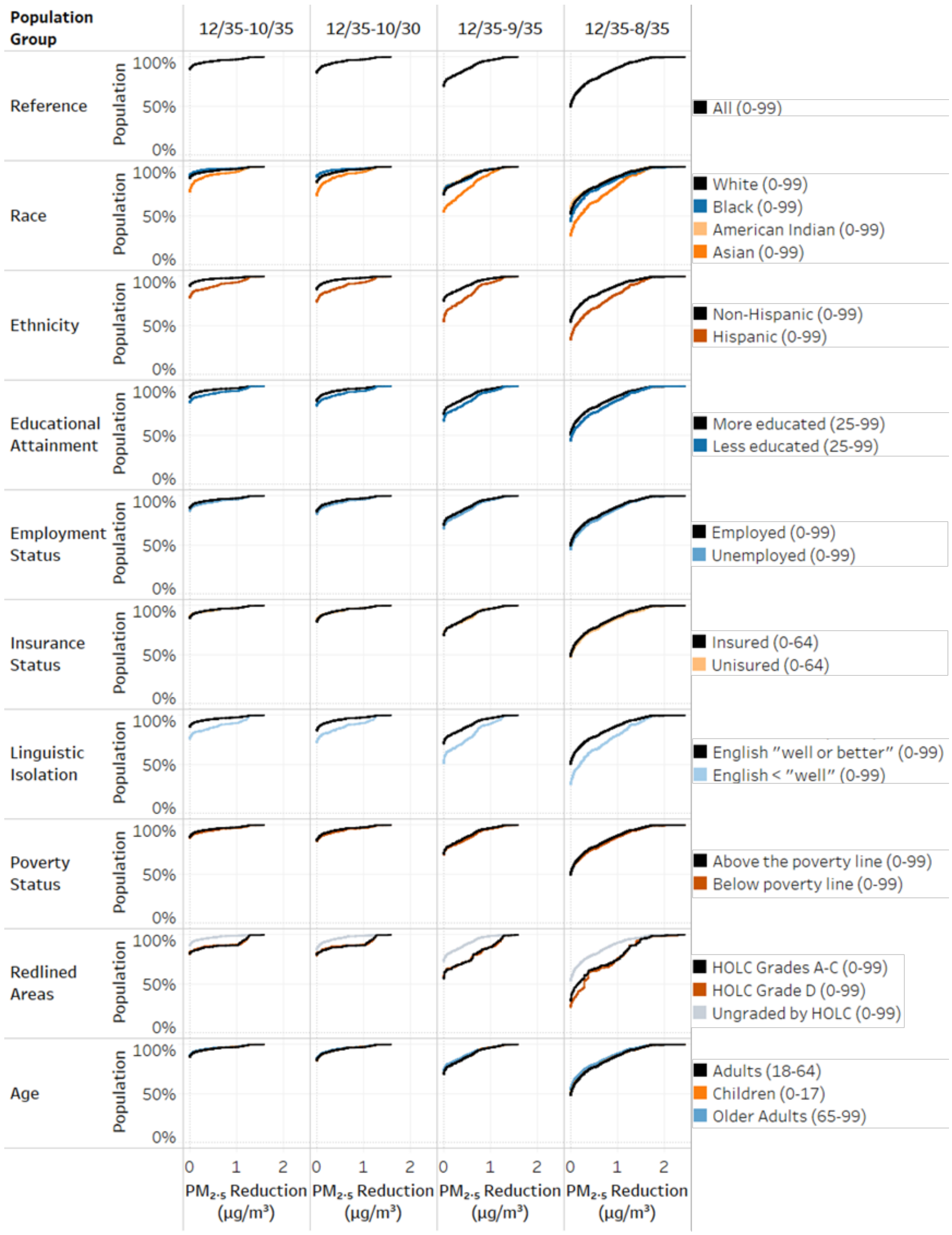

Figure 6-4 National Distributions of Annual $PM_{2.5}$ Concentration Reductions by Demographic from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032

6.3.1.2 Proportional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

To put the changes in exposure discussed in section 6.3.1.1in perspective, especially in light of the disparities in the exposure baseline across population groups also discussed in section 6.3.1.1, it helps to consider whether the absolute changes represent equivalent (proportional) reductions in exposure. In some cases, moving to more stringent control strategies could both reduce total average exposures and reduce disparities in exposure across groups. However, it can be difficult to determine the relative proportionality of changes in $PM_{2.5}$ concentrations for demographic populations using just the absolute exposure changes when moving from the current standards to a potential alternative standard level, like those shown above.

In this section, the proportionality of $PM_{2.5}$ concentration changes when moving from the current (baseline) to revised and alternative standard levels under air quality scenarios associated with the illustrative emissions control strategies is directly calculated.[12] To compare air quality improvements on a percentage basis, first exposures under the alternative standard levels are divided by exposures under the current standards at the national and regional levels. Those results are then subtracted from 1 to get the remainder, and then multiplied by 100 to get the percent change. For example, if the average annual $PM_{2.5}$ concentration in population A is 6 μg/m^3 under an alternative standard level and 7 μg/m^3 under control strategies associated with the current standards, the proportional change would be (1-(6/7)) x 100 = (1-0.857) x 100 = 0.143 x 100 = 14.3%. If the average annual $PM_{2.5}$ concentration in population B is 5 μg/m^3 under an alternative standard level and 6 μg/m^3 under the current standards, the proportional change would be (1-(5/6)) x 100 = (1-0.833) x 100 = 0.167 x 100 = 16.7%. Therefore, even though the absolute reduction is equivalent, population B would experience a proportionally larger reduction under controls strategies associated with the alternate standard level because the starting concentration was lower. As average $PM_{2.5}$ concentrations have generally been

[12] Results for air quality scenarios associated with meeting the revised and alternative standard levels can be found in the Appendix to this chapter.

representative of the distributions, for simplicity we only present the average proportional reduction for each population and scenario.

Alternative PM standard levels associated with control strategies reduce the national average $PM_{2.5}$ exposure concentrations experienced by the reference population by an increasing percentage as the alternative standards become lower, with a 0.7% improvement for 12/35-10/35 and a 3.9% improvement for 12/35-8/35 (Figure 6-5). Non-Hispanics experience slightly smaller proportional reductions, 0.5% for 12/35-10/35 and 3.5% for 12/35-8/35. Hispanics, linguistically isolated, HOLC Grade D, and HOLC Grades A-C populations are predicted to experience the relatively largest proportional reductions in $PM_{2.5}$ concentrations under all alternative standard levels evaluated, followed by Asians populations and those less educated. Black populations are predicted to experience smaller proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-10/35, 12/35-10/30, and 12/35-9/35, but greater proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-8/35. This is likely because disparities between the $PM_{2.5}$ concentrations experienced by Black and White populations in the baseline occur at lower ambient $PM_{2.5}$ concentrations (Figure 6-2 and Figure 6-4). This leads to proportionally greater improvements for Black populations (i.e., a narrowing of disparities as compared to White populations) at the lowest alternative $PM_{2.5}$ standards evaluated. This phenomenon is due to the standards needing to be reduced to the level at which the disparities are occuring (i.e., $PM_{2.5}$ concentrations below ~8.5 $\mu g/m^3$).

Certain populations (e.g., Native Americans and older adults) are estimated to experience proportionally smaller reductions in $PM_{2.5}$ concentrations under all alternative standard levels evaluated, but it should be noted that these populations are predicted to experience lower baseline $PM_{2.5}$ concentrations under air quality scenarios associated with control strategies (Figure 6-1 through Figure 6-10).

Population Groups	Populations (Ages)	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
Reference	All (0-99)	0.7	0.9	1.9	3.9
Race	White (0-99)	0.7	0.9	1.8	3.7
	American Indian (0-99)	0.8	1.0	1.7	3.7
	Asian (0-99)	1.3	1.5	3.1	5.7
	Black (0-99)	0.5	0.5	1.7	4.2
Ethnicity	Non-Hispanic (0-99)	0.5	0.6	1.5	3.5
	Hispanic (0-99)	1.5	1.7	2.8	5.1
Educational Attainment	More educated (25-99)	0.7	0.8	1.8	3.8
	Less educated (25-99)	1.2	1.3	2.4	4.5
Employment Status	Employed (0-99)	0.7	0.8	1.8	4.0
	Not in the labor force (0-99)	0.7	0.9	1.9	3.9
	Unemployed (0-99)	1.0	1.1	2.2	4.4
Insurance Status	Insured (0-64)	0.8	0.9	1.9	4.0
	Unisured (0-64)	0.8	0.9	1.9	4.3
Linguistic Isolation	English "well or better" (0-99)	0.7	0.8	1.8	3.8
	English < "well" (0-99)	1.8	1.9	3.2	5.6
Poverty Status	Above the poverty line (0-99)	0.7	0.8	1.8	3.9
	Below poverty line (0-99)	0.9	1.0	2.0	4.1
Redlined Areas	HOLC Grades A-C (0-99)	1.8	1.9	3.5	5.9
	HOLC Grade D (0-99)	1.7	1.8	3.4	6.2
	Ungraded by HOLC (0-99)	0.5	0.6	1.5	3.5
Age	Adults (18-64)	0.8	0.9	1.9	4.0
	Children (0-17)	0.7	0.9	1.9	4.0
	Older Adults (65-99)	0.7	0.8	1.7	3.6
Sex	Females (0-99)	0.7	0.9	1.9	3.9
	Males (0-99)	0.7	0.9	1.8	3.9

Figure 6-5 Heat Map of National Percent Reductions (%) in Average Annual $PM_{2.5}$ Concentrations for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032

6.3.2 Regional

Like the national analysis, we evaluate if there are potential EJ concerns 1) in the baseline, and 2) for the regulatory option(s) under consideration with respect to $PM_{2.5}$ exposures within each of the four regions used in this RIA. We also consider the extent to which exposures change for each demographic population and how disparities observed between demographic groups in the baseline scenario (12/35) are impacted (e.g., exacerbated/mitigated) under alternative standard levels within each region.

6.3.2.1 Absolute Exposures Under Current, Revised, and Alternative Standard Levels

As both emissions changes and the proportion of people/communities of color (POC/COC) vary with respect to location, we also parse the aggregated and distributional absolute $PM_{2.5}$ concentration by geographic region (northeast [NE], southeast [SE], west

[W], and California [CA]) (Figure 6-6 through Figure 6-10).[13,14] Beginning with total exposure burdens, average annual reference $PM_{2.5}$ concentrations are highest in CA across all current, revised, and alternative standard levels, followed by the SE, then and NE, and are lowest in the W (Figure 6-6 and Figure 6-7). Comparing populations of potential EJ concern with their respective references within each region, disparities are observed in all four regions, although not all for the same demographic populations.

Regarding racial and ethnic disparities, annual $PM_{2.5}$ concentrations for Black populations are higher in all four regions than either the overall reference population or the White population (Figure 6-6, Figure 6-7, and Figure 6-8). These increases are most visible in the distributional figures for the NE, W, and CA (Figure 6-7). $PM_{2.5}$ concentrations among Hispanics are higher than concentrations for Non-Hispanic populations in all four regions, with disparities being largest at higher $PM_{2.5}$ concentrations in the SE under controls associated with the current standards (Figure 6-6 and Figure 6-7). Total $PM_{2.5}$ concentrations for Asian populations are higher than White population concentrations in all four regions.

People living below the poverty level, less educated, unemployed, children, and those living in areas previously designated as redlined areas are predicted to experience higher annual $PM_{2.5}$ concentrations than the overall reference population to varying degrees within certain regions. Older adults (65-99) and those living in urban areas that were not graded by HOLC are predicted to experience lower $PM_{2.5}$ concentrations than the overall reference population in all regions.

[13] The regions defined here and used throughout this chapter are consistent with the areas used to present the costs and benefits in this RIA.
[14] Some potential EJ population groups and scenarios were excluded from the distributional figures for visual clarity.

Population Group	Population (Ages)	12/35				10/35				10/30				9/35				8/35			
		NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6
Race	White (0-99)	6.6	7.1	6.7	9.2	6.6	7.0	6.7	8.9	6.6	7.0	6.7	8.8	6.5	7.0	6.7	8.7	6.4	6.8	6.5	8.6
	American Indian (0-99)	6.6	7.1	5.5	9.1	6.5	7.1	5.5	8.8	6.5	7.1	5.5	8.7	6.5	7.1	5.5	8.6	6.4	6.9	5.4	8.5
	Asian (0-99)	7.1	7.5	7.0	9.4	7.1	7.5	7.0	9.1	7.1	7.5	7.0	9.0	7.0	7.4	7.0	8.8	6.8	7.1	6.8	8.6
	Black (0-99)	7.3	7.2	7.1	9.7	7.2	7.2	7.1	9.3	7.2	7.2	7.1	9.2	7.1	7.1	7.0	9.1	6.9	6.9	6.7	9.0
Ethnicity	Non-Hispanic (0-99)	6.7	6.9	6.6	9.1	6.6	6.9	6.6	8.7	6.6	6.9	6.6	8.7	6.6	6.9	6.6	8.5	6.4	6.7	6.4	8.4
	Hispanic (0-99)	7.1	7.7	7.0	9.6	7.1	7.6	7.0	9.1	7.1	7.6	7.0	9.1	7.0	7.5	7.0	9.0	6.8	7.3	6.7	8.9
Educational Attainment	Less educated (25-99)	6.8	7.2	6.9	9.6	6.8	7.2	6.9	9.1	6.8	7.2	6.9	9.1	6.7	7.1	6.8	9.0	6.6	7.0	6.6	8.9
	More educated (25-99)	6.7	7.0	6.7	9.2	6.7	7.0	6.7	8.9	6.7	7.0	6.7	8.8	6.6	7.0	6.6	8.7	6.5	6.8	6.5	8.5
Employment Status	Employed (0-99)	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.6
	Unemployed (0-99)	6.8	7.2	6.8	9.4	6.8	7.2	6.8	9.0	6.8	7.2	6.8	9.0	6.7	7.1	6.7	8.9	6.5	6.9	6.5	8.8
	Not in the labor force (0-99)	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.8	6.5	8.6
Insurance Status	Insured (0-64)	6.7	7.1	6.8	9.3	6.7	7.1	6.8	9.0	6.7	7.1	6.8	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.6
	Unisured (0-64)	6.9	7.3	6.7	9.4	6.8	7.3	6.7	9.0	6.8	7.3	6.7	8.9	6.7	7.2	6.6	8.8	6.6	7.0	6.4	8.7
Linguistic Isolation	English "well or better" (0-99)	6.7	7.1	6.7	9.2	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.8	6.6	7.0	6.7	8.7	6.5	6.8	6.5	8.6
	English < "well" (0-99)	7.2	7.8	7.3	9.8	7.2	7.8	7.3	9.3	7.2	7.8	7.3	9.2	7.1	7.7	7.2	9.1	7.0	7.4	6.9	9.0
Poverty Status	Above 200% of the poverty line (0-99)	6.7	7.1	6.7	9.2	6.7	7.0	6.7	8.9	6.7	7.0	6.7	8.8	6.6	7.0	6.6	8.7	6.5	6.8	6.5	8.5
	Below 200% of the poverty line (0-9..	6.8	7.2	6.8	9.5	6.8	7.2	6.8	9.0	6.8	7.2	6.8	9.0	6.7	7.1	6.8	8.9	6.6	6.9	6.6	8.8
Redlined Areas	HOLC Grades A-C (0-99)	7.4	7.9	7.5	10.5	7.4	7.9	7.5	9.6	7.4	7.9	7.5	9.6	7.2	7.8	7.5	9.5	7.0	7.6	7.4	9.4
	HOLC Grade D (0-99)	7.7	8.0	7.7	10.4	7.7	8.0	7.7	9.7	7.7	8.0	7.7	9.7	7.5	7.9	7.7	9.5	7.2	7.7	7.6	9.4
	Ungraded by HOLC (0-99)	6.5	7.0	6.7	9.0	6.4	7.0	6.7	8.7	6.4	7.0	6.6	8.7	6.4	7.0	6.6	8.6	6.3	6.8	6.4	8.4
Age	Adults (18-64)	6.8	7.1	6.8	9.3	6.7	7.1	6.8	9.0	6.7	7.1	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.7
	Children (0-17)	6.7	7.2	6.8	9.3	6.7	7.2	6.8	9.0	6.7	7.2	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.7
	Older Adults (65-99)	6.6	6.9	6.6	9.2	6.6	6.9	6.6	8.8	6.6	6.9	6.5	8.8	6.5	6.9	6.5	8.6	6.4	6.7	6.3	8.5
Sex	Females (0-99)	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6
	Males (0-99)	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6

Figure 6-6 Heat Map of Regional Average Annual $PM_{2.5}$ Concentrations (µg/m³) by Demographic for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032

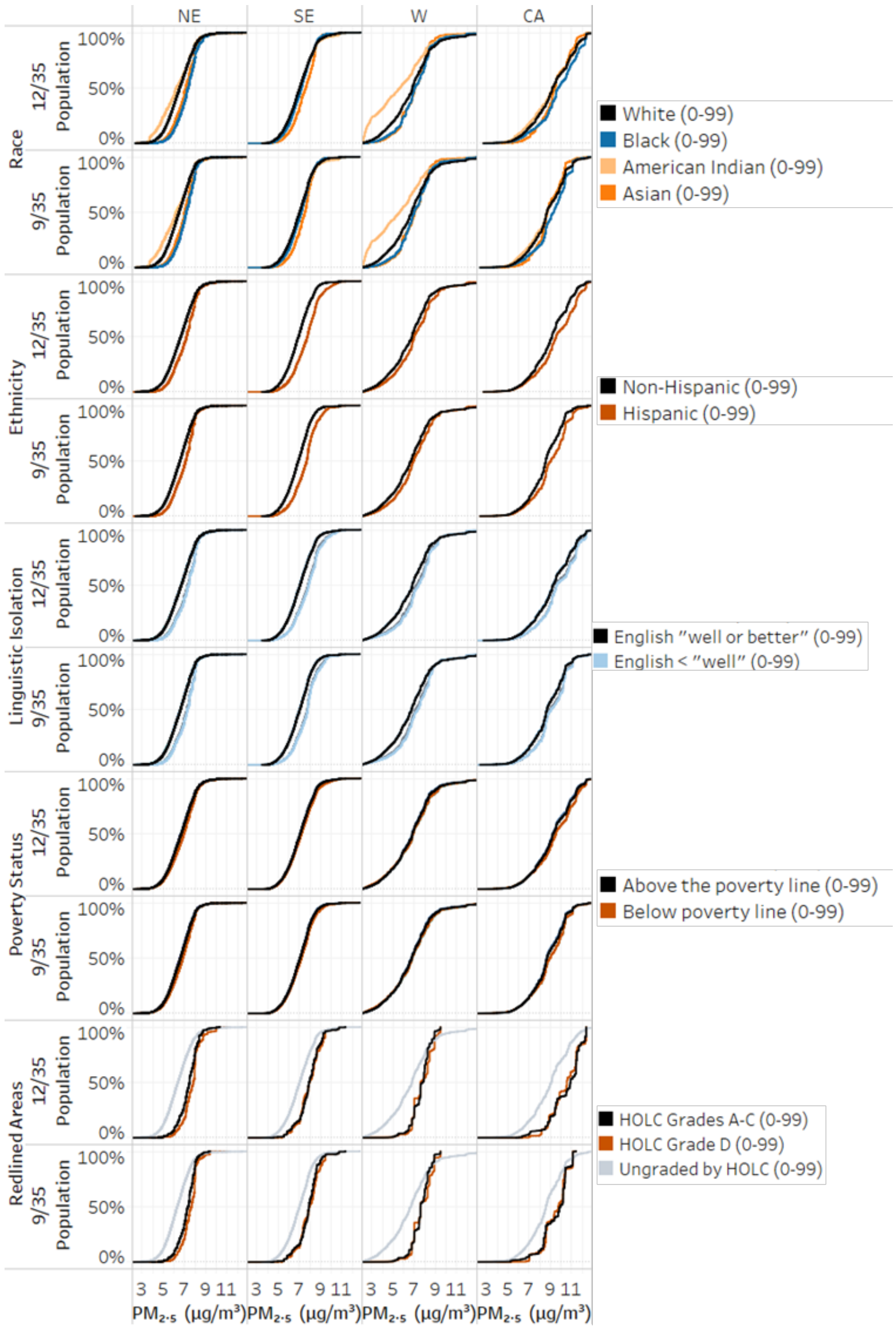

Figure 6-7 Regional Distributions of Annual $PM_{2.5}$ Concentration Reductions for Demographic Groups for Current PM NAAQS Levels and the Revised 9/35 Standard Scenario After Application of Controls in 2032

The highest burden $PM_{2.5}$ concentrations are again enlarged in Figure 6-8, for each region under control strategies associated with 12/35 and 9/35, making it clearer which potential populations of EJ concern are being impacted by lowering the $PM_{2.5}$ standard levels.

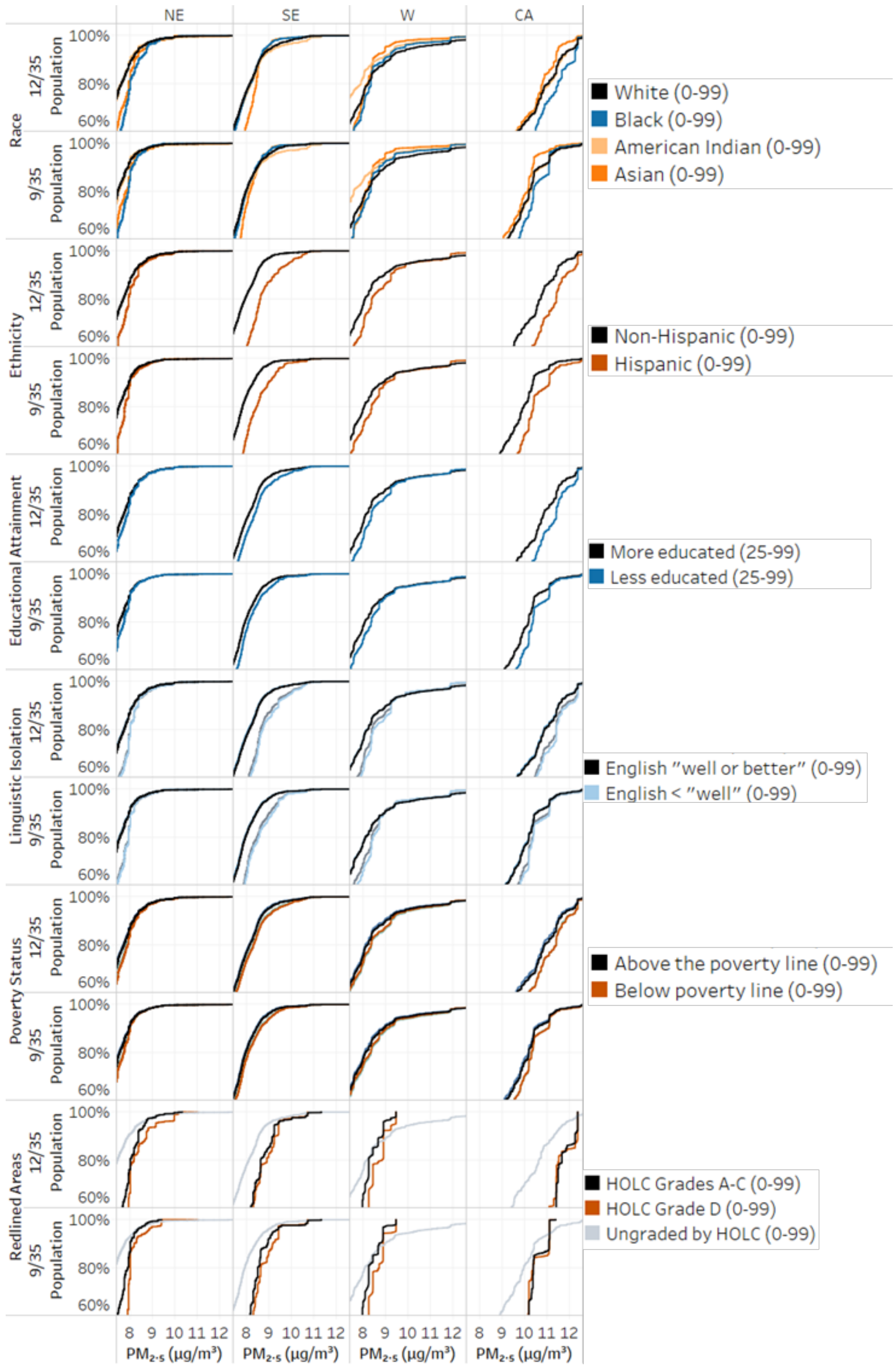

Figure 6-8 Regional Distributions of High Annual $PM_{2.5}$ Concentration Reductions for Demographic Groups for Current PM NAAQS Levels and the 9/35 Revised Standard Scenario After Application of Controls in 2032 (Revised Scale)

6.3.2.2 Absolute Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Next, we consider how average exposures change across different demographic groups at the regional level. Information on average and distributional exposure changes by region when moving from control strategies associated with the current standards to control strategies associated with alternative standard levels are available in Figure 6-9 and Figure 6-10, respectively.[15] Similar to the average annual $PM_{2.5}$ concentrations going from highest in CA, followed by the SE and NE, and being lowest in the W (Section 6.3.1.2), average $PM_{2.5}$ concentration reductions also follow the same order. Comparing how these reductions affect populations of potential EJ concern within each region, we note that there are differences across regions in terms of which demographic populations benefit the most (or least), particularly for 12/35-9/35 or 12/35-8/35.

Going through each region, the largest regional $PM_{2.5}$ concentration reductions occur in CA, where populations of HOLC Grade D, HOLC Grades A-C, Blacks, Hispanics, those below the poverty line, unemployed, uninsured, and those less educated are expected to experience greater $PM_{2.5}$ concentration reductions when moving from the baseline to alternative standard levels. In the SE, there are greater $PM_{2.5}$ concentration reductions for Asians, Hispanics, and those less educated under all alternative standard levels. Asian and Black populations in CA experience greater $PM_{2.5}$ concentration reductions when moving from 12/35-8/35. In the NE for 12/35-9/35 and 12/35-8/35, there are greater $PM_{2.5}$ concentration reductions for Blacks, and slightly greater $PM_{2.5}$ concentration reductions for Asians. This is similar to the W, where Blacks, Hispanics, and those less educated are predicted to see greater $PM_{2.5}$ concentration reductions for 12/35-9/35 and 12/35-8/35.

[15] Distributions for the reference, male, and female populations were excluded from Figure 6-8 as they closely reflect overall distributions.

Population Group	Population (Ages)	12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
		NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
Race	White (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.6
	American Indian (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.5	0.2	0.2	0.2	0.6
	Asian (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.0	0.6	0.3	0.4	0.3	0.8
	Black (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.2	0.0	0.1	0.6	0.3	0.2	0.3	0.7
Ethnicity	Non-Hispanic (0-99)	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.5	0.2	0.2	0.2	0.7
	Hispanic (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.4	0.3	0.7
Educational Attainment	More educated (25-99)	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.0	0.1	0.5	0.2	0.2	0.2	0.7
	Less educated (25-99)	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.3	0.3	0.7
Employment Status	Employed (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	Unemployed (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.3	0.3	0.7
	Not in the labor force (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
Insurance Status	Insured (0-64)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	Unisured (0-64)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.3	0.3	0.7
Linguistic Isolation	English "well or better" (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	English < "well" (0-99)	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.4	0.4	0.7
Poverty Status	Above the poverty line (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	Below poverty line (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.2	0.3	0.7
Redlined Areas	HOLC Grades A-C (0-99)	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.2	0.1	0.0	1.0	0.4	0.4	0.1	1.1
	HOLC Grade D (0-99)	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.2	0.0	0.0	0.9	0.4	0.3	0.1	1.1
	Ungraded by HOLC (0-99)	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.4	0.2	0.2	0.2	0.6
Age	Adults (18-64)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	Children (0-17)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.3	0.2	0.7
	Older Adults (65-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.0	0.1	0.5	0.2	0.2	0.2	0.7
Sex	Females (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
	Males (0-99)	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7

Figure 6-9 Heat Map of Regional Reductions in Average Annual $PM_{2.5}$ Concentrations ($\mu g/m^3$) for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032

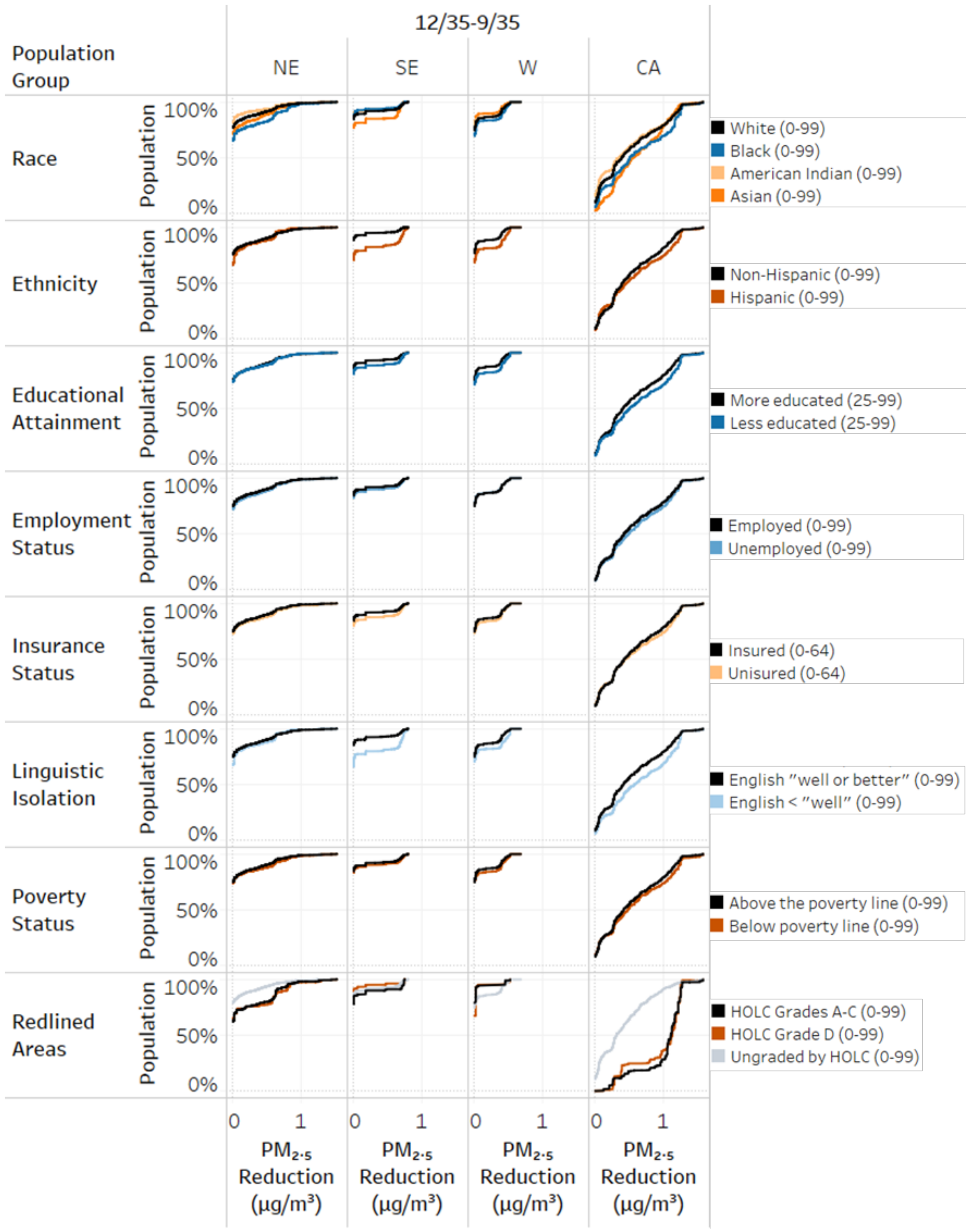

Figure 6-10 Regional Distributions of Annual $PM_{2.5}$ Concentration Reductions for Demographic Groups When Moving from Current PM NAAQS Levels to 9/35 After Application of Controls in 2032

6.3.2.3 Proportional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Regionally the greatest proportional reductions are estimated for CA when moving from the current standards to all alternative standard levels associated with the illustrative emission control strategies (Figure 6-11). Like the national analysis, percent reductions get larger as alternative standard levels decrease.

Population Groups	Populations (Ages)	12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
		NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.3	3.5	7.2
Race	White (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.4	0.8	0.8	5.5	3.0	3.2	3.4	6.9
	American Indian (0-99)	0.1	0.0	0.0	3.9	0.1	0.0	0.3	4.5	1.1	0.6	0.9	5.2	2.6	3.3	3.1	6.4
	Asian (0-99)	0.2	0.0	0.0	3.8	0.2	0.0	0.2	4.2	1.6	1.4	0.6	6.5	3.6	5.3	3.6	8.7
	Black (0-99)	0.2	0.0	0.0	4.5	0.2	0.0	0.2	5.1	2.2	0.6	1.0	6.3	4.6	3.3	4.9	7.6
Ethnicity	Non-Hispanic (0-99)	0.2	0.0	0.0	3.5	0.2	0.0	0.4	4.1	1.5	0.5	0.7	5.6	3.2	2.8	3.0	7.5
	Hispanic (0-99)	0.1	0.3	0.0	4.6	0.1	0.3	0.3	4.9	1.5	1.6	1.2	5.8	3.7	4.6	4.9	6.9
Educational Attainment	More educated (25-99)	0.2	0.1	0.0	3.8	0.2	0.1	0.4	4.3	1.5	0.7	0.8	5.6	3.2	3.1	3.3	7.3
	Less educated (25-99)	0.1	0.2	0.0	4.9	0.1	0.2	0.4	5.3	1.5	1.1	1.1	6.2	3.5	3.6	4.6	7.4
Employment Status	Employed (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.8	3.2	3.4	3.4	7.3
	Unemployed (0-99)	0.2	0.1	0.0	4.6	0.2	0.1	0.3	5.0	1.7	1.0	0.8	6.0	3.6	3.7	3.8	7.3
	Not in the labor force (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.6	3.3	3.2	3.5	7.1
Insurance Status	Insured (0-64)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.4	3.4	7.2
	Unisured (0-64)	0.2	0.2	0.0	4.6	0.2	0.2	0.4	5.1	1.7	1.2	1.0	5.9	3.7	4.0	4.1	7.1
Linguistic Isolation	English "well or better" (0-99)	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.5	0.8	0.8	5.6	3.2	3.2	3.4	7.2
	English < "well" (0-99)	0.1	0.3	0.0	5.1	0.1	0.3	0.2	5.4	1.5	1.8	1.1	6.5	3.8	5.1	5.1	7.6
Poverty Status	Above the poverty line (0-99)	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.5	0.8	0.8	5.6	3.2	3.3	3.4	7.2
	Below poverty line (0-99)	0.2	0.2	0.0	4.6	0.2	0.2	0.4	5.1	1.7	0.9	1.0	6.0	3.6	3.3	4.0	7.2
Redlined Areas	HOLC Grades A-C (0-99)	0.2	0.0	0.0	8.2	0.2	0.0	0.1	8.4	2.3	1.0	0.3	9.4	5.2	4.5	1.4	10.2
	HOLC Grade D (0-99)	0.2	0.0	0.0	7.3	0.2	0.0	0.2	7.4	2.4	0.5	0.3	9.0	5.8	3.4	1.8	10.2
	Ungraded by HOLC (0-99)	0.2	0.1	0.0	2.8	0.2	0.1	0.4	3.4	1.2	0.8	0.9	4.6	2.4	3.2	3.6	6.3
Age	Adults (18-64)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.8	3.3	3.4	3.5	7.3
	Children (0-17)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.9	0.8	5.6	3.3	3.5	3.4	7.1
	Older Adults (65-99)	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.4	0.6	0.8	5.6	3.1	2.7	3.3	7.2
Sex	Females (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.3	3.5	7.2
	Males (0-99)	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.2	3.3	3.5	7.2

Figure 6-11 Heat Map of Regional Percent Reductions (%) in Average Annual $PM_{2.5}$ Concentrations for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032

6.4 EJ Analysis of Health Effects under Current, Revised, and Alternative Standard Levels

In addition to comparing $PM_{2.5}$ concentrations for potential demographic populations of concern in the EJ exposure analysis (Section 6.3.1), we conducted an EJ analysis of health effects. This analysis aims to evaluate the potential for EJ concerns related to $PM_{2.5}$ health outcomes among populations potentially at increased risk of or to higher $PM_{2.5}$ exposures from three perspectives, which correspond to the three EJ questions listed in Section 6.1. Specifically, the following questions are addressed:

1) Are there disparate $PM_{2.5}$ health effects (e.g., mortality) under baseline/current PM NAAQS standard levels (question 1)?
2) Are there disparate $PM_{2.5}$ health effects under illustrative alternative PM NAAQS standard levels (question 2)?
3) Are disparities in $PM_{2.5}$ health effects created, exacerbated, or mitigated under illustrative alternative PM NAAQS standard levels as compared to the baseline (question 3)?

There is considerable scientific evidence that specific populations and lifestages are at increased risk of $PM_{2.5}$-related health effects (Section 1.5.5 and Chapter 12 of U.S. EPA, 2019). Factors that may contribute to increased risk of $PM_{2.5}$-related health effects include lifestage (e.g., children), pre-existing diseases (e.g., cardiovascular disease and respiratory disease), race/ethnicity, and socioeconomic status.[16] Of these factors, the ISA found "adequate evidence" indicating that children and some races are at increased risk of $PM_{2.5}$-related health effects, in part due to disparities in exposure. However, we lack associated epidemiologic information that would enable us to conduct a health effects analysis for children.

Due to the limited availability of both new scientific evidence in this NAAQS review and input information (U.S. EPA, 2019, 2022a), the one health endpoint for which we evaluate EJ implications is premature mortality. The PM ISA and PM ISA Supplement provided evidence that there are consistent racial and ethnic disparities in $PM_{2.5}$ exposure across the U.S., particularly for Black/African Americans, as compared to non-Hispanic White populations. Additionally, some studies provided evidence of increased $PM_{2.5}$-related mortality and other health effects from long-term exposure to $PM_{2.5}$ among Black

[16] As described in the 2019 ISA, other factors that have the potential to contribute to increased risk include obesity, diabetes, genetic factors, smoking status, sex, diet, and residential location (U.S. EPA, 2019, chapter 12).

populations. Taken together, the 2019 PM ISA concluded that the evidence was adequate to conclude that race and ethnicity modify $PM_{2.5}$-related risk, and that non-White individuals, particularly Black individuals, are at increased risk for $PM_{2.5}$-related health effects, in part due to disparities in exposure (U.S. EPA, 2019, 2022a).

As such, this EJ health analysis assesses long-term $PM_{2.5}$-attributable mortality rates stratified by racial and ethnic demographic populations.[17] Mortality is presented as a rate per 100,000 (100k) individuals to permit direct comparisons between population demographics with different total population counts.[18] Additional information on the concentration-response functions and baseline incidence rates used as input information in this health EJ analysis can be found in Section 6.6.2 and Appendix C of the draft PM Policy Assessment (U.S. EPA, 2021).

In the proposal RIA for this rulemaking, a single epidemiological study (i.e., Di et al., 2017) providing race/ethnicity-stratified exposure-mortality relationships was identified as best characterizing risk across the U.S. While this was the largest study of race/ethnicity-stratified exposure-mortality relationships to date, the Pope III et al., 2019 study of the National Health Interview Survey (NHIS) cohort also provided national, high-quality race/ethnicity-stratified exposure-mortality relationships. However, at the time of the PM NAAQS proposal RIA development, BenMAP-CE was unable to appropriately include the combined race and ethnicity populations used by Pope III et al., 2019. When preparing for this final RIA EJ assessment, we were able to update the input parameters necessary to also include concentration-response relationships from Pope III et al., 2019. This allows for two independent estimates of race/ethnicity-stratified mortality impacts of different age ranges, similar to the approach currently used for assessing benefits (Chapter 5).

[17] As the ISA and ISA Supplement found that mortality studies evaluated continued to support a linear, no-threshold concentration-response relationship, mortality rates are calculated here using exposure estimates across all $PM_{2.5}$ concentrations (U.S. EPA, 2019, 2022a). However, uncertainties remain regarding the shape of mortality concentration-response functions, particularly at low concentrations. Additional uncertainties are related to this analysis, as a single epidemiologic study was used to relate exposure to mortality health effects that applies only to older adults aged 65 and over (Di et al., 2017).

[18] Current Agency VSL practices do not differentiate based on race or ethnicity, so the health analysis did not include monetization. Separately, although the valuation of morbidity outcomes may differ by race or ethnicity (e.g., someone without insurance may delay seeing seen by a medical professional until the situation requires more expensive treatment), available scientific evidence for race/ethnicity-stratified valuation estimates is lacking.

Additional study information, including the specific hazard ratios (HRs), beta coefficients, and standard errors are available in appendix Table 6-2.

National and regional absolute mortality rates (per 100k individuals) under air quality scenarios associated with control strategies for the current standards and revised and alternative lower standard levels and changes in mortality rates when moving from air quality scenarios associated with control strategies for the current standards to potential alternative lower standard levels across the demographic-specific mortality rates are provided in Sections 6.4.1 and 6.4.1.2, respectively.

Similar to what was done for the exposure analysis above, we address the guiding EJ questions with respect to $PM_{2.5}$-attributable mortality impacts first across the contiguous U.S. in Section 6.4.1, and then at the regional level in Section 6.4.2.

6.4.1 National

National absolute $PM_{2.5}$-attributable mortality impacts are provided in Section 6.4.1.1 and national proportional $PM_{2.5}$-attributable mortality impacts are provided in Section 6.4.1.2.

6.4.1.1 Absolute Mortality Rates Under Current, Revised, and Alternative Standard Levels and Mortality Rate Changes When Moving from Current to Revised and Alternative Standard Levels

Figure 6-12 and Figure 6-13 show the national averages and distributions of estimated mortality rates per 100k individuals for each race/ethnicity evaluated. It is important to note that Di et al., 2017 and Pope III et al., 2019 evaluate different age ranges. Di et al., 2017 evaluated Medicare enrollees aged 65-99 and Pope III et al., 2019 evaluated ages 18-99. In this assessment, hazard ratios (HRs) derived from each study-specific age range were applied to populations of the same ages in this assessment, across the contiguous U.S. in 2032.

Mortality rate estimates are calculated using additional inputs as compared to exposure estimates, specifically HRs and baseline incidence. In general, while the greater magnitude HR for the Black population of older adults found by Di et al., 2017 resulted in higher estimated mortality rates in Black than White populations, the greater magnitude HR for the Black population of all adults from Pope III et al., 2019 did not lead to higher estimated mortality rates in Black than White populations, due to a lower ratio of baseline deaths (Figure 6-12). However, HRs from the Pope III et al., 2019 study did lead to higher estimated mortality rates in both Black and White populations, as compared to the overall reference population.

Study (Ages)	Population Group	Number of People	Baseline Mortality	Ratio of Baseline Mortality	HR (Beta)	12/35	10/35	12/35-10/35	10/30	12/35-10/30	9/35	12/35-9/35	8/35	12/35-8/35
Di 2017 (65-99)	Reference	75M	2,926K	3.9	0.0070	186	185	1	185	1	183	3	180	7
	White	62M	2,479K	4.0	0.0061	163	162	1	162	1	161	2	158	5
	American Indian	1M	14K	2.6	0.0095	151	150	1	150	2	149	2	147	5
	Asian	4M	76K	2.0	0.0092	145	142	4	142	4	139	7	136	10
	Black	8M	298K	3.6	0.0189	464	462	3	462	3	456	9	445	22
	Hispanic	9M	216K	2.4	0.0110	206	203	4	203	4	201	6	197	10
Pope 2019 (18-99)	Reference	287M	3,414K	1.2	0.0113	90	90	1	90	1	89	2	87	3
	NH White	167M	2,577K	1.5	0.0104	104	104	0	104	1	103	1	101	3
	NH American Indian	2M	17K	0.8	0.0095	45	45	0	45	0	45	0	44	1
	NH Asian	21M	96K	0.5	0.0095	34	34	1	34	1	33	1	32	2
	NH Black	37M	397K	1.1	0.0140	103	103	1	103	1	102	2	99	5
	Hispanic	59M	298K	0.5	0.0182	69	67	1	67	1	67	2	65	4

Figure 6-12 Heat Map of National Average Annual Total Mortality Rates and Rate Reductions (per 100K) for Demographic Groups for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

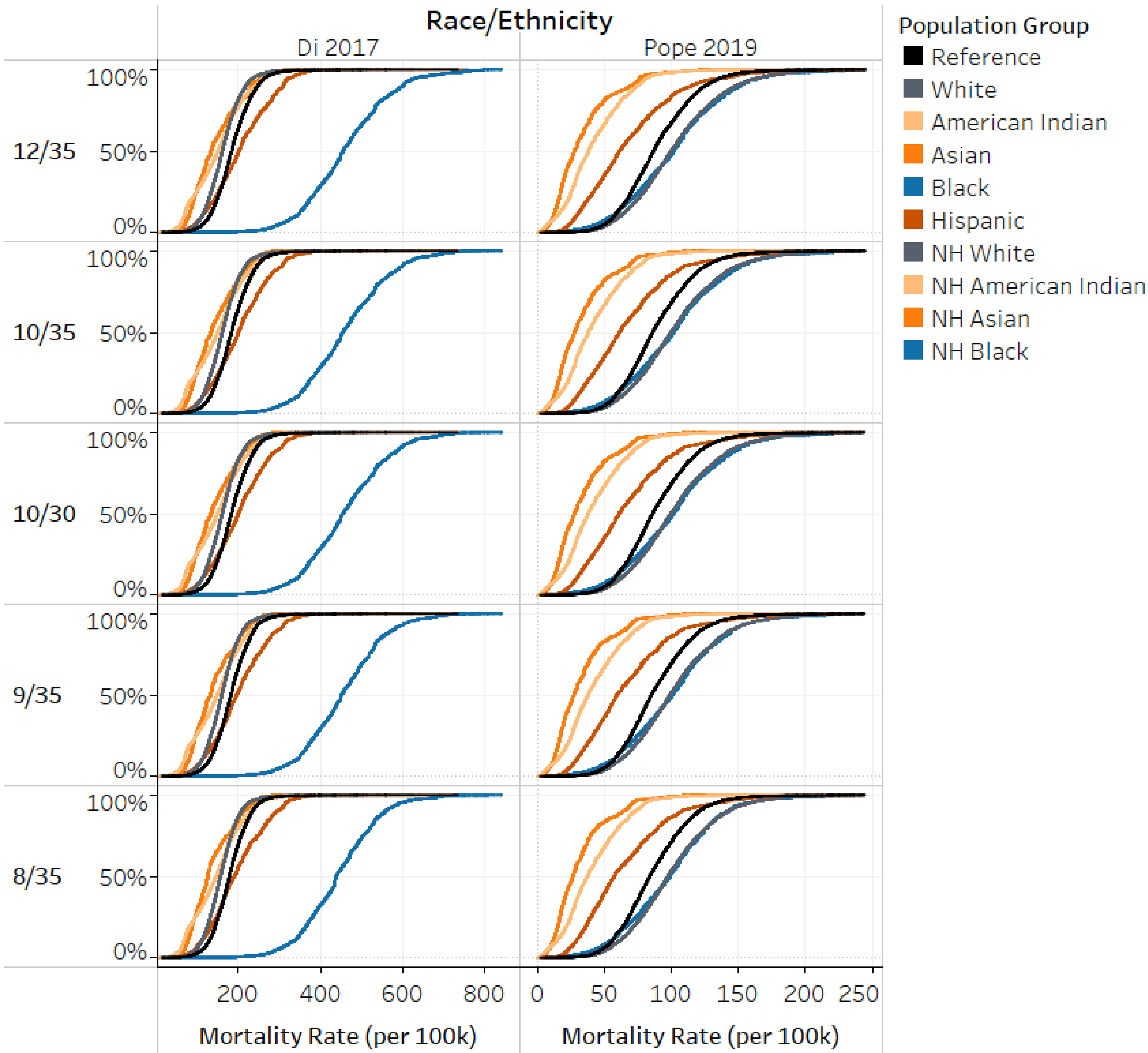

Figure 6-13 National Distributions of Total Annual Mortality Rates (per 100k) for Demographic Groups for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

While mortality rate reductions are small when averaged across the contiguous U.S., due to the inclusion of areas with no air quality improvements (Figure 6-12), reductions can be substantial in individual tracts (Figure 6-14). Nationally, the rate of $PM_{2.5}$-attributable mortality is estimated to decrease for most races and ethnicities when moving from current standards to alternative standard levels, and more so under lower alternative standard levels (Figure 6-14). In addition, reductions in mortality rates are often larger for other races as compared to White or non-Hispanic White populations.

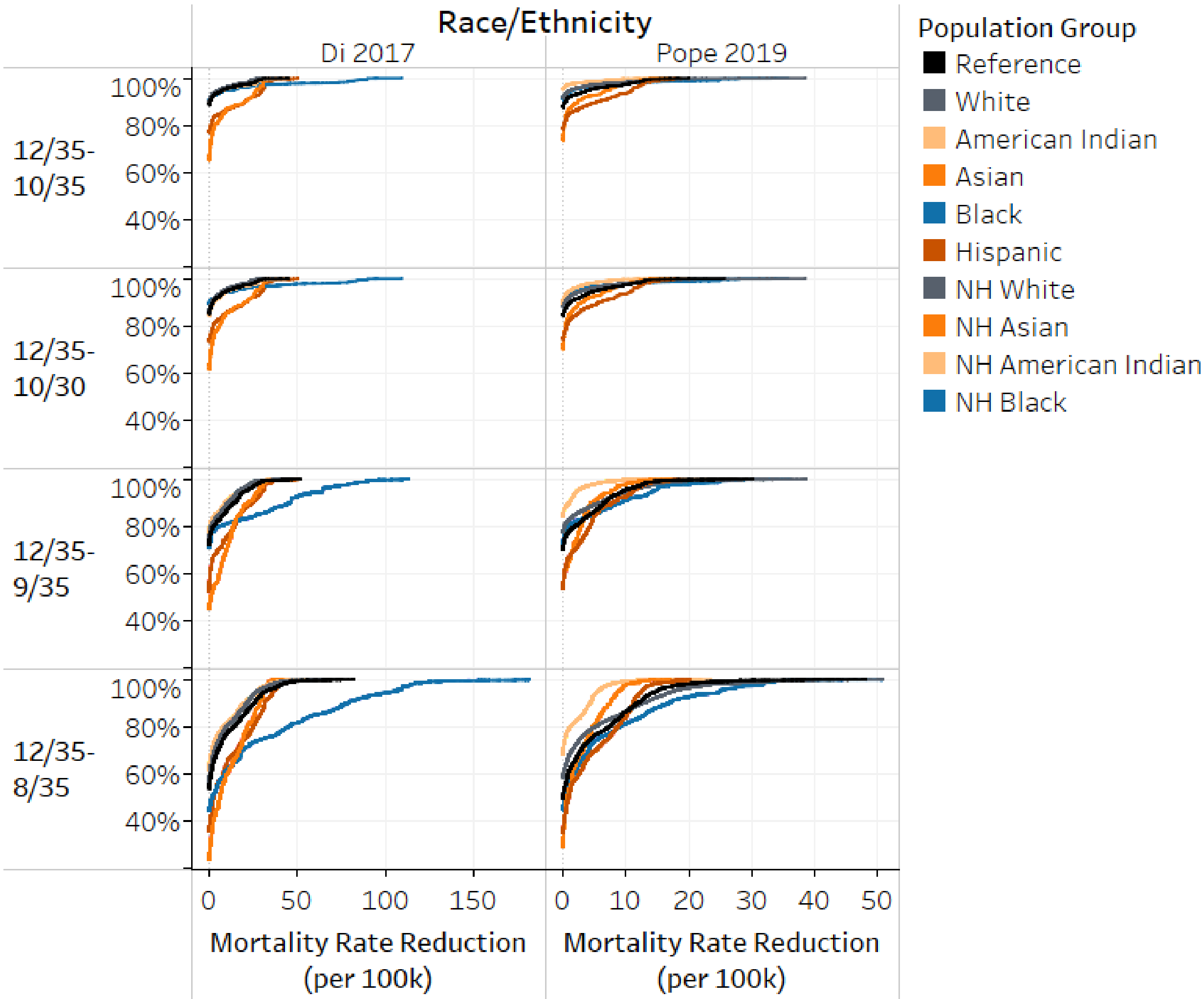

Figure 6-14 National Distributions of Annual Mortality Rate Reductions for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

6.4.1.2 Proportional Mortality Rate Changes When Moving from Current to Revised and Alternative Standard Levels

To put the changes in exposure discussed in Section 6.3.1.1 in perspective, especially in light of disparities in the exposure baseline across population groups, it helps to consider whether the absolute changes represent equivalent (i.e., proportional) reductions in exposure. In some cases, moving to more stringent control strategies could both reduce total average exposures and reduce disparities in exposure across groups. However, it can be difficult to determine the relative proportionality of changes in $PM_{2.5}$ concentrations for demographic populations using just the absolute exposure changes when moving from the current standards to a potential alternative standard level, like those shown in Section 6.3.1.1.

In this section, the proportionality of $PM_{2.5}$ concentration changes when moving from the current standard (i.e., baseline) to alternative lower standard levels under air quality scenarios associated with the illustrative emissions control strategies is directly calculated, using a similar approach to calculating the proportionality of exposures in Sections 6.3.1.2 and 6.3.2.3. As average $PM_{2.5}$ concentrations have generally been representative of the distributions, for simplicity we only present the average national proportional reduction for each population and scenario.

Results from both studies estimate Hispanics and Asian populations experience proportionally larger reductions in mortality rates when moving from the current standards to all lower alternative standard levels associated with control strategies, thereby mitigating disparities (Figure 6-15). However, national mortality rate disparities in Black/non-Hispanic Black populations are only mitigated when moving from the current standards to alternative standard levels of 9/35 or 8/35.

Study	Race/Ethnicity	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
Di 2017 (65-99)	Reference	0.6	0.8	1.7	3.6
	White	0.6	0.7	1.5	3.3
	American Indian	0.8	1.0	1.5	3.2
	Asian	2.6	2.9	4.7	7.1
	Black	0.6	0.6	2.0	4.7
	Hispanic	1.8	2.0	3.0	5.0
Pope 2019 (18-99)	Reference	0.7	0.8	1.7	3.7
	NH White	0.4	0.5	1.3	3.1
	NH American Indian	0.4	0.6	0.9	2.3
	NH Asian	2.4	2.7	4.4	6.9
	NH Black	0.6	0.6	2.0	4.7
	Hispanic	1.9	2.0	3.1	5.3

Figure 6-15 Heat Map of National Average Percent Mortality Rate Reductions (per 100k People) for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

6.4.2 Regional

Regional absolute $PM_{2.5}$-attributable mortality impacts are provided in Sections 6.4.2.1 and 6.4.2.2, whereas regional proportional $PM_{2.5}$-attributable mortality impacts are provided in Section 6.4.2.3.

6.4.2.1 Absolute Mortality Rates Under Current, Revised, and Alternative Standard Levels

Regionally, the highest mortality rates for reference populations are in CA under air quality scenarios associated with control strategies for both current standards and alternative PM standard levels, followed by the NE, SE, and then the W (Figure 6-16 and Figure 6-17). Total mortality rates in the reference populations decrease slightly under alternative standard levels in all regions, and by the greatest absolute number in CA. Within each of the four regions, average and distributional mortality rates are highest among Black populations, although there are differences in the ordinality of other races and ethnicities across regions. Interestingly, the distribution of Hispanic mortality rates in the SE suggests there may be a subset of locations in which Hispanics have higher baseline incidence rates, as the $PM_{2.5}$ concentration differentials between Hispanic and non-Hispanic populations remained fairly constant across $PM_{2.5}$ concentration distributions (Figure 6-7).

		12/35				10/35				10/30				9/35				8/35			
		NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di	Reference	184	183	172	220	184	183	172	212	184	183	172	210	181	182	171	208	178	179	167	205
2017	White	160	161	153	198	160	161	153	191	160	161	152	190	158	160	152	188	156	157	148	185
	American Indian	130	161	133	202	129	161	133	195	129	161	133	193	128	160	133	192	126	157	131	190
	Asian	106	103	128	199	106	103	128	191	106	103	127	190	105	101	127	186	102	97	124	183
	Black	467	447	417	596	466	447	417	569	466	447	416	567	456	445	413	559	444	435	396	552
	Hispanic	157	211	181	249	157	210	181	238	157	210	181	237	155	208	179	235	151	204	174	233
Pope	Reference	91	89	82	97	91	89	82	94	91	89	82	93	90	89	82	92	88	87	80	91
2019	NH White	100	106	97	138	100	106	97	134	100	106	97	133	99	105	97	132	97	104	95	130
	NH Asian	22	21	31	60	22	21	31	57	22	21	31	57	22	21	31	56	21	20	30	55
	NH Black	103	99	78	155	103	99	78	148	103	99	78	147	101	98	77	145	98	96	74	144
	NH American Indian	35	47	38	60	35	47	38	58	35	47	38	57	35	47	38	57	35	46	38	57
	Hispanic	49	73	58	86	49	73	58	82	49	73	57	82	48	72	57	81	47	71	55	80

Figure 6-16 Heat Map of Regional Average Annual Total Mortality Rates (per 100K) for Demographic Groups for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

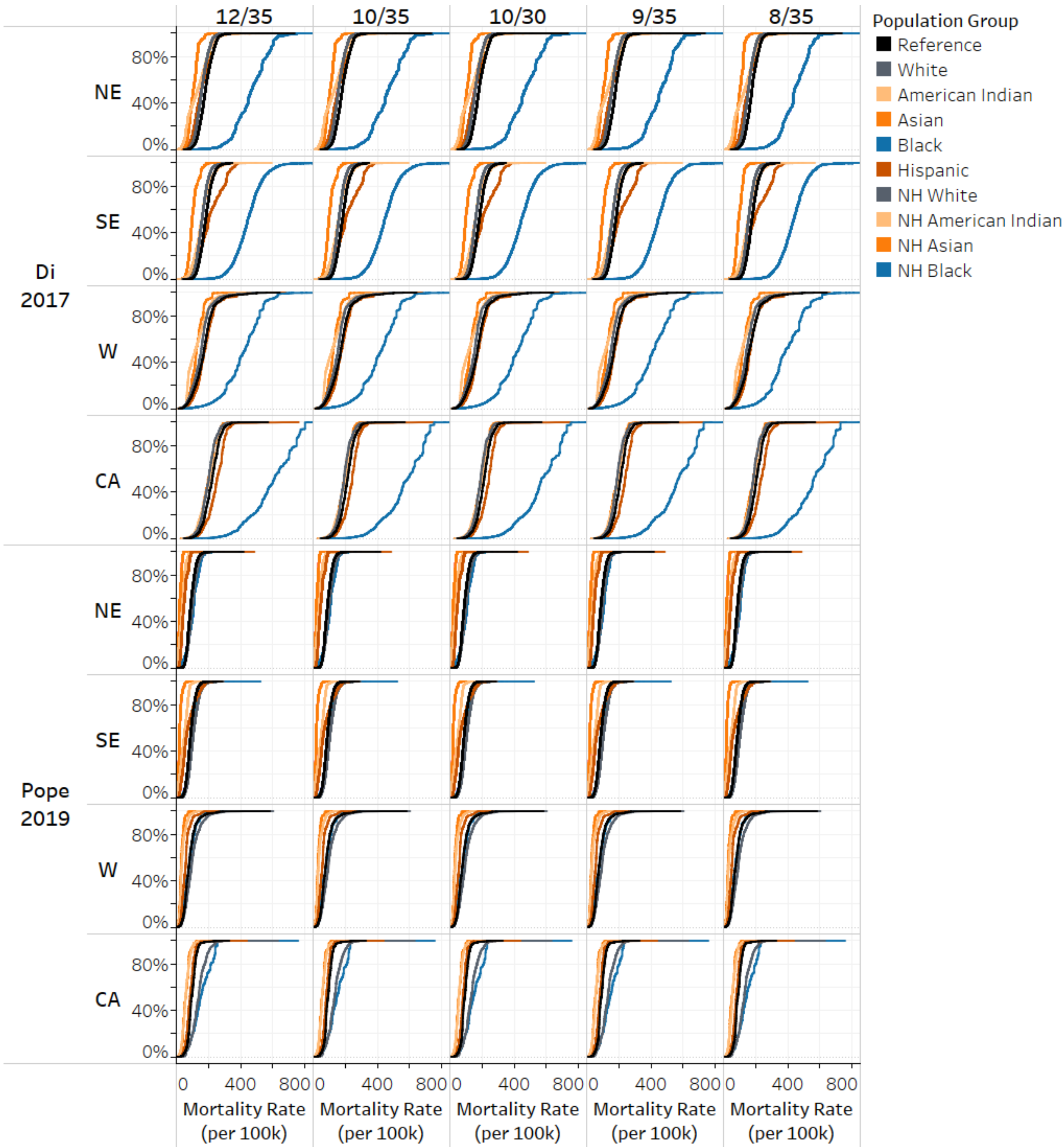

Figure 6-17 Regional Distributions of Total Annual Mortality Rates (per 100k) for Demographic Groups for Current, Revised, and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

6.4.2.2 Absolute Mortality Rate Changes When Moving from Current to Revised and Alternative Standard Levels

Of the four regions, the largest absolute mortality rate reductions for each population are estimated in CA when moving from the current to alternative standard levels (Figure 6-18 and Figure 6-19). Reductions are smaller in the other three regions, although reductions become more substantial for 12/35-9/35 or 12/35-8/35, especially in the NE. When comparing across race and ethnicities, Black and non-Hispanic Black populations are predicted to see the largest mortality rate reductions when moving to lower standard levels.

		12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
		NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di 2017	Reference	0.4	0.1	0.0	8.7	0.4	0.1	0.7	10.0	2.9	1.0	1.3	12.4	6.0	4.8	5.6	16.0
	White	0.3	0.1	0.0	7.3	0.3	0.1	0.7	8.6	2.3	0.8	1.1	10.4	4.8	3.9	4.9	13.5
	American Indian	0.2	0.0	0.0	8.2	0.2	0.0	0.4	9.6	1.6	0.6	0.7	10.7	3.6	3.9	2.7	13.0
	Asian	0.1	0.0	0.0	9.5	0.1	0.0	0.2	10.3	2.0	2.3	0.6	14.3	4.5	6.9	4.2	18.1
	Black	1.3	0.0	0.0	31.7	1.3	0.0	0.6	35.0	12.7	2.4	3.9	43.7	26.7	13.6	24.0	51.9
	Hispanic	0.1	0.9	0.0	12.7	0.1	0.9	0.4	13.6	2.3	3.1	1.9	15.5	6.3	7.9	8.3	18.3
Pope 2019	Reference	0.2	0.0	0.0	4.0	0.2	0.0	0.3	4.5	1.5	0.5	0.6	5.7	3.1	2.4	2.8	7.2
	NH White	0.2	0.0	0.0	4.5	0.2	0.0	0.4	5.5	1.4	0.4	0.7	6.9	3.0	2.4	3.0	9.4
	NH Asian	0.0	0.0	0.0	2.8	0.0	0.0	0.1	3.0	0.4	0.4	0.2	4.2	0.9	1.4	1.0	5.4
	NH Black	0.3	0.0	0.0	8.1	0.3	0.0	0.1	9.0	2.8	0.5	0.8	11.3	5.9	3.0	4.6	13.3
	NH American Indian	0.0	0.0	0.0	1.9	0.0	0.0	0.1	2.5	0.3	0.1	0.2	2.6	0.7	1.0	0.6	3.2
	Hispanic	0.0	0.3	0.0	4.5	0.0	0.3	0.2	4.8	0.8	1.2	0.7	5.5	2.0	3.0	2.8	6.5

Figure 6-18 Heat Map of Regional Average Annual Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

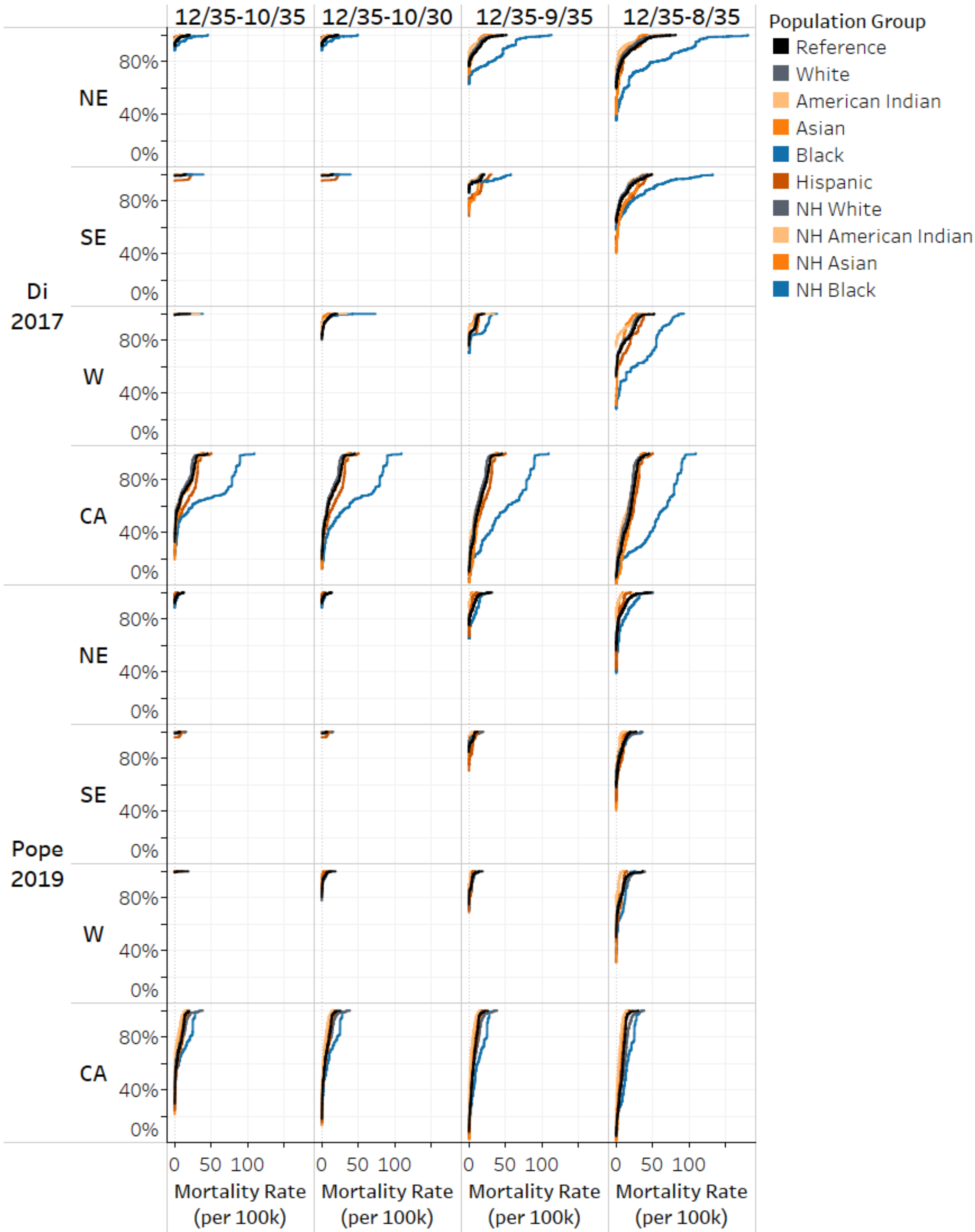

Figure 6-19 Regional Distributions of Annual Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

6.4.2.3 Proportional Mortality Rate Changes When Moving from Current to Revised and Alternative Standard Levels

Proportionally, CA is also predicted to have the largest mortality rate reductions for each population when moving from current to all lower alternative standard levels evaluated. Reductions are proportionally larger for both Black and non-Hispanic Black populations in CA and the NE under all lower standards in which baseline mortality rate disparities were observed in Section 6.4.2.1. Further, we see a mitigation of mortality rate disparities in Hispanic populations aged 65-99 in the SE and CA, where baseline disparities were present in Figure 6-16.

When moving from 12/35-9/35 and 12/35-8/35, the proportional mitigation of disparities in Black and non-Hispanic Black populations in CA and the NE is predicted to be notably larger in magnitude. Also, mortality rate disparities in Black populations aged 65-99 in the W are expected to be reduced when moving from 12/35-9/35 and 12/35-8/35, where baseline disparities were also found using the Di et al., 2017 study in Section 6.4.2.1. Finally, mortality rate disparities in non-Hispanic Black and Hispanic populations aged 18-99 in the W are expected to be reduced when moving from 12/35-9/35 and 12/35-8/35.

		12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
Study	Race/Ethnicity	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di 2017 (65-99)	Reference	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.5	1.6	0.5	0.7	5.7	3.3	2.6	3.3	7.3
	White	0.2	0.1	0.0	3.7	0.2	0.1	0.4	4.3	1.4	0.5	0.7	5.2	3.0	2.4	3.2	6.8
	American Indian	0.1	0.0	0.0	4.1	0.1	0.0	0.3	4.8	1.3	0.4	0.6	5.3	2.8	2.4	2.1	6.4
	Asian	0.1	0.0	0.0	4.7	0.1	0.0	0.1	5.1	1.8	2.2	0.5	7.1	4.2	6.7	3.3	9.1
	Black	0.3	0.0	0.0	5.3	0.3	0.0	0.1	5.9	2.7	0.5	0.9	7.3	5.7	3.0	5.8	8.7
	Hispanic	0.1	0.4	0.0	5.1	0.1	0.4	0.2	5.5	1.5	1.5	1.1	6.2	4.0	3.7	4.6	7.3
Pope 2019 (18-99)	Reference	0.2	0.1	0.0	4.1	0.2	0.1	0.4	4.7	1.6	0.6	0.8	5.8	3.4	2.7	3.4	7.4
	NH White	0.2	0.0	0.0	3.2	0.2	0.0	0.5	4.0	1.4	0.4	0.7	5.0	2.9	2.3	3.1	6.8
	NH American Indian	0.1	0.0	0.0	3.2	0.1	0.0	0.3	4.2	1.0	0.2	0.5	4.3	2.0	2.1	1.7	5.4
	NH Asian	0.1	0.0	0.0	4.6	0.1	0.0	0.2	5.1	1.7	2.0	0.6	7.1	4.0	6.5	3.3	9.0
	NH Black	0.3	0.0	0.0	5.2	0.3	0.0	0.1	5.8	2.7	0.6	1.0	7.3	5.7	3.1	5.9	8.6
	Hispanic	0.1	0.4	0.0	5.3	0.1	0.4	0.3	5.6	1.6	1.6	1.2	6.5	4.1	4.0	4.8	7.6

Figure 6-20 Heat Map of Regional Average Proportional Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current to Revised and Alternative PM NAAQS Levels After Application of Controls in 2032 (NH, Non-Hispanic)

6.5 Summary

For this final rulemaking, we quantitatively evaluate the potential for disparities in $PM_{2.5}$ concentrations and mortality effects across different demographic populations for the current standards (12/35, i.e., baseline) and potential alternative $PM_{2.5}$ NAAQS levels (10/35, 10/30, 9/35, and 8/35) under air quality scenarios associated with illustrative emissions control strategies. Specifically, we provide information on totals, changes, and proportional changes in 1) annual average $PM_{2.5}$ concentrations and 2) premature mortality as rates per 100,000 individuals across and within various demographic populations, at national and regional scales. Each type of analysis has strengths and weaknesses, but when taken together can respond to the three questions from EPA's EJ Technical Guidance. Total concentration/mortality rate analyses provide information on absolute $PM_{2.5}$ concentrations and mortality rates; however, it can be difficult to compare improvements in air quality/mortality rates among populations from total information. In contrast, comparing *changes* in concentration/mortality rates provides information on how improvements compare across and within populations, but does not provide information on which populations experience higher total concentration/mortality rates. Proportional changes are provided as a percent of the total concentration/mortality rate information, so although they are similar to absolute changes, they are more closely related to total concentration/mortality rate information.

EJ analyses were performed both at national and regional scales, as geography is relevant both to PM NAAQS attainment and population demographics. We also conducted an analysis focusing on relatively high $PM_{2.5}$ exposures, to examine the subset of areas in which air quality is projected to change after the application of controls outlined in Chapter 3. For all of these analyses, we note that the results should be considered illustrative only, Further, as with all EJ analyses, data limitations make it possible that disparities may exist that our analysis did not identify. This is especially relevant for potential EJ characteristics, environmental impacts, and more granular spatial resolutions that were not evaluated. We note again that this analysis is based on air quality modeling conducted on a 12 x 12 km grid scale, which may mask more local disparities in exposure and risk. Additionally, EJ concerns for each rulemaking are unique and should be considered on a case-by-case basis.

Whereas all populations experience reductions in $PM_{2.5}$ concentrations and health effects at lower PM standard levels, to make conclusions regarding EJ impacts of this final rule we refer back to the three questions that EPA's EJ Technical Guidance (U.S. EPA, 2015) states should be addressed, which for purposes of the PM NAAQS RIA EJ analysis are:

1) Are there disparate $PM_{2.5}$ exposures/mortality rates under baseline/current PM NAAQS standard levels?
2) Are there disparate $PM_{2.5}$ exposures/ mortality rates under illustrative alternative PM NAAQS standard levels?
3) Are $PM_{2.5}$ exposure/ mortality rates disparities created, exacerbated, or mitigated under illustrative alternative PM NAAQS standard levels as compared to the baseline?

Considering results of both the EJ exposure analysis (Section 6.3) and the EJ health effects analysis (Section 6.4), responses to the above three questions can be summarized as:

1) **Disparities in the baseline**: Regarding exposures, under air quality scenarios associated with control strategies for the baseline (12/35) PM NAAQS scenario, some populations are predicted to experience disproportionately higher annual $PM_{2.5}$ concentrations nationally than the reference (overall) population, both in terms of aggregated average concentrations and across the distribution of air quality (Figure 6-1 through Figure 6-5). Specifically, populations living in redlined areas or not redlined areas, linguistically isolated, Hispanic, Asian, Black, less educated, unemployed, uninsured, and below the poverty line have higher national annual concentrations, on average and across the distributions, than both the overall reference population or other populations (e.g., non-Hispanic, White, and more educated). In particular, those living in redlined areas are estimated to experience the highest concentrations, both on average and across $PM_{2.5}$ concentration distributions, of all demographic groups analyzed. These disproportionalities are also observed in the baseline at the regional level, though to different extents (Figure 6-6 through Figure 6-11).

In terms of mortality rates, some racial/ethnic populations are also predicted to experience notably higher rates of premature mortality than reference populations (Figure 6-12 through Figure 6-20). Black populations are estimated to have the highest national and regional mortality rates in older adults aged 65-99, both on average and across population distributions. This may be partly due to higher $PM_{2.5}$ concentrations for this population, which could contribute to the higher magnitude concentration-response relationship between exposure concentrations and premature mortality (Di et al., 2017), as well as other underlying health factors that may increase susceptibility to adverse outcomes among Black populations. There may be additional baseline disparities in some populations in certain regions, to varying degrees.

2) **Disparities under alternative policy options**: While more stringent control strategies reduce $PM_{2.5}$ concentrations and mortality rates across all demographic groups, disparities seen in the baseline also persist in the alternative policy options and revised standard levels. Higher $PM_{2.5}$ concentrations and health effects remain for Asian, Black, Hispanic, less educated, unemployed, uninsured, linguistically isolated, those below the poverty line, HOLC Grade D, and HOLC Grades A-C populations, as compared to the reference population under air quality scenarios associated with the illustrative control strategies (10/35, 10/30, 9/35, and 8/35) (Figure 6-1 through Figure 6-20). Nationally and regionally, these patterns and the populations affected are similar to those seen in the baseline.

3) **Relative impact of alternative policy options on disparities in the baseline**: For most populations assessed, $PM_{2.5}$ exposure disparities are mitigated in the illustrative air quality scenarios associated with control strategies for more stringent $PM_{2.5}$ control strategies (10/35, 10/30, 9/35, and 8/35) as compared to the baseline (12/35), to differing degrees (Figure 6-5 and Figure 6-11). More specifically, increasing portions of certain populations of potential EJ concern are expected to experience greater $PM_{2.5}$ concentration reductions as the illustrative control strategies become more stringent (Figure 6-4 and Figure 6-9). At the national scale, linguistically isolated, redlined areas, not redlined areas, Hispanic,

Asian, those less educated, and unemployed populations are estimated to experience greater proportional reductions in $PM_{2.5}$ concentrations than reference populations under all lower standard levels evaluated, with proportional reductions increasing as the standard levels decrease. In addition, exposure disparities in baseline Black and uninsured populations are estimated to be mitigated when moving to an alternative standard level of 8/35. Average concentration reductions were also similar across Black and White populations when evaluating the relatively high $PM_{2.5}$ exposures that are most affected by the illustrative control strategies. Considering the four geographic regions, $PM_{2.5}$ baseline exposure disparities were mitigated in CA under all lower standard levels for many populations in other regions when moving to either 9/35 or 8/35.

In general, more stringent control strategies are also associated with reductions in mortality rate disparities. Specifically, the analysis shows that as the illustrative $PM_{2.5}$ control strategies become increasingly stringent, differences in mortality rates across demographic groups decline, particularly for the lowest alternatives evaluated (12/35-9/35 and 12/35-8/35). Nationally, Black and non-Hispanic Black populations are predicted to experience proportionally similar mortality rate reductions to the reference populations under control strategies associated with 12/35-10/35 or 12/35-10/30, but greater reductions in mortality rates under control strategies associated with 12/35-9/35 or 12/35-8/35. Similar to the estimated changes in $PM_{2.5}$ concentrations following reductions in $PM_{2.5}$ concentrations under alternative standard levels, disparities in national $PM_{2.5}$ mortality rates across demographic groups are mitigated for Hispanics in all the alternative PM standard levels (10/35, 10/30, 9/35, and 8/35) as compared to the baseline (Figure 6-15).

6.6 Environmental Justice Appendix

6.6.1 EJ Exposure Analysis Input Data

In Appendix 2A, the exposure assessment involves demographic population data projected out to the future year 2032. We use population projections based on economic forecasting models developed by Woods and Poole, Inc. (Woods & Poole, 2015). The Woods and Poole database contains county-level projections of population by age, sex, and race/ethnicity out to 2060, relative to a baseline using the 2010 Census data. Projections in each county are determined simultaneously with every other county in the U.S. to consider patterns of economic growth and migration. The sum of growth in county-level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates (Hollmann et al., 2000). According to Woods and Poole, linking county-level growth projections together and constraining to a national-level total growth avoids potential errors introduced by forecasting each county independently (Woods & Poole, 2015).

We also include data on educational attainment, poverty status, unemployment, health insurance coverage, occupational status, linguistic isolation, and redlining status. These datasets are included in BenMAP-CE. The data sources and processing methodology for each dataset is described below. County-level datasets were generated for 3,109 counties in the contiguous U.S. Census tract level datasets were generated for 72,538 census tracts in the contiguous U.S.

6.6.1.1 Educational Attainment

We use data from the ACS to provide tract-level summaries of educational attainment. These data represent 5-year average ACS estimates from 2015 to 2019 and span the same two education categories as county-level demographic variables: no high school diploma (termed "no_hs_degree_tract") and high school diploma (or equivalency) and above (termed "hs_degree_plus_tract"). For both education groups (with/without high school diploma), we estimate the fraction of the total tract population (ages 25 years and above) in each education group. Thus, the two estimates sum to one for each tract. All estimates were generated at the tract level for 72,538 tracts in the contiguous United States. For each estimate, we generate a coefficient of variation (CV) equal to the ratio of the standard error to the point estimate. For tracts with a CV greater than 0.3, we impute the tract-level estimate with a county-level estimate following Census guidance, which defines any estimate with a CV greater than 0.3 as low reliability and to be used with extreme caution (King et al. 2015). In cases of counties with a CV greater than 0.3, we further impute to the state-level.

6.6.1.2 Poverty Status

To determine the poverty status at the tract level, we utilize ACS 5-year estimates from 2015 to 2019. The resulting datasets represent the fraction of the total population in the tract that falls below the federal poverty line (termed "below_poverty_line_tract") and the fraction of the population that falls above the poverty line (termed "above_poverty_line_tract"). The EPA Standard Variables dataset also includes two variables representing the fraction of the tract-level population below and above 200% of the poverty line (termed "below_2x_poverty_line_tract" and "above_2x_poverty_line_tract"). We followed the same imputation procedures described in Section 6.6.1.1 to process poverty variables.

6.6.1.3 Unemployment Status

BenMAP includes county-level employment variables representing average rates from 2017 to 2021 (termed "adj_employment_rate" and "adj_unemployment_rate"). Importantly, the employment variables are adjusted for use in BenMAP to use total population as the denominator rather than labor force. This allows users to multiply the rates by the total population (in a health impact function) to assess populations that are (a) employed, (b) unemployed, and (c) not part of the labor force (e.g., retirees, students, discouraged workers). County-level unemployment rates are from the Bureau of Labor Statistics. We adjusted these rates using county-level population estimates from the U.S. Census Bureau from 2017 to 2021. The calculations were done for each year individually and then averaged together to create a five-year average. The value calculated in BenMAP represents the average rate across all months within this period. The rate of residents not in the labor force (termed "not_in_labor_force_rate") was calculated by subtracting the labor force from the total population and then dividing the remainder by the total population.

6.6.1.4 Health Insurance Status

We use data from the Small Area Health Insurance Estimates (SAHIE) collected by the U.S. Census Bureau from 2015 to 2019 to calculate the percentage of individuals with and without health insurance in each county. The SAHIE date provides the number of individuals with and without health insurance by county. Calculations were done for each year individually and then averaged together over the five-year period.

6.6.1.5 Linguistic Isolation

We use 5-year ACS estimates from 2015-2019 to estimate linguistic isolation at the tract level. The resulting datasets represent the fraction of the total population age 5 and over in the tract that are linguistically isolated (defined by speaking English "less than very well", termed "english_less_than_verywell_tract") and the fraction of the population age 5 and over that speak English "very well or better" (termed "english_verywell_or_better_tract"). This definition follows as closely as possible the definition of linguistic isolation used in EJ Screen and in other regulatory analyses. Additionally, we produced an alternative definition in which the linguistically isolated population is more restrictive, i.e., those who speak English less than "well" (termed "english_less_than_well_tract"), and inversely, those who speak English "well or better" (termed "english_well_or_better_tract"). Instead of imputing in cases of uncertainty, we generate tract-level point estimates of linguistic isolation in an effort to prioritize geographic specificity in these estimates.

6.6.1.6 Redlined Areas

We use graded census tracts developed by Noelke et al., 2022 from digitized Home Owners' Loan Corporation (HOLC) residential security maps overlaid onto 2010 Census tracts. Each census tract is classified as being covered by "Mainly A," "Mainly B," "Mainly C," and "Mainly D" grading, corresponding to coverage of different hazard ratings from original HOLC maps. The dataset covers 14,818 census tracts, since HOLC maps only covered certain urban areas. This dataset was adapted to cover 72,538 census tracts for use in BenMAP, with the remaining census tracts categorized as "redlined_na" since they were not covered by HOLC grading. Census tracts labeled as "Mainly D" were categorized as "redlined" and census tracts that were mainly A-C were categorized as "not_redlined."

6.6.2 EJ Health Effects Analysis Input Data

The health assessment requires input data in addition to the information used in the exposure assessment (Section 6.3). As such, there are additional uncertainties related to the HRs and baseline incidence data used, albeit similar to the benefits assessment results (Section 5.3).

When selecting HRs to use when estimating race/ethnicity-stratified mortality effects, we first evaluated the available studies and concentration-response functions to determine if sufficient information exists for use in a quantitative analysis and to determine which study or studies best characterizes at-risk nonwhite populations across the U.S. from the PM ISAs. Of the available studies, Di et al., 2017 and Pope III et al., 2019 were identified as best characterizing populations potentially at increased risk of long-term exposure and all-cause mortality, in order to provide two independent estimates of race- and ethnicity-stratified all-cause mortality impacts of this final rulemaking. Factors contributing to their selection include that were nationwide studies, included substantial study sizes (i.e., hundreds of thousands to millions of individuals), used sophisticated exposure estimation techniques over fairly recent time spans, and provided sufficient information to apply risk models quantifying increased risks to non-White/non-Hispanic White groups.

Health impact functions used in this EJ health effects analysis, including beta parameters and standard errors (SE), were developed for each at-risk population demographic described by Di et al., 2017 and Pope III et al., 2019 are provided in Table 6-2. Di et al., 2017 effect estimates were derived from a cohort aged 65 and older and provided HRs for reference, White, Hispanic, Black, Asian, and Native American populations. The Pope III et al., 2019 effect estimates were derived from a cohort aged 18 and over and provided HRs for reference, non-Hispanic White, non-Hispanic Black, Hispanic, and other/unknown populations. In this analysis, the other/unknown HRs were applied to non-Hispanic Asian, and non-Hispanic Native American populations.

Table 6-2 Hazard Ratios, Beta Coefficients, and Standard Errors (SE) from (Di et al., 2017)

Study	Demographic Population	Risk of Death Associated with a 10 μg/m^3 Increase in $PM_{2.5}$	Beta Coefficient (SE)
Di et al., 2017	All	1.073 (1.071, 1.075)	0.0070 (0.0001)
	White	1.063 (1.060, 1.065)	0.0061 (0.0001)
	Hispanic	1.116 (1.100, 1.133)	0.0110 (0.0008)
	Black	1.208 (1.199, 1.217)	0.0189 (0.0004)
	Asian	1.096 (1.075, 1.117)	0.0092 (0.0010)
	Native American	1.100 (1.060, 1.140)	0.0095 (0.0019)
Pope III et al., 2019	All	1.12 (1.08-1.15)	0.0113 (0.0016)
	Non-Hispanic White	1.11 (1.07-1.15)	0.0104 (0.0018)
	Non-Hispanic Black	1.15 (1.05-1.27)	0.0139 (0.0048)
	Hispanic	1.20 (1.11-1.30)	0.0182 (0.0040)
	Other/Unknown	1.10 (0.94-1.28)	0.0095 (0.0078)

BenMAP-CE includes baseline incidence rates at the most geographically- and age-specific levels available for each health endpoint assessed. For many locations within the U.S., these data are resolved at the county- or state-level, providing a better characterization of the geographic distribution of mortality rates than the national-level rates. Race- and ethnicity-stratified baseline incidence rates from 2007-2016 Census data were recently improved for the all-cause mortality health endpoint, by adding the geographic level option of rural/urban state between county-level and state-level. Both overall and race/ethnicity-stratified baseline rates are used in this analysis of EJ health impacts analysis.

To estimate race-stratified and age-stratified incidence rates at the county level, we downloaded all-cause mortality data from 2007 to 2016 from the CDC WONDER mortality database.[19] Race-stratified incidence rates were calculated for the following age groups: < 1 year, 1-4 years, 5-14 years, 15-24 years, 25-34 years, 35-44 years, 45-54 years, 55-64 years, 65-74 years, 75-84 years, and 85+ years. To address the frequent county-level data suppression for race-specific death counts, we stratified the county-level data into two broad race categories, White and Non-White populations. In a later step, we stratified the

[19] https://wonder.cdc.gov/

non-White incidence rates by race and ethnicity using the relative magnitudes of incidence values by race at the regional level, described in more detail below.

We followed methods outlined in Section D.1.1 of the BenMAP-CE User Manual with one notable difference in methodology; we included an intermediate spatial scale between county and state for imputation purposes.[20] We designated urban and rural counties within each state using CDC WONDER and, where possible, imputed missing data using the state-urban and state-rural classifications before relying on broader statewide data. We followed methods for dealing with suppressed and unreliable data at each spatial scale as described in Section D.1.1.

A pooled non-White incidence rate masks important differences in mortality risks by race. To estimate county-level mortality rates by individual race (Black, Asian, Native American), we applied regional race-specific incidence relationships to the county-level pooled non-White incidence rates. We calculated a weighted average of race-specific incidence rates using regional incidence rates for each region/age/race group normalized to one reference population (the Asian race group) and county population proportions based on race-specific county populations from CDC WONDER where available. In cases of population suppression across two or more races per county, we replaced all three race-specific population proportions derived from CDC WONDER with population proportions derived from 2010 Census data in BenMAP-CE (e.g., 50 percent Black, 30 percent Asian, 20 percent Native American).

To estimate ethnicity-stratified and age-stratified incidence rates at the county level, we downloaded all-cause and respiratory mortality data from 2007 to 2016 from the CDC WONDER mortality database.[21] Ethnicity-stratified incidence rates were calculated for the following age groups: < 1 year, 1-4 years, 5-14 years, 15-24 years, 25-34 years, 35-44 years, 45-54 years, 55-64 years, 65-74 years, 75-84 years, and 85+ years. We stratified county-level data by Hispanic origin (Hispanic and non-Hispanic). We followed the methods outlined in Section D.1.1 to deal with suppressed and unreliable data. We also included an intermediate spatial scale between county and state designating urban and rural counties

[20] https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf
[21] https://wonder.cdc.gov/

for imputation purposes, described in detail in Section D.1.3 of the BenMAP-CE User Manual. [22]

6.6.3 National EJ Analysis of Total Exposures and Exposure Changes Associated with Meeting the Revised and Alternative Standard Levels

In addition to air quality surfaces associated with the illustrative emissions control strategies evaluated in the main EJ chapter, $PM_{2.5}$ air quality surfaces associated with meeting the current standards and alternative standard levels were also developed. Air quality associated with meeting the standards was based on assumptions that emissions controls could be identified to obtain the estimated emissions reductions needed (Appendix 2A). Results for both air quality scenarios (termed "controls" when associated with the illustrative control strategies and "standards" when it is assumed areas are fully meeting the current standards or alternate standard levels) are included in this appendix, to allow for direct comparisons. In general, for populations experiencing higher baseline $PM_{2.5}$ concentrations and mortality rates, air quality scenarios associated with meeting the current and alternative standard levels reduce disparities more so than air quality scenarios associated with the control strategies, especially for populations in CA.

National and regional $PM_{2.5}$ concentrations and concentration changes by demographic populations for air quality scenarios associated with both the control strategies and meeting the standards are provided in Sections 6.6.5 and 6.6.6.

National absolute $PM_{2.5}$ exposure impacts are provided in Section 6.6.3.1 and national proportional $PM_{2.5}$ exposure impacts are provided in Section 6.6.3.2

6.6.3.1 Absolute National Exposures Under Current, Revised, and Alternative Standard Levels and Exposure Changes When Moving from Current Standard to Revised and Alternative Standard Levels

At the national level, air quality scenarios associated with meeting the standards led to similar and/or slightly lower $PM_{2.5}$ concentrations under the current standards and lower alternative standard levels than air quality scenarios associated with control strategies (Figure 6-21 and Figure 6-22). This may narrow disproportionate $PM_{2.5}$ concentrations for certain populations, such as Hispanics, under air quality associated with

[22] https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf

more stringent alternative standard levels. Please note, some populations are excluded from the distributional figure for visual clarity.

Population Group	Population (Ages)	12/35		10/35		12/35-10/35		10/30		12/35-10/30		9/35		12/35-9/35		8/35		12/35-8/35	
		Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	7.2	7.2	7.1	7.1	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5
Race	White (0-99)	7.1	7.1	7.0	7.0	0.1	0.1	7.0	6.9	0.1	0.1	6.9	6.8	0.1	0.2	6.8	6.6	0.3	0.5
	American Indian (0-99)	6.8	6.8	6.7	6.6	0.1	0.1	6.7	6.6	0.1	0.1	6.6	6.5	0.1	0.2	6.5	6.3	0.3	0.5
	Asian (0-99)	7.8	7.8	7.7	7.6	0.1	0.2	7.7	7.6	0.1	0.2	7.6	7.4	0.2	0.4	7.4	7.0	0.4	0.8
	Black (0-99)	7.4	7.3	7.3	7.3	0.0	0.1	7.3	7.3	0.0	0.1	7.2	7.2	0.1	0.2	7.0	6.9	0.3	0.4
Ethnicity	Non-Hispanic (0-99)	6.9	6.9	6.9	6.9	0.0	0.1	6.9	6.9	0.0	0.1	6.8	6.8	0.1	0.2	6.7	6.6	0.2	0.4
	Hispanic (0-99)	7.9	7.9	7.8	7.7	0.1	0.2	7.8	7.6	0.1	0.3	7.7	7.4	0.2	0.5	7.5	7.0	0.4	0.9
Educational Attainment	More educated (25-99)	7.1	7.1	7.0	7.0	0.0	0.1	7.0	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.8	6.6	0.3	0.4
	Less educated (25-99)	7.5	7.5	7.4	7.3	0.1	0.2	7.4	7.3	0.1	0.2	7.3	7.1	0.2	0.4	7.1	6.8	0.3	0.7
Employment Status	Employed (0-99)	7.2	7.2	7.1	7.1	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5
	Unemployed (0-99)	7.3	7.3	7.2	7.2	0.1	0.1	7.2	7.1	0.1	0.2	7.1	7.0	0.2	0.3	7.0	6.7	0.3	0.6
	Not in the labor force (0-99)	7.2	7.2	7.1	7.0	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5
Insurance Status	Insured (0-64)	7.2	7.2	7.1	7.1	0.1	0.1	7.1	7.1	0.1	0.1	7.1	7.0	0.1	0.2	6.9	6.7	0.3	0.5
	Unisured (0-64)	7.3	7.3	7.3	7.2	0.1	0.1	7.2	7.2	0.1	0.1	7.2	7.1	0.1	0.2	7.0	6.8	0.3	0.5
Linguistic Isolation	English "well or better" (0-99)	7.1	7.1	7.1	7.0	0.0	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.8	6.7	0.3	0.5
	English < "well" (0-99)	8.1	8.1	8.0	7.8	0.1	0.3	8.0	7.8	0.2	0.3	7.9	7.6	0.3	0.5	7.7	7.2	0.5	1.0
Poverty Status	Above the poverty line (0-99)	7.1	7.1	7.1	7.0	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5
	Below poverty line (0-99)	7.3	7.3	7.2	7.2	0.1	0.1	7.2	7.2	0.1	0.1	7.2	7.0	0.1	0.3	7.0	6.8	0.3	0.5
Redlined Areas	HOLC Grades A-C (0-99)	8.0	8.0	7.8	7.7	0.1	0.2	7.8	7.7	0.2	0.2	7.7	7.5	0.3	0.4	7.5	7.2	0.5	0.8
	HOLC Grade D (0-99)	8.2	8.2	8.1	8.0	0.1	0.2	8.1	8.0	0.1	0.2	7.9	7.8	0.3	0.4	7.7	7.4	0.5	0.8
	Ungraded by HOLC (0-99)	7.0	7.0	7.0	6.9	0.0	0.1	7.0	6.9	0.0	0.1	6.9	6.8	0.1	0.2	6.8	6.6	0.2	0.4
Age	Adults (18-64)	7.2	7.2	7.2	7.1	0.1	0.1	7.1	7.1	0.1	0.1	7.1	7.0	0.1	0.2	6.9	6.7	0.3	0.5
	Children (0-17)	7.2	7.2	7.2	7.1	0.1	0.1	7.2	7.1	0.1	0.1	7.1	7.0	0.1	0.2	6.9	6.7	0.3	0.5
	Older Adults (65-99)	7.0	7.0	6.9	6.9	0.0	0.1	6.9	6.9	0.1	0.1	6.9	6.8	0.1	0.2	6.7	6.6	0.3	0.4
Sex	Females (0-99)	7.2	7.2	7.1	7.1	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5
	Males (0-99)	7.2	7.2	7.1	7.0	0.1	0.1	7.1	7.0	0.1	0.1	7.0	6.9	0.1	0.2	6.9	6.7	0.3	0.5

Figure 6-21 Heat Map of National Average Annual $PM_{2.5}$ Concentrations and Concentration Reductions ($\mu g/m^3$) Associated Either with Control Strategies (Controls) or with Meeting the Standards (Standards) by Demographic for Current (12/35) and Revised and Alternative PM NAAQS Levels (10/35, 10/30, 9/35, and 8/35) in 2032

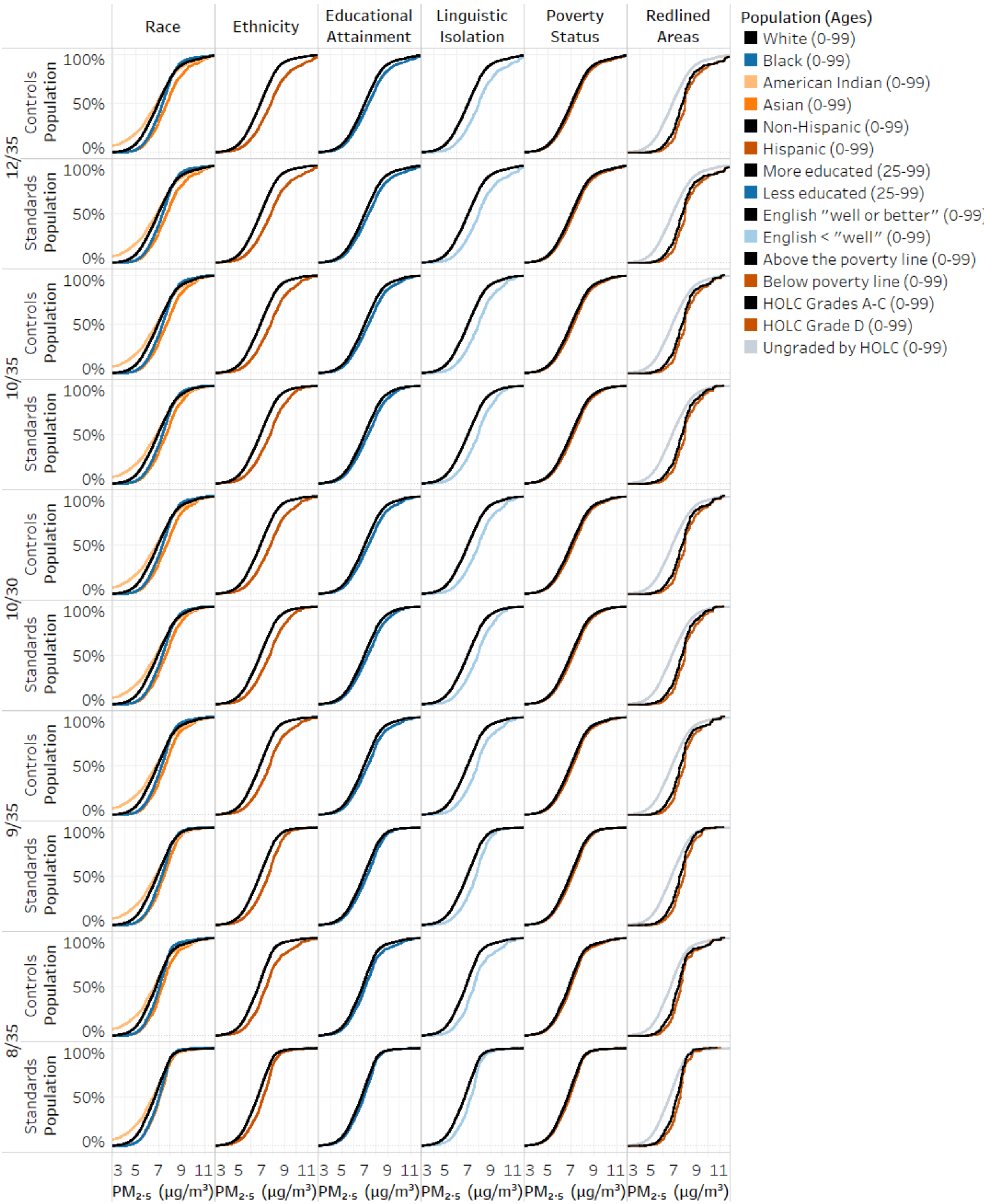

Figure 6-22 National Distributions of Annual PM2.5 Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Levels in 2032

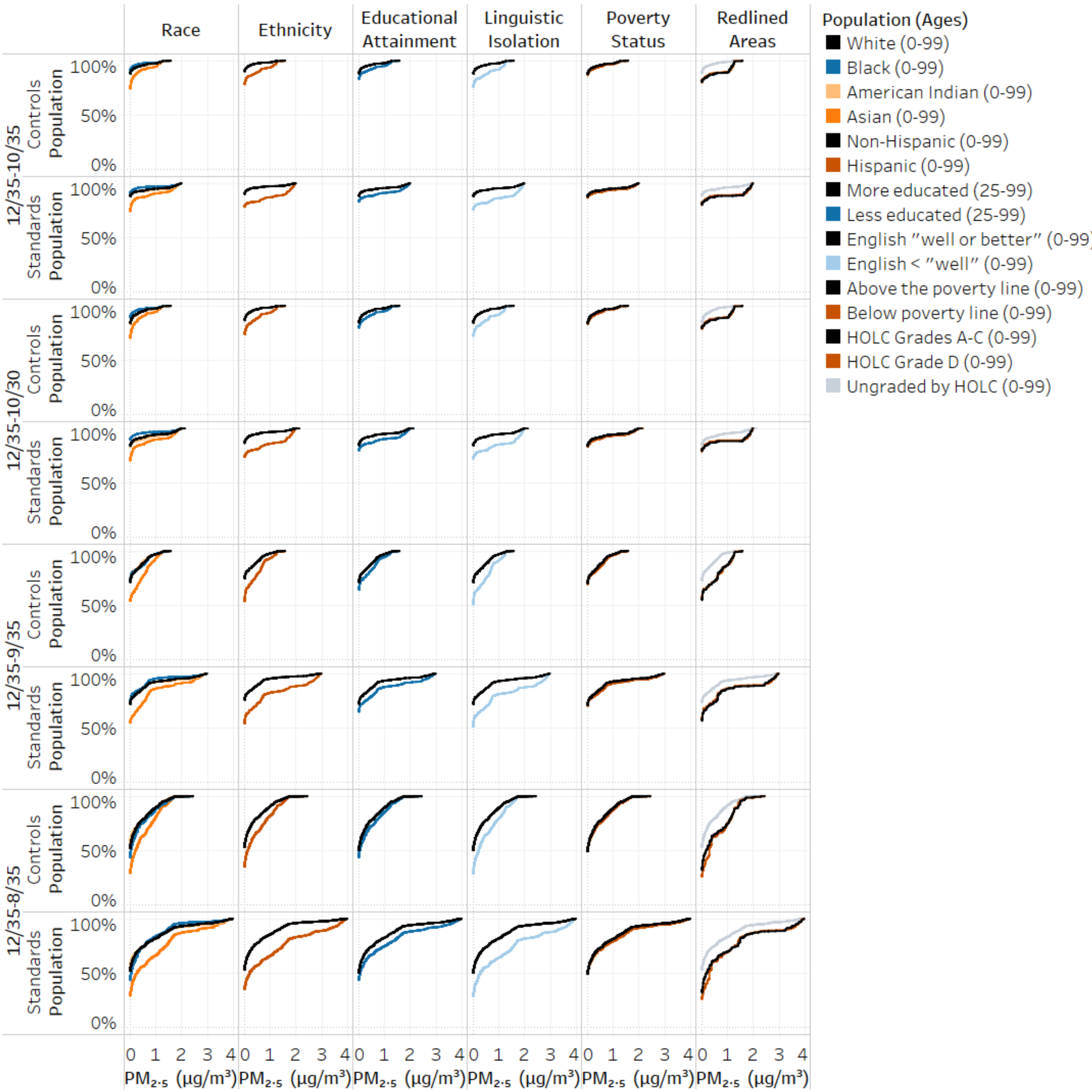

Figure 6-23 National Distributions of Annual Reductions in $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032

We also provide exposure distributions for the overall reference population under the current standard and alternative PM standard levels, to show the greater downward shift in higher annual PM exposures associated with "Standards" as opposed to associated with "Controls" (Figure 6-24).

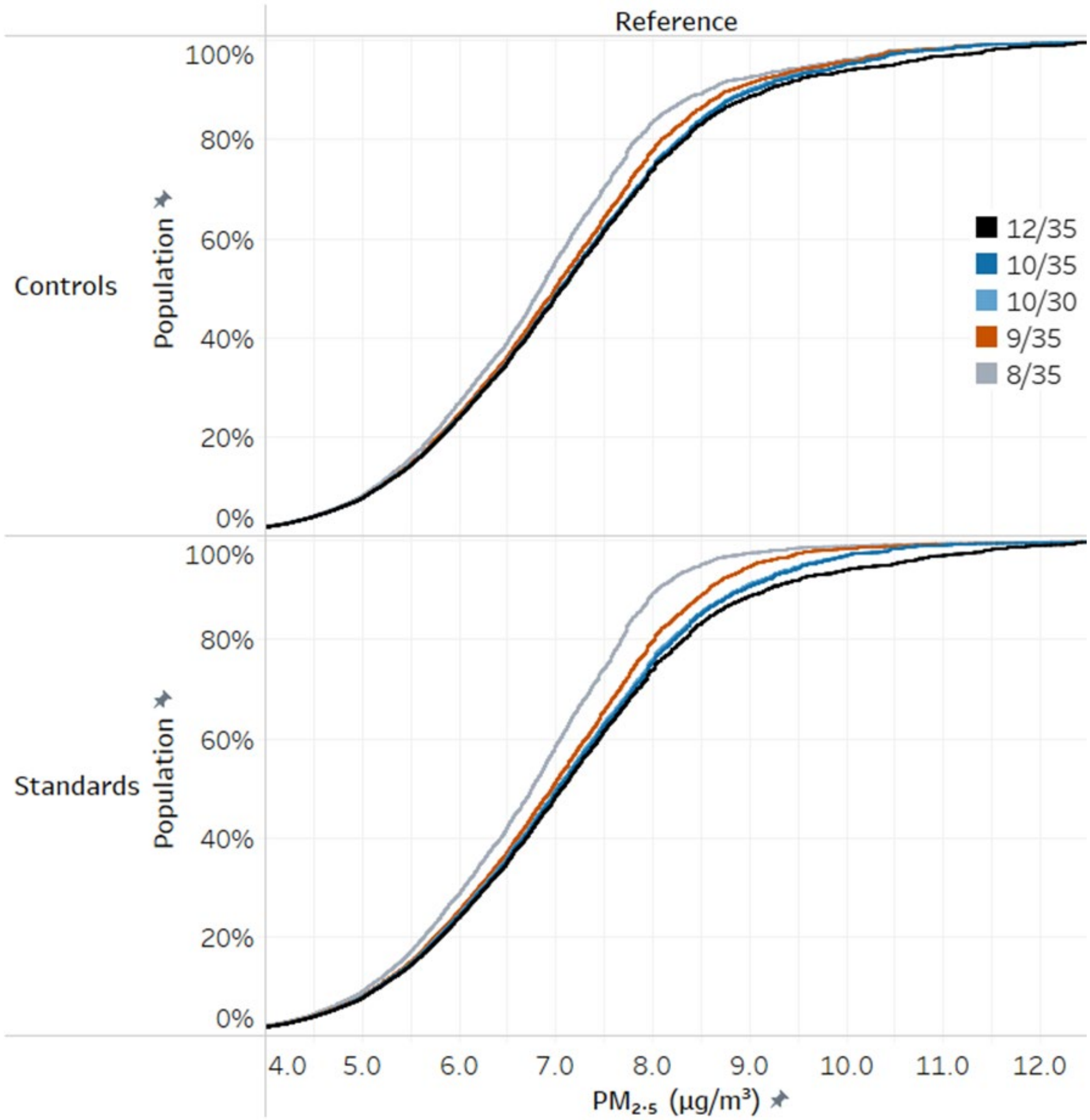

Figure 6-24 National Distributions of Annual Concentrations Experienced by the Reference Population Associated Either with Control Strategies or with Meeting the Standards for Current PM NAAQS of 12/35 in 2032

6.6.3.2 Proportional Regional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Proportionally, national air quality scenarios associated with meeting the standards reduce $PM_{2.5}$ concentrations in the reference population by a larger amount than air quality scenarios associated with the illustrative control strategies as alternative standard levels are lowered (Figure 6-25).

Population Groups	Populations (Ages)	Attainment	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
			Scenario			
Reference	All (0-99)	Controls	0.7	0.9	1.9	3.9
		Standards	1.4	1.7	3.3	6.7
Race	White (0-99)	Controls	0.7	0.9	1.8	3.7
		Standards	1.4	1.7	3.2	6.5
	American Indian (0-99)	Controls	0.8	1.0	1.7	3.7
		Standards	1.7	2.1	3.5	6.9
	Asian (0-99)	Controls	1.3	1.5	3.1	5.7
		Standards	2.4	2.8	5.5	10.4
	Black (0-99)	Controls	0.5	0.5	1.7	4.2
		Standards	0.9	0.9	2.3	5.7
Ethnicity	Non-Hispanic (0-99)	Controls	0.5	0.6	1.5	3.5
		Standards	0.9	1.1	2.3	5.2
	Hispanic (0-99)	Controls	1.5	1.7	2.8	5.1
		Standards	3.2	3.6	6.3	11.2
Educational Attainment	More educated (25-99)	Controls	0.7	0.8	1.8	3.8
		Standards	1.3	1.5	3.0	6.2
	Less educated (25-99)	Controls	1.2	1.3	2.4	4.5
		Standards	2.3	2.7	4.8	8.9
Employment Status	Employed (0-99)	Controls	0.7	0.8	1.8	4.0
		Standards	1.4	1.6	3.2	6.6
	Unemployed (0-99)	Controls	1.0	1.1	2.2	4.4
		Standards	1.9	2.2	4.1	7.9
	Not in the labor force (0-99)	Controls	0.7	0.9	1.9	3.9
		Standards	1.5	1.8	3.4	6.8
Insurance Status	Insured (0-64)	Controls	0.8	0.9	1.9	4.0
		Standards	1.5	1.8	3.4	6.9
	Unisured (0-64)	Controls	0.8	0.9	1.9	4.3
		Standards	1.4	1.7	3.4	7.1
Linguistic Isolation	English "well or better" (0-99)	Controls	0.7	0.8	1.8	3.8
		Standards	1.3	1.6	3.1	6.4
	English < "well" (0-99)	Controls	1.8	1.9	3.2	5.6
		Standards	3.3	3.7	6.7	11.8
Poverty Status	Above the poverty line (0-99)	Controls	0.7	0.8	1.8	3.9
		Standards	1.4	1.7	3.2	6.6
	Below poverty line (0-99)	Controls	0.9	1.0	2.0	4.1
		Standards	1.7	1.9	3.7	7.3
Redlined Areas	HOLC Grades A-C (0-99)	Controls	1.8	1.9	3.5	5.9
		Standards	2.8	2.9	5.6	10.0
	HOLC Grade D (0-99)	Controls	1.7	1.8	3.4	6.2
		Standards	2.6	2.6	5.2	10.0
	Ungraded by HOLC (0-99)	Controls	0.5	0.6	1.5	3.5
		Standards	1.2	1.5	2.8	6.0
Age	Adults (18-64)	Controls	0.8	0.9	1.9	4.0
		Standards	1.5	1.7	3.4	6.9
	Children (0-17)	Controls	0.7	0.9	1.9	4.0
		Standards	1.5	1.8	3.4	6.9
	Older Adults (65-99)	Controls	0.7	0.8	1.7	3.6
		Standards	1.3	1.5	2.9	6.0
Sex	Females (0-99)	Controls	0.7	0.9	1.9	3.9
		Standards	1.4	1.7	3.3	6.7
	Males (0-99)	Controls	0.7	0.9	1.8	3.9
		Standards	1.4	1.7	3.3	6.7

Figure 6-25 Heat Map of National Percent Reductions (%) in Average Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standard Levels by Demographic When Moving from Current to Revised and Alternative PM NAAQS Standard Levels in 2032

6.6.4 Regional EJ Analysis of Total Exposures and Exposure Changes Associated with Meeting the Standards

Regional absolute exposure burdens, changes, and proportional changes are in Sections 6.6.4.1, 6.6.4.2, and 6.6.4.3, respectively.

6.6.4.1 Absolute Regional Exposures Under Current, Revised, and Alternative Standard Levels

Comparing 'Controls' and 'Standards' in CA associated with the lower alternative standard levels allows for some insight into areas without identified emissions control strategies. Regionally, air quality scenarios associated with meeting the standards also led to similar or slightly lower $PM_{2.5}$ exposure burdens as air quality scenarios associated with the current standards or more stringent standard levels, except for in CA, where air quality associated with the standards resulted in lower $PM_{2.5}$ concentrations (Figure 6-26 and Figure 6-27).[23] In other words, disparities between Hispanics and non-Hispanics predicted with controls at 9/35 are mitigated to a greater extent if CA were to fully meet the revised standard level of 9/35.

[23] The overall reference, ages, and sex population groups were excluded from Figure 6-30 to so that the figure could fit on a single page.

Population Group	Population (Ages)	Attainment	12/35				10/35				10/30				9/35				8/35			
			NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6
		Standards	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.0	6.7	7.9	6.5	6.8	6.5	7.1
Race	White (0-99)	Controls	6.6	7.1	6.7	9.2	6.6	7.0	6.7	8.9	6.6	7.0	6.7	8.8	6.5	7.0	6.7	8.7	6.4	6.8	6.5	8.6
		Standards	6.6	7.1	6.7	9.2	6.6	7.0	6.7	8.4	6.6	7.0	6.7	8.3	6.5	7.0	6.7	7.8	6.4	6.8	6.5	7.1
	American Indian (0-99)	Controls	6.6	7.1	5.5	9.1	6.5	7.1	5.5	8.8	6.5	7.1	5.5	8.7	6.5	7.1	5.5	8.6	6.4	6.9	5.4	8.5
		Standards	6.6	7.1	5.5	9.1	6.5	7.1	5.5	8.3	6.5	7.1	5.5	8.2	6.5	7.1	5.5	7.7	6.4	6.9	5.4	7.0
	Asian (0-99)	Controls	7.1	7.5	7.0	9.4	7.1	7.5	7.0	9.1	7.1	7.5	7.0	9.0	7.0	7.4	7.0	8.8	6.8	7.1	6.8	8.6
		Standards	7.1	7.5	7.0	9.4	7.1	7.5	7.0	8.7	7.1	7.5	7.0	8.7	7.0	7.4	7.0	8.1	6.8	7.1	6.7	7.3
	Black (0-99)	Controls	7.3	7.2	7.1	9.7	7.2	7.2	7.1	9.3	7.2	7.2	7.1	9.2	7.1	7.1	7.0	9.1	6.9	6.9	6.7	9.0
		Standards	7.3	7.2	7.1	9.7	7.2	7.2	7.1	8.8	7.2	7.2	7.1	8.7	7.1	7.1	7.0	8.1	6.9	6.9	6.7	7.3
Ethnicity	Non-Hispanic (0-99)	Controls	6.7	6.9	6.6	9.1	6.6	6.9	6.6	8.7	6.6	6.9	6.6	8.7	6.6	6.9	6.6	8.5	6.4	6.7	6.4	8.4
		Standards	6.7	6.9	6.6	9.0	6.6	6.9	6.6	8.4	6.6	6.9	6.6	8.3	6.6	6.9	6.6	7.9	6.4	6.7	6.4	7.1
	Hispanic (0-99)	Controls	7.1	7.7	7.0	9.6	7.1	7.6	7.0	9.1	7.1	7.6	7.0	9.1	7.0	7.5	7.0	9.0	6.8	7.3	6.7	8.9
		Standards	7.1	7.7	7.0	9.5	7.1	7.6	7.0	8.6	7.1	7.6	7.0	8.5	7.0	7.5	7.0	7.9	6.8	7.2	6.7	7.1
Educational Attainment	More educated (25-99)	Controls	6.7	7.0	6.7	9.2	6.7	7.0	6.7	8.9	6.7	7.0	6.7	8.8	6.6	7.0	6.6	8.7	6.5	6.8	6.5	8.5
		Standards	6.7	7.0	6.7	9.2	6.7	7.0	6.7	8.5	6.7	7.0	6.6	8.3	6.6	7.0	6.6	7.9	6.4	6.8	6.4	7.1
	Less educated (25-99)	Controls	6.8	7.2	6.9	9.6	6.8	7.2	6.9	9.1	6.8	7.2	6.9	9.1	6.7	7.1	6.8	9.0	6.6	7.0	6.6	8.9
		Standards	6.8	7.2	6.9	9.5	6.8	7.2	6.9	8.6	6.8	7.2	6.9	8.5	6.7	7.1	6.8	7.9	6.6	6.9	6.5	7.2
Employment Status	Employed (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.6
		Standards	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.1	6.7	7.9	6.5	6.9	6.5	7.2
	Unemployed (0-99)	Controls	6.8	7.2	6.8	9.4	6.8	7.2	6.8	9.0	6.8	7.2	6.8	9.0	6.7	7.1	6.7	8.9	6.5	6.9	6.5	8.8
		Standards	6.8	7.2	6.8	9.4	6.8	7.2	6.8	8.5	6.8	7.2	6.7	8.4	6.7	7.1	6.7	7.9	6.5	6.9	6.5	7.1
	Not in the labor force (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.8	6.5	8.6
		Standards	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.0	6.7	7.9	6.5	6.8	6.4	7.1
Insurance Status	Insured (0-64)	Controls	6.7	7.1	6.8	9.3	6.7	7.1	6.8	9.0	6.7	7.1	6.8	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.6
		Standards	6.7	7.1	6.8	9.3	6.7	7.1	6.8	8.5	6.7	7.1	6.7	8.4	6.7	7.1	6.7	7.9	6.5	6.9	6.5	7.1
	Unisured (0-64)	Controls	6.9	7.3	6.7	9.4	6.8	7.3	6.7	9.0	6.8	7.3	6.7	8.9	6.7	7.2	6.6	8.8	6.6	7.0	6.4	8.7
		Standards	6.9	7.3	6.7	9.3	6.8	7.3	6.7	8.4	6.8	7.3	6.7	8.3	6.7	7.2	6.6	7.8	6.6	6.9	6.4	7.1
Linguistic Isolation	English "well or better" (0-99)	Controls	6.7	7.1	6.7	9.2	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.8	6.6	7.0	6.7	8.7	6.5	6.8	6.5	8.6
		Standards	6.7	7.1	6.7	9.2	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.3	6.6	7.0	6.7	7.9	6.5	6.8	6.4	7.1
	English < "well" (0-99)	Controls	7.2	7.8	7.3	9.8	7.2	7.8	7.3	9.3	7.2	7.8	7.3	9.2	7.1	7.7	7.2	9.1	7.0	7.4	6.9	9.0
		Standards	7.2	7.8	7.3	9.7	7.2	7.8	7.3	8.8	7.2	7.8	7.2	8.7	7.2	7.6	7.2	8.1	6.9	7.3	6.9	7.3
Poverty Status	Above the poverty line (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.7	6.5	6.8	6.5	8.6
		Standards	6.7	7.1	6.7	9.2	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.0	6.7	7.9	6.5	6.8	6.5	7.1
	Below poverty line (0-99)	Controls	6.9	7.2	6.8	9.5	6.9	7.2	6.8	9.1	6.9	7.2	6.8	9.0	6.8	7.1	6.7	8.9	6.6	7.0	6.5	8.8
		Standards	6.9	7.2	6.8	9.5	6.9	7.2	6.8	8.6	6.9	7.2	6.8	8.4	6.8	7.1	6.7	7.9	6.6	6.9	6.5	7.1
Redlined Areas	HOLC Grades A-C (0-99)	Controls	7.4	7.9	7.5	10.5	7.4	7.9	7.5	9.6	7.4	7.9	7.5	9.6	7.2	7.8	7.5	9.5	7.0	7.6	7.4	9.4
		Standards	7.4	7.9	7.5	10.5	7.4	7.9	7.5	9.1	7.4	7.9	7.5	9.1	7.2	7.8	7.5	8.4	7.0	7.6	7.3	7.5
	HOLC Grade D (0-99)	Controls	7.7	8.0	7.7	10.4	7.7	8.0	7.7	9.7	7.7	8.0	7.7	9.7	7.5	7.9	7.7	9.5	7.2	7.7	7.6	9.4
		Standards	7.7	8.0	7.7	10.4	7.7	8.0	7.7	9.3	7.7	8.0	7.7	9.2	7.6	7.9	7.7	8.5	7.2	7.7	7.5	7.6
	Ungraded by HOLC (0-99)	Controls	6.5	7.0	6.7	9.0	6.4	7.0	6.7	8.7	6.4	7.0	6.6	8.7	6.4	7.0	6.6	8.6	6.3	6.8	6.4	8.4
		Standards	6.5	7.0	6.7	8.9	6.4	7.0	6.7	8.3	6.4	7.0	6.6	8.2	6.4	7.0	6.6	7.7	6.3	6.8	6.4	7.0
Age	Adults (18-64)	Controls	6.8	7.1	6.8	9.3	6.7	7.1	6.8	9.0	6.7	7.1	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.7
		Standards	6.8	7.1	6.8	9.3	6.7	7.1	6.8	8.5	6.7	7.1	6.7	8.4	6.7	7.1	6.7	7.9	6.5	6.9	6.5	7.1
	Children (0-17)	Controls	6.7	7.2	6.8	9.3	6.7	7.2	6.8	9.0	6.7	7.2	6.7	8.9	6.6	7.1	6.7	8.8	6.5	6.9	6.5	8.7
		Standards	6.7	7.2	6.8	9.3	6.7	7.2	6.8	8.5	6.7	7.2	6.7	8.4	6.7	7.1	6.7	7.9	6.5	6.9	6.5	7.1
	Older Adults (65-99)	Controls	6.6	6.9	6.6	9.2	6.6	6.9	6.6	8.8	6.6	6.9	6.5	8.8	6.5	6.9	6.5	8.6	6.4	6.7	6.3	8.5
		Standards	6.6	6.9	6.6	9.1	6.6	6.9	6.6	8.4	6.6	6.9	6.5	8.3	6.5	6.8	6.5	7.8	6.4	6.7	6.3	7.1
Sex	Females (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6
		Standards	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.0	6.7	7.9	6.5	6.8	6.5	7.1
	Males (0-99)	Controls	6.7	7.1	6.7	9.3	6.7	7.1	6.7	8.9	6.7	7.1	6.7	8.9	6.6	7.0	6.7	8.8	6.5	6.9	6.5	8.6
		Standards	6.7	7.1	6.7	9.2	6.7	7.1	6.7	8.5	6.7	7.1	6.7	8.4	6.6	7.0	6.7	7.9	6.5	6.8	6.4	7.1

Figure 6-26 Heat Map of Regional Average Annual $PM_{2.5}$ Concentrations (µg/m³) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Standard Levels in 2032

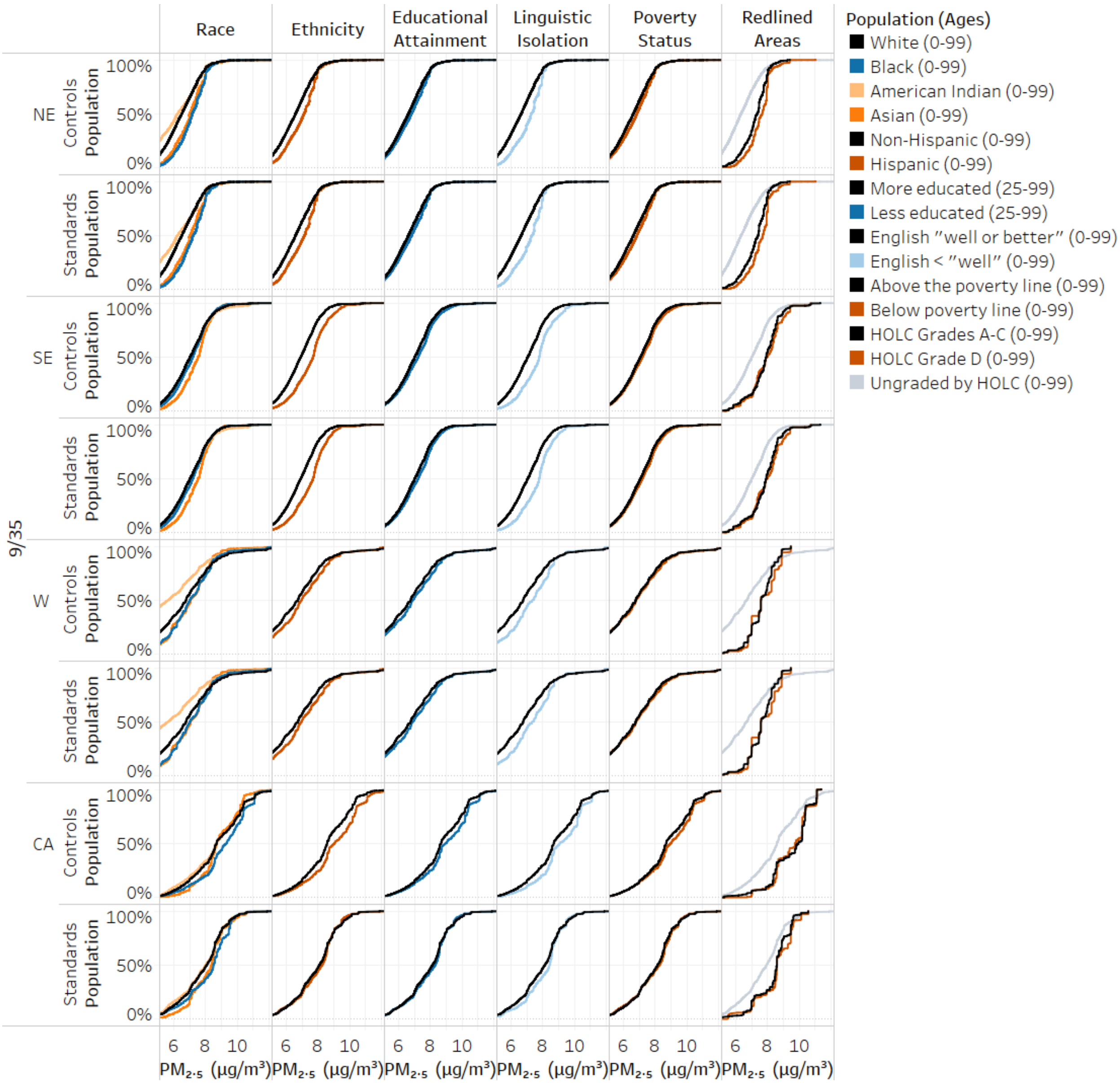

Figure 6-27 **Regional Distributions of Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the 12/35 and Revised 9/35 Standard Levels in 2032**

6.6.4.2 Absolute Regional Exposure Changes When Moving from Current Standard to Revised and Alternative Standard Levels

Regional absolute exposure changes are shows as averages (Figure 6-28) and as distributions (Figure 6-29). Again, absolute changes in exposure are greater associated with the "Standards" than with the "Controls" associated with 9/35 in CA.

Population Group	Population (Ages)	Attainment	12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
			NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
Race	White (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.6
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
	American Indian (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.5	0.2	0.2	0.2	0.6
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.0	0.1	1.3	0.2	0.2	0.2	2.0
	Asian (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.0	0.6	0.3	0.4	0.3	0.8
		Standards	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.7	0.1	0.1	0.0	1.3	0.3	0.4	0.3	2.1
	Black (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.2	0.0	0.1	0.6	0.3	0.2	0.3	0.7
		Standards	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.1	0.0	0.1	1.6	0.4	0.2	0.4	2.4
Ethnicity	Non-Hispanic (0-99)	Controls	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.7	0.1	0.0	0.0	1.2	0.2	0.2	0.2	1.9
	Hispanic (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.4	0.3	0.7
		Standards	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.1	0.2	0.1	1.6	0.3	0.5	0.4	2.4
Educational Attainment	More educated (25-99)	Controls	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.0	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.8	0.1	0.1	0.1	1.3	0.2	0.2	0.3	2.0
	Less educated (25-99)	Controls	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.3	0.3	0.7
		Standards	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.1	0.1	0.1	1.6	0.3	0.3	0.4	2.4
Employment Status	Employed (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
	Unemployed (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.3	0.3	0.7
		Standards	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.1	0.1	0.1	1.5	0.3	0.3	0.3	2.3
	Not in the labor force (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
Insurance Status	Insured (0-64)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
	Unisured (0-64)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.3	0.3	0.7
		Standards	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.1	0.1	0.1	1.5	0.3	0.3	0.3	2.3
Linguistic Isolation	English "well or better" (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.3	0.2	0.2	0.3	2.1
	English < "well" (0-99)	Controls	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.3	0.4	0.4	0.7
		Standards	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.1	0.2	0.1	1.6	0.3	0.5	0.4	2.4
Poverty Status	Above the poverty line (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.3	0.2	0.3	0.3	2.1
	Below poverty line (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.1	0.1	0.6	0.2	0.2	0.3	0.7
		Standards	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.1	0.1	0.1	1.5	0.3	0.3	0.3	2.3
Redlined Areas	HOLC Grades A-C (0-99)	Controls	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.2	0.1	0.0	1.0	0.4	0.4	0.1	1.1
		Standards	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.4	0.2	0.1	0.0	2.1	0.4	0.4	0.2	3.0
	HOLC Grade D (0-99)	Controls	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.2	0.0	0.0	0.9	0.4	0.3	0.1	1.1
		Standards	0.0	0.0	0.0	1.2	0.0	0.0	0.0	1.2	0.1	0.0	0.0	1.9	0.5	0.3	0.3	2.8
	Ungraded by HOLC (0-99)	Controls	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.4	0.2	0.2	0.2	0.6
		Standards	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.8	0.1	0.1	0.1	1.2	0.2	0.3	0.3	1.9
Age	Adults (18-64)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
	Children (0-17)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.3	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.2
	Older Adults (65-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.0	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.8	0.1	0.0	0.1	1.3	0.2	0.2	0.2	2.0
Sex	Females (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1
	Males (0-99)	Controls	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.7
		Standards	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.1	0.1	0.1	1.4	0.2	0.3	0.3	2.1

Figure 6-28 Heat Map of National Average Annual Reductions in $PM_{2.5}$ Concentrations (µg/m^3) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032

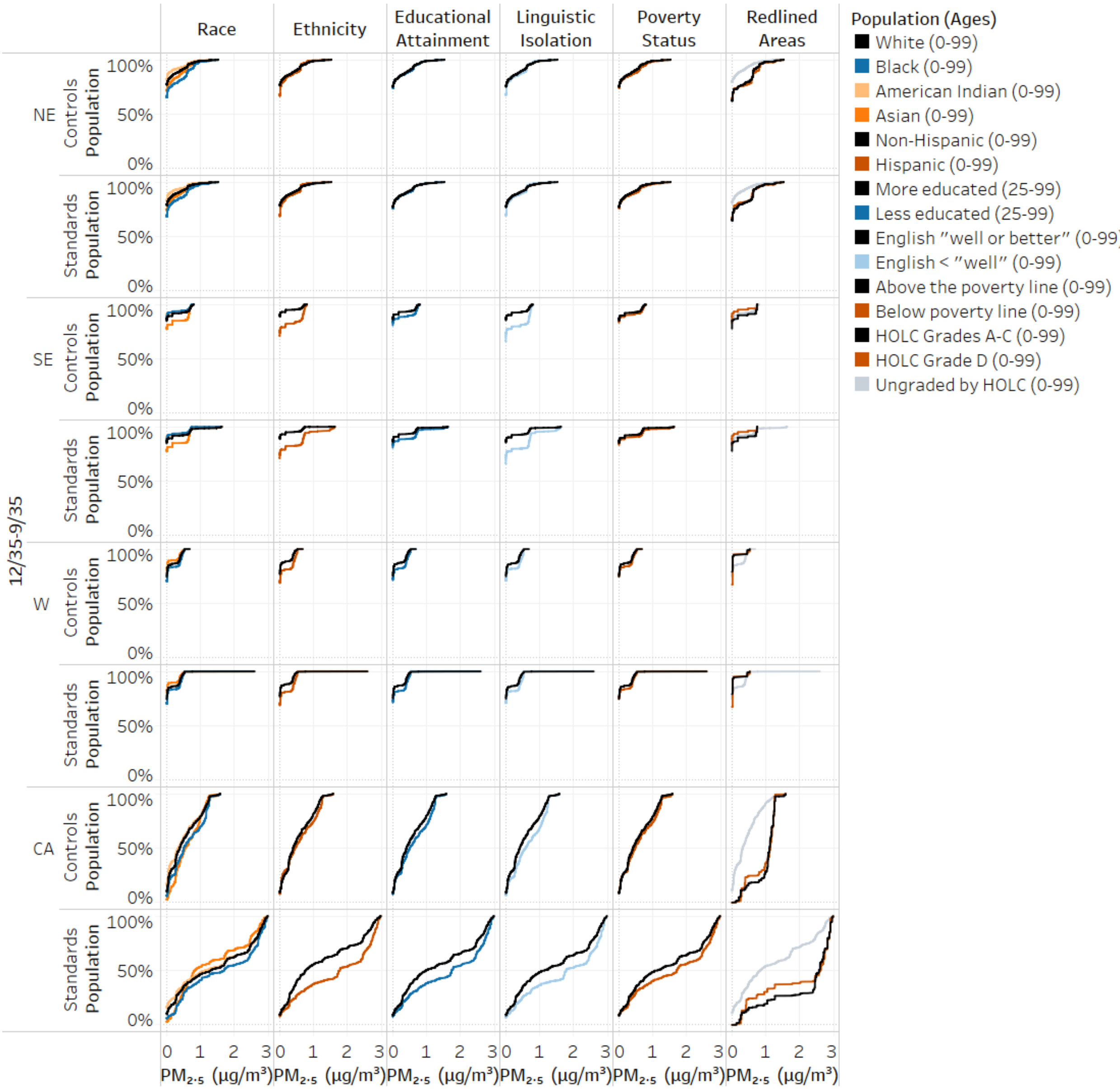

Figure 6-29 Regional Distributions of Annual $PM_{2.5}$ Concentration Reductions When Moving From 12/35-9/35 Associated Either with Control Strategies or Meeting the Standards in 2032

6.6.4.3 Proportional Regional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

The proportionality of regional changes in demographic-specific $PM_{2.5}$ concentrations when moving from air quality scenarios associated with meeting the standards, as opposed to air quality scenarios associated with control strategies, when moving from current standards to more stringent alternative standard levels are provided in Figure 6-30. Dividing the country into the four regions shows that air quality associated with the "Standards" in CA would lead to substantially greater proportional $PM_{2.5}$ concentration reductions under all scenarios evaluated. Also, differences between air quality scenarios associated with "Controls" are slightly larger than differences associated with the "Standards" when moving to lower alternative standard levels.

			Scenario / Region union															
			12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
Population Groups	Populations (Ages)	Attainment	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Reference	All (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.3	3.5	7.2
		Standards	0.2	0.1	0.0	8.4	0.2	0.1	0.6	9.6	1.3	1.0	0.8	14.8	3.5	3.6	4.0	23.0
Race	White (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.4	0.8	0.8	5.5	3.0	3.2	3.4	6.9
		Standards	0.2	0.1	0.0	8.6	0.2	0.1	0.6	10.0	1.2	1.0	0.9	15.0	3.2	3.6	3.9	23.0
	American Indian (0-99)	Controls	0.1	0.0	0.0	3.9	0.1	0.0	0.3	4.5	1.1	0.6	0.9	5.2	2.6	3.3	3.1	6.4
		Standards	0.1	0.0	0.0	8.5	0.1	0.0	0.7	10.0	1.0	0.7	0.9	14.7	2.8	3.4	3.5	22.3
	Asian (0-99)	Controls	0.2	0.0	0.0	3.8	0.2	0.0	0.2	4.2	1.6	1.4	0.6	6.5	3.6	5.3	3.6	8.7
		Standards	0.2	0.0	0.0	7.0	0.2	0.0	0.2	7.9	1.3	1.4	0.6	13.6	3.8	5.3	4.0	22.2
	Black (0-99)	Controls	0.2	0.0	0.0	4.5	0.2	0.0	0.2	5.1	2.2	0.6	1.0	6.3	4.6	3.3	4.9	7.6
		Standards	0.2	0.0	0.0	9.4	0.2	0.0	0.3	10.3	1.7	0.6	1.0	16.2	4.9	3.3	5.5	24.5
Ethnicity	Non-Hispanic (0-99)	Controls	0.2	0.0	0.0	3.5	0.2	0.0	0.4	4.1	1.5	0.5	0.7	5.6	3.2	2.8	3.0	7.5
		Standards	0.2	0.0	0.0	6.9	0.2	0.0	0.6	8.3	1.3	0.5	0.7	13.0	3.4	2.8	3.4	21.1
	Hispanic (0-99)	Controls	0.1	0.3	0.0	4.6	0.1	0.3	0.3	4.9	1.5	1.6	1.2	5.8	3.7	4.6	4.9	6.9
		Standards	0.1	0.3	0.0	10.0	0.1	0.3	0.6	11.2	1.3	2.1	1.2	16.9	4.0	5.9	5.5	25.1
Educational Attainment	More educated (25-99)	Controls	0.2	0.1	0.0	3.8	0.2	0.1	0.4	4.3	1.5	0.7	0.8	5.6	3.2	3.1	3.3	7.3
		Standards	0.2	0.1	0.0	7.8	0.2	0.1	0.6	9.1	1.3	0.8	0.8	14.1	3.4	3.4	3.8	22.3
	Less educated (25-99)	Controls	0.1	0.2	0.0	4.9	0.1	0.2	0.4	5.3	1.5	1.1	1.1	6.2	3.5	3.6	4.6	7.4
		Standards	0.1	0.2	0.0	9.8	0.1	0.2	0.7	11.0	1.3	1.4	1.1	16.7	3.7	4.3	5.2	24.9
Employment Status	Employed (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.8	3.2	3.4	3.4	7.3
		Standards	0.2	0.1	0.0	8.2	0.2	0.1	0.6	9.5	1.3	0.9	0.8	14.6	3.5	3.6	4.0	23.0
	Unemployed (0-99)	Controls	0.2	0.1	0.0	4.6	0.2	0.1	0.3	5.0	1.7	1.0	0.8	6.0	3.6	3.7	3.8	7.3
		Standards	0.2	0.1	0.0	9.4	0.2	0.1	0.6	10.6	1.4	1.2	0.8	16.0	3.8	4.1	4.4	24.2
	Not in the labor force (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.6	3.3	3.2	3.5	7.1
		Standards	0.2	0.1	0.0	8.4	0.2	0.1	0.6	9.7	1.3	1.0	0.9	14.9	3.5	3.6	4.0	23.1
Insurance Status	Insured (0-64)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.4	3.4	7.2
		Standards	0.2	0.1	0.0	8.4	0.2	0.1	0.6	9.6	1.3	0.9	0.8	14.9	3.5	3.7	4.0	23.0
	Unisured (0-64)	Controls	0.2	0.2	0.0	4.6	0.2	0.2	0.4	5.1	1.7	1.2	1.0	5.9	3.7	4.0	4.1	7.1
		Standards	0.2	0.2	0.0	9.6	0.2	0.2	0.7	10.9	1.5	1.5	1.0	16.3	4.0	4.7	4.7	24.5
Linguistic Isolation	English "well or better" (0-99)	Controls	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.5	0.8	0.8	5.6	3.2	3.2	3.4	7.2
		Standards	0.2	0.1	0.0	8.2	0.2	0.1	0.6	9.5	1.3	0.9	0.8	14.6	3.5	3.5	3.9	22.7
	English < "well" (0-99)	Controls	0.1	0.3	0.0	5.1	0.1	0.3	0.2	5.4	1.5	1.8	1.1	6.5	3.8	5.1	5.1	7.6
		Standards	0.1	0.3	0.0	10.0	0.1	0.3	0.6	11.0	1.3	2.4	1.1	16.9	4.1	6.4	5.8	25.1
Poverty Status	Above the poverty line (0-99)	Controls	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.5	0.8	0.8	5.6	3.2	3.3	3.4	7.2
		Standards	0.2	0.1	0.0	8.1	0.2	0.1	0.6	9.4	1.3	0.9	0.8	14.5	3.4	3.6	3.9	22.7
	Below poverty line (0-99)	Controls	0.2	0.2	0.0	4.6	0.2	0.2	0.4	5.1	1.7	0.9	1.0	6.0	3.6	3.3	4.0	7.2
		Standards	0.2	0.2	0.0	9.5	0.2	0.2	0.6	10.7	1.4	1.2	1.0	16.3	3.8	4.0	4.5	24.4
Redlined Areas	HOLC Grades A-C (0-99)	Controls	0.2	0.0	0.0	8.2	0.2	0.0	0.1	8.4	2.3	1.0	0.3	9.4	5.2	4.5	1.4	10.2
		Standards	0.2	0.0	0.0	12.7	0.2	0.0	0.1	13.0	2.1	1.0	0.3	20.2	5.5	4.5	2.4	28.6
	HOLC Grade D (0-99)	Controls	0.2	0.0	0.0	7.3	0.2	0.0	0.2	7.4	2.4	0.5	0.3	9.0	5.8	3.4	1.8	10.2
		Standards	0.2	0.0	0.0	11.2	0.2	0.0	0.2	11.5	1.9	0.4	0.3	18.4	5.9	3.4	3.7	27.0
	Ungraded by HOLC (0-99)	Controls	0.2	0.1	0.0	2.8	0.2	0.1	0.4	3.4	1.2	0.8	0.9	4.6	2.4	3.2	3.6	6.3
		Standards	0.2	0.1	0.0	7.1	0.2	0.1	0.6	8.7	1.0	1.0	0.9	13.3	2.6	3.6	4.1	21.3
Age	Adults (18-64)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.8	3.3	3.4	3.5	7.3
		Standards	0.2	0.1	0.0	8.4	0.2	0.1	0.6	9.6	1.3	1.0	0.8	14.9	3.5	3.8	4.1	23.1
	Children (0-17)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.9	0.8	5.6	3.3	3.5	3.4	7.1
		Standards	0.2	0.1	0.0	8.6	0.2	0.1	0.6	9.9	1.3	1.1	0.8	15.2	3.5	4.0	3.9	23.4
	Older Adults (65-99)	Controls	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.4	1.4	0.6	0.8	5.6	3.1	2.7	3.3	7.2
		Standards	0.2	0.1	0.0	7.9	0.2	0.1	0.7	9.2	1.3	0.7	0.8	14.1	3.3	2.9	3.8	22.1
Sex	Females (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.3	3.3	3.5	7.2
		Standards	0.2	0.1	0.0	8.4	0.2	0.1	0.6	9.7	1.3	1.0	0.8	14.9	3.5	3.6	4.0	23.0
	Males (0-99)	Controls	0.2	0.1	0.0	4.0	0.2	0.1	0.4	4.5	1.5	0.8	0.8	5.7	3.2	3.3	3.5	7.2
		Standards	0.2	0.1	0.0	8.3	0.2	0.1	0.6	9.6	1.3	1.0	0.8	14.8	3.4	3.7	4.0	22.9

Figure 6-30 Heat Map of Regional Percent Reductions (%) in Average Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Standard Levels in 2032

6.6.5 National EJ Analysis of Total Mortality Rates and Rate Changes Associated with Meeting the Standards

National absolute mortality rate burdens and changes in absolute mortality rates for air quality associated with the “Standards” and “Controls” are provided in Section 6.6.5.1. National proportional changes in mortality rate burdens are provided in Section 6.6.5.2.

National and regional changes in demographic-specific mortality rates when moving from current to alternative standard levels under air quality surfaces associated with either control strategies or meeting the standards levels are provided in Sections respectively.

6.6.5.1 Absolute Mortality Rates Under Current and Alternative Standard Levels and Mortality Rate Reductions When Moving from Current to Revised and Alternative Standard Levels

Using concentration-response relationships derived from Di et al., 2017 and Pope III et al., 2019, absolute mortality rates and mortality rate changes were similar under air quality scenarios associated with the “Standards” as opposed to the “Controls”, except for mortality rate reductions in the distributional figure for older Asian and Hispanic populations when moving to 9/35 or 8/35 (Figure 6-31, Figure 6-32, and Figure 6-33). This is because while reductions can be small when averaged across the contiguous U.S., due to the inclusion of areas with no $PM_{2.5}$ air quality improvements, reductions can be substantial within certain tracts.

Study (Ages)	Population Group	Number of People	12/35		10/35		12/35-10/35		10/30		12/35-10/30		9/35		12/35-9/35		8/35		12/35-8/35	
			Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Di 2017 (65-99)	Reference	75M	186	186	185	184	1	2	185	184	1	3	183	181	3	5	180	176	7	11
	White	62M	163	163	162	162	1	2	162	161	1	2	161	159	2	4	158	155	5	9
	American Indian	1M	151	151	150	149	1	3	150	148	2	3	149	146	2	5	147	142	5	10
	Asian	4M	145	145	142	139	4	7	142	138	4	7	139	133	7	13	136	124	10	23
	Black	8M	464	464	462	460	3	5	462	460	3	5	456	453	9	12	445	438	22	29
	Hispanic	9M	206	206	203	199	4	8	203	198	4	9	201	193	6	15	197	183	10	25
Pope 2019 (18-99)	Reference	287M	90	90	90	89	1	1	90	89	1	1	89	88	2	3	87	85	3	5
	NH White	167M	104	104	104	103	0	1	104	103	1	1	103	102	1	2	101	100	3	5
	NH American Indian	2M	42	42	42	42	0	0	42	42	0	1	42	42	0	1	41	41	1	2
	NH Asian	21M	34	34	33	33	1	1	33	32	1	2	32	31	1	3	32	29	2	5
	NH Black	37M	103	103	102	102	1	1	102	102	1	1	101	100	2	3	99	97	5	6
	Hispanic	59M	69	68	67	66	1	3	67	66	1	3	67	64	2	5	65	61	4	9

Figure 6-31 Heat Map of National Average Annual Total Mortality Rates (per 100K People) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Levels in 2032

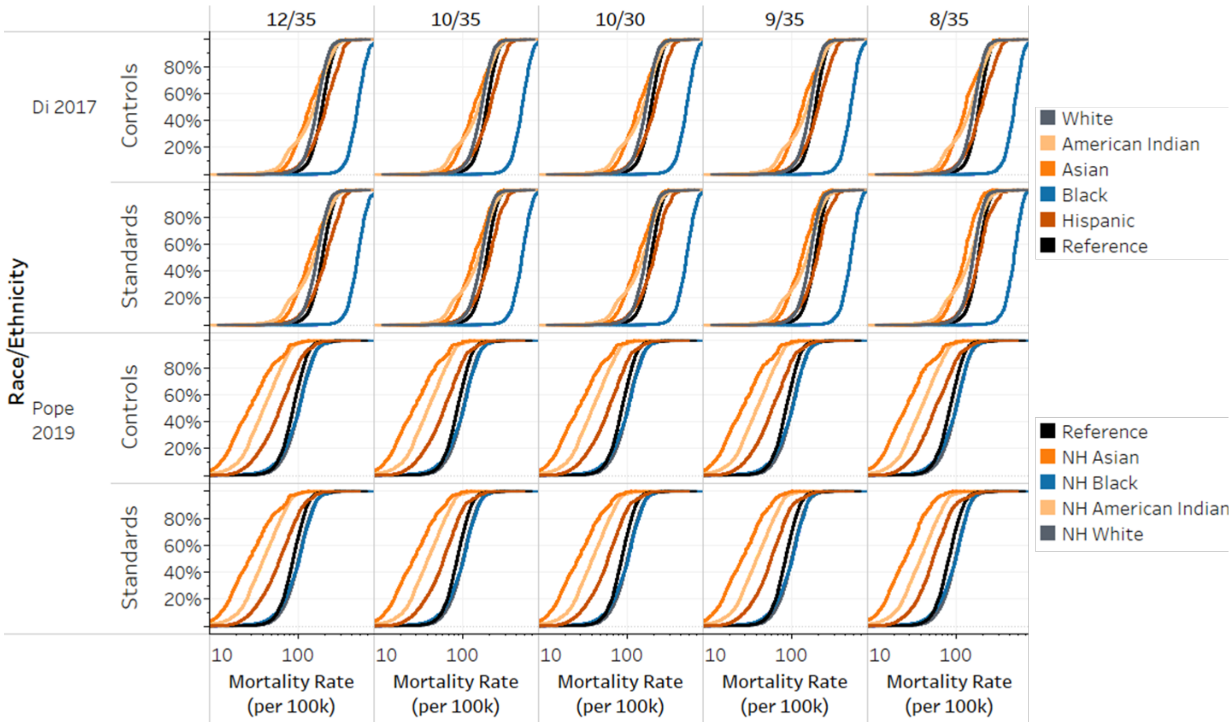

Figure 6-32 National Distributions of Total Mortality Rates (per 100k) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Levels in 2032 (NH, Non-Hispanic)

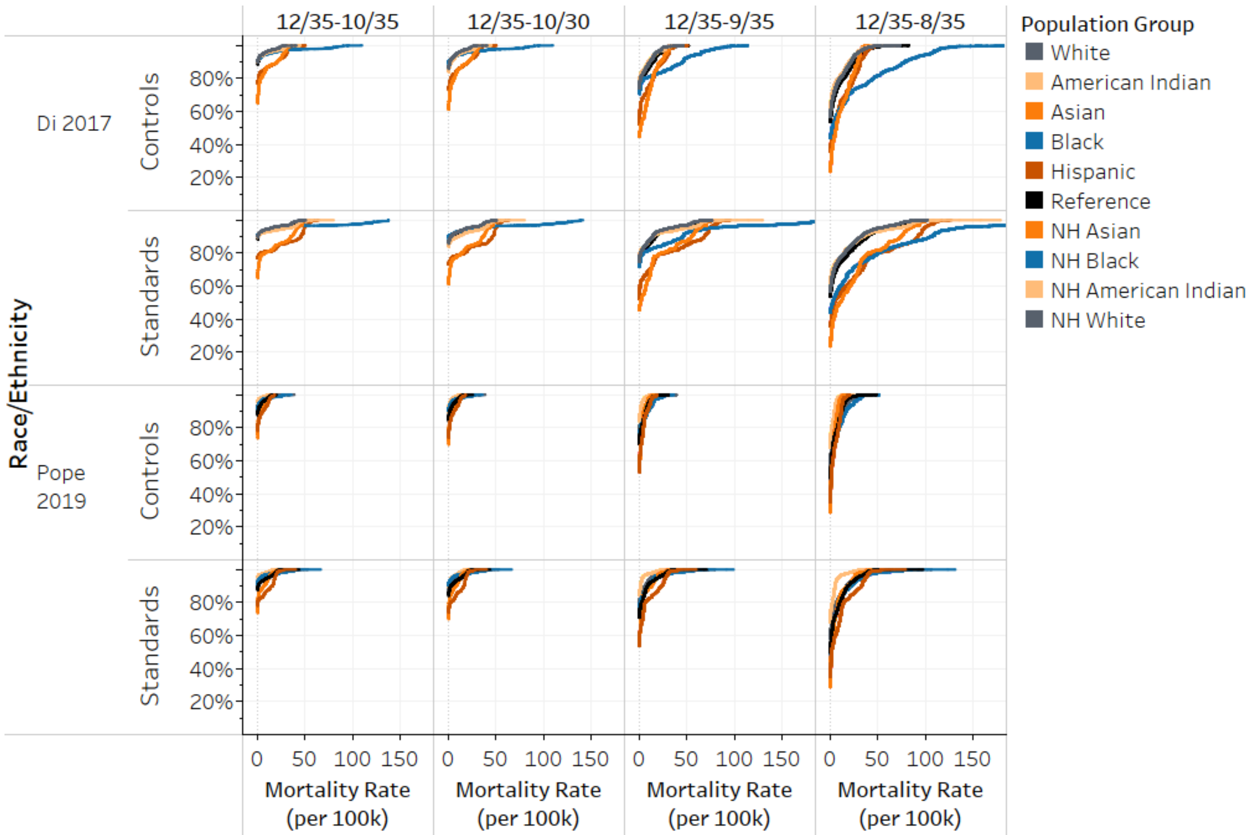

Figure 6-33 National Distributions of Annual Total Mortality Rate Reductions (per 100k) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032

6.6.5.2 Proportional Regional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Proportional reductions when moving to air quality scenarios associated with the "Standards" led to approximately twice the level of disparity mitigation for most populations when moving to most lower standard levels (Figure 6-34). Some populations and scenarios led to even great disparity mitigations, such as Hispanic populations for 12/35-9/35 and 12/35-8/35.

Study	Race/Ethnicity	Attainment	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
Di 2017 (65-99)	Reference	Controls	0.6	0.8	1.7	3.6
		Standards	1.2	1.4	2.8	5.8
	White	Controls	0.6	0.7	1.5	3.3
		Standards	1.1	1.3	2.5	5.3
	American Indian	Controls	0.8	1.0	1.5	3.2
		Standards	1.7	2.3	3.4	6.4
	Asian	Controls	2.6	2.9	4.7	7.1
		Standards	4.6	5.1	9.2	15.6
	Black	Controls	0.6	0.6	2.0	4.7
		Standards	1.0	1.1	2.7	6.3
	Hispanic	Controls	1.8	2.0	3.0	5.0
		Standards	3.8	4.2	7.1	12.2
Pope 2019 (18-99)	Reference	Controls	0.7	0.8	1.7	3.7
		Standards	1.2	1.5	2.9	5.9
	NH White	Controls	0.4	0.5	1.3	3.1
		Standards	0.7	1.0	2.0	4.5
	NH American Indian	Controls	0.4	0.6	0.9	2.3
		Standards	0.8	1.3	1.7	3.8
	NH Asian	Controls	2.4	2.7	4.4	6.9
		Standards	4.3	4.7	8.6	14.8
	NH Black	Controls	0.6	0.6	2.0	4.7
		Standards	1.0	1.0	2.6	6.2
	Hispanic	Controls	1.9	2.0	3.1	5.3
		Standards	3.8	4.2	7.2	12.5

Figure 6-34 Heat Map of National Percent Reductions (%) in Average Mortality Rate Reductions Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032

6.6.6 Regional National EJ Analysis of Total Mortality Rates and Mortality Rate Changes Associated with Meeting the Standards

Absolute regional mortality rate burdens are shown in Section 6.6.4.1, absolute regional mortality rate changes when moving to lower standard levels are in Section 6.6.4.2, and proportional regional mortality rate changes when moving to lower standard levels are in Section 6.6.4.3.

6.6.6.1 Absolute Regional Mortality Rates Under Current, Revised, and Alternative Standard Levels

Regional trends are virtually identical when comparing across air quality scenarios associated with the "Controls " and the "Standards" for the current standards, although at more stringent standard levels, lower mortality rates are observed in air quality scenarios associated with the "Standards" (Figure 6-35 and Figure 6-36).

			12/35				10/35				10/30				9/35				8/35			
			NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di 2017	Reference	Controls	184	183	172	220	184	183	172	212	184	183	172	210	181	182	171	208	178	179	167	205
		Standards	184	183	172	219	184	183	172	203	184	183	171	200	182	182	171	189	178	178	166	172
	White	Controls	160	161	153	198	160	161	153	191	160	161	152	190	158	160	152	188	156	157	148	185
		Standards	160	161	153	197	160	161	153	183	160	161	152	180	158	160	152	171	156	157	147	156
	American Indian	Controls	130	161	133	202	129	161	133	195	129	161	133	193	128	160	133	192	126	157	131	190
		Standards	130	161	133	201	129	161	133	185	129	161	132	182	128	160	133	173	126	157	130	159
	Asian	Controls	106	103	128	199	106	103	128	191	106	103	127	190	105	101	127	186	102	97	124	183
		Standards	106	103	128	199	106	103	128	184	106	103	127	182	105	101	127	171	102	97	123	154
	Black	Controls	467	447	417	596	466	447	417	569	466	447	416	567	456	445	413	559	444	435	396	552
		Standards	467	447	417	593	466	447	417	541	466	447	416	536	458	445	413	503	443	435	393	456
	Hispanic	Controls	157	211	181	249	157	210	181	238	157	210	181	237	155	208	179	235	151	204	174	233
		Standards	157	211	181	248	157	210	181	223	157	210	180	221	155	207	179	207	151	200	172	187
Pope 2019	Reference	Controls	91	89	82	97	91	89	82	94	91	89	82	93	90	89	82	92	88	87	80	91
		Standards	91	89	82	97	91	89	82	90	91	89	82	89	90	89	82	84	88	87	79	77
	NH White	Controls	100	106	97	138	100	106	97	134	100	106	97	133	99	105	97	132	97	104	95	130
		Standards	100	106	97	138	100	106	97	130	100	106	97	127	99	105	97	122	97	104	94	112
	NH Asian	Controls	23	23	31	60	23	23	31	57	23	23	31	57	22	22	31	56	22	21	30	55
		Standards	23	23	31	60	23	23	31	55	23	23	31	55	22	22	31	51	22	21	30	46
	NH Black	Controls	104	99	79	155	104	99	79	148	104	99	79	148	101	99	78	146	99	96	75	144
		Standards	104	99	79	155	104	99	79	141	104	99	79	140	102	99	78	131	98	96	74	118
	NH American Indian	Controls	40	50	40	60	40	50	40	59	40	50	40	58	40	50	40	58	40	49	40	57
		Standards	40	50	40	60	40	50	40	56	40	50	40	55	40	50	40	53	40	49	39	50
	Hispanic	Controls	49	73	58	86	49	73	58	82	49	73	57	82	48	72	57	81	47	71	55	80
		Standards	49	73	58	86	49	73	58	77	49	73	57	76	48	72	57	72	47	69	55	65

Figure 6-35 Heat Map of Regional Average Annual Total Mortality Rates (per 100K People) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Levels in 2032 (NH, Non-Hispanic)

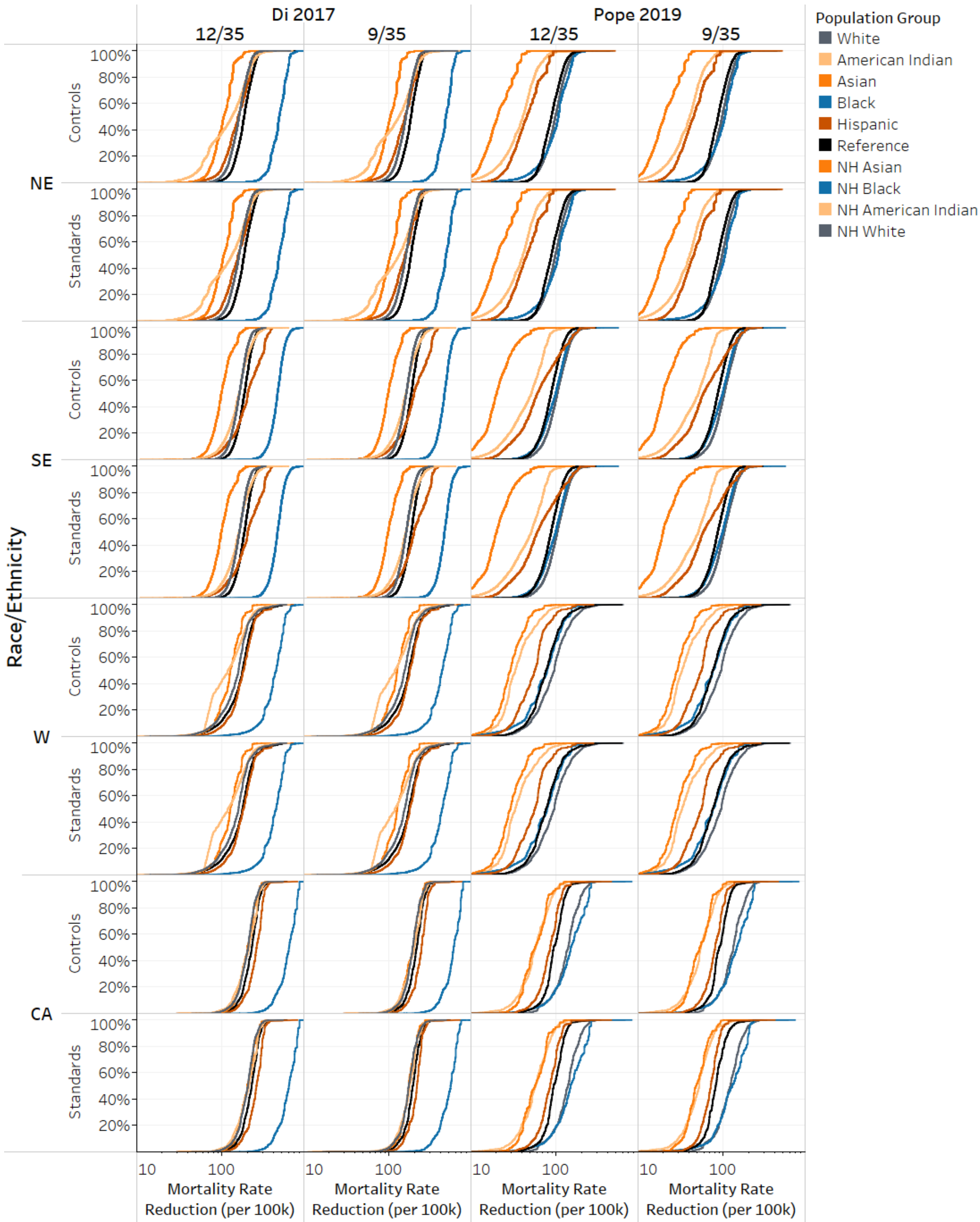

Figure 6-36 Regional Distributions of Total Mortality Rates (per 100k) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current, Revised, and Alternative PM NAAQS Levels in 2032

6.6.6.2 Absolute Regional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Absolute mortality rate reductions per 100k individuals are most notably larger under air quality scenarios associated with the “Standards” as opposed to with the “Controls” in CA (Figure 6-37 and Figure 6-38).

			12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
			NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di 2017	Reference	Controls	0.4	0.1	0.0	8.7	0.4	0.1	0.7	10.0	2.9	1.0	1.3	12.4	6.0	4.8	5.6	16.0
		Standards	0.4	0.1	0.1	17.5	0.4	0.1	1.2	20.6	2.5	1.2	1.4	31.3	6.4	5.2	6.5	49.1
	White	Controls	0.3	0.1	0.0	7.3	0.3	0.1	0.7	8.6	2.3	0.8	1.1	10.4	4.8	3.9	4.9	13.5
		Standards	0.3	0.1	0.1	15.2	0.3	0.1	1.1	18.4	2.0	1.0	1.3	27.2	5.0	4.3	5.7	42.8
	American Indian	Controls	0.2	0.0	0.0	8.2	0.2	0.0	0.4	9.6	1.6	0.6	0.7	10.7	3.6	3.9	2.7	13.0
		Standards	0.2	0.0	0.0	17.7	0.2	0.0	1.0	20.9	1.5	0.7	0.8	30.1	3.8	3.9	3.2	45.4
	Asian	Controls	0.1	0.0	0.0	9.5	0.1	0.0	0.2	10.3	2.0	2.3	0.6	14.3	4.5	6.9	4.2	18.1
		Standards	0.1	0.0	0.0	16.6	0.1	0.0	0.3	18.2	1.5	2.3	0.6	30.7	4.7	6.9	4.6	48.4
	Black	Controls	1.3	0.0	0.0	31.7	1.3	0.0	0.6	35.0	12.7	2.4	3.9	43.7	26.7	13.6	24.0	51.9
		Standards	1.3	0.0	0.0	61.9	1.3	0.0	1.1	67.3	10.2	2.4	4.0	105.5	27.7	13.5	27.5	157.8
	Hispanic	Controls	0.1	0.9	0.0	12.7	0.1	0.9	0.4	13.6	2.3	3.1	1.9	15.5	6.3	7.9	8.3	18.3
		Standards	0.1	0.9	0.0	27.5	0.1	0.9	0.9	30.3	2.0	4.6	1.9	45.4	6.6	12.1	9.7	66.4
Pope 2019	Reference	Controls	0.2	0.0	0.0	4.0	0.2	0.0	0.3	4.5	1.5	0.5	0.6	5.7	3.1	2.4	2.8	7.2
		Standards	0.2	0.0	0.0	8.0	0.2	0.0	0.6	9.4	1.3	0.6	0.7	14.3	3.2	2.6	3.2	22.3
	NH White	Controls	0.2	0.0	0.0	4.5	0.2	0.0	0.4	5.5	1.4	0.4	0.7	6.9	3.0	2.4	3.0	9.4
		Standards	0.2	0.0	0.0	9.0	0.2	0.0	0.7	11.6	1.3	0.4	0.8	16.9	3.1	2.4	3.5	27.7
	NH Asian	Controls	0.0	0.0	0.0	2.8	0.0	0.0	0.1	3.0	0.4	0.4	0.2	4.2	0.9	1.4	1.0	5.4
		Standards	0.0	0.0	0.0	4.9	0.0	0.0	0.1	5.4	0.3	0.4	0.2	9.1	0.9	1.4	1.2	14.4
	NH Black	Controls	0.3	0.0	0.0	8.1	0.3	0.0	0.1	9.0	2.8	0.5	0.8	11.3	5.9	3.0	4.6	13.4
		Standards	0.3	0.0	0.0	15.9	0.3	0.0	0.2	17.2	2.3	0.6	0.8	27.1	6.1	3.0	5.3	40.5
	NH American Indian	Controls	0.0	0.0	0.0	1.9	0.0	0.0	0.1	2.5	0.3	0.1	0.2	2.6	0.7	1.0	0.6	3.3
		Standards	0.0	0.0	0.0	4.1	0.0	0.0	0.3	5.3	0.3	0.1	0.2	7.2	0.8	1.0	0.7	11.1
	Hispanic	Controls	0.0	0.3	0.0	4.5	0.0	0.3	0.2	4.8	0.8	1.2	0.7	5.5	2.0	3.0	2.8	6.5
		Standards	0.0	0.3	0.0	9.7	0.0	0.3	0.3	10.7	0.7	1.7	0.7	16.1	2.1	4.4	3.2	23.4

Figure 6-37 Heat Map of Regional Average Annual Total Mortality Rate Reductions (per 100K People) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032 (NH, Non-Hispanic)

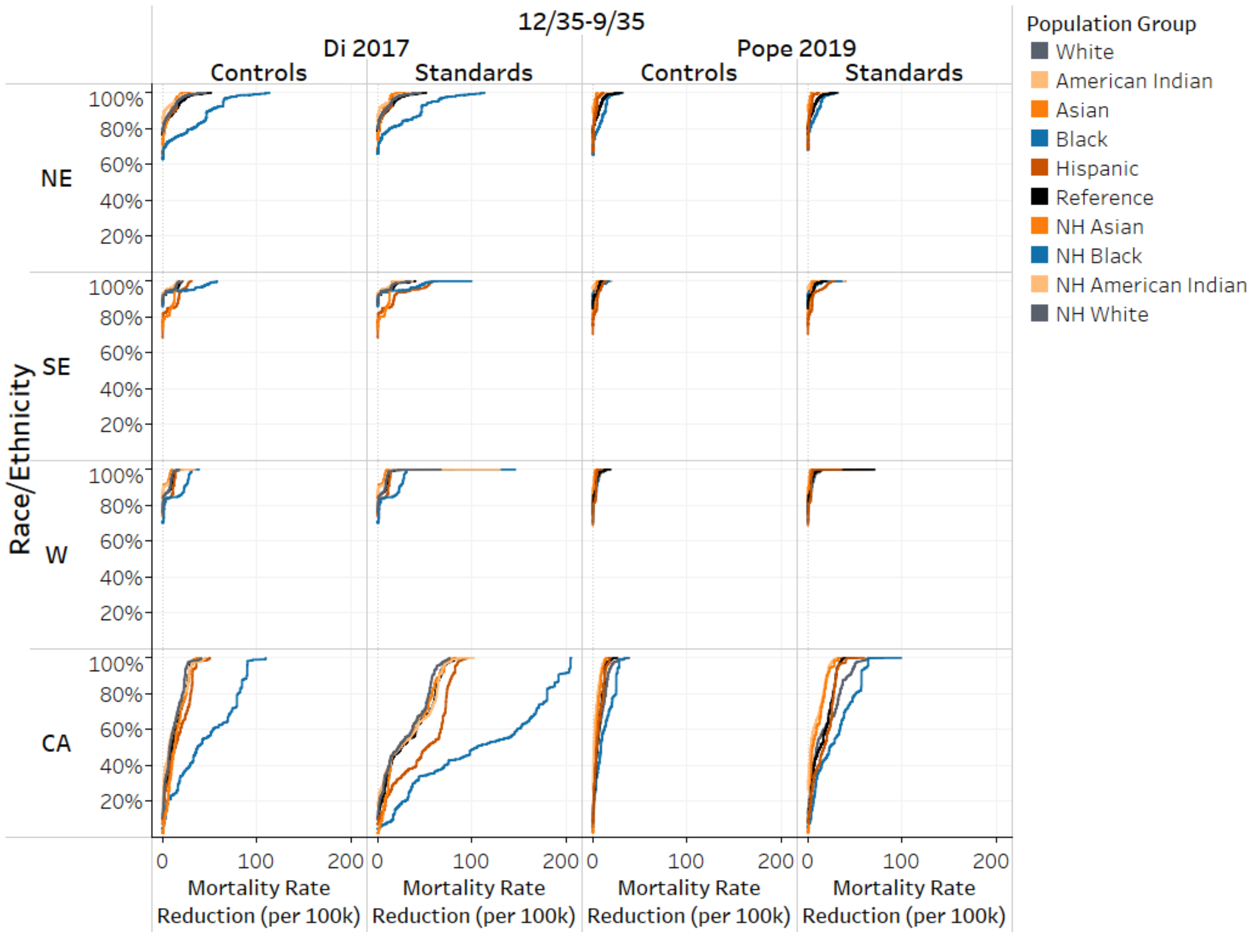

Figure 6-38 Regional Distributions of Average Annual Total Mortality Rate Reductions (per 100k) Associated Either with Control Strategies or with Meeting the Standards by Demographic for When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032

6.6.6.3 Proportional Regional Exposure Changes When Moving from Current to Revised and Alternative Standard Levels

Proportional changes also demonstrate that mortality rates disparities are expected to be further reduced on average for all populations in CA under the "Standards", as opposed to the "Controls", especially under more stringent alternative standard (Figure 6-39).

			12/35-10/35				12/35-10/30				12/35-9/35				12/35-8/35			
Study	Race/Ethnicity	Attainment	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
Di 2017 (65-99)	Reference	Controls	0.2	0.1	0.0	3.9	0.2	0.1	0.4	4.5	1.6	0.5	0.7	5.7	3.3	2.6	3.3	7.3
		Standards	0.2	0.1	0.0	8.0	0.2	0.1	0.7	9.4	1.4	0.6	0.8	14.3	3.5	2.8	3.8	22.4
	White	Controls	0.2	0.1	0.0	3.7	0.2	0.1	0.4	4.3	1.4	0.5	0.7	5.2	3.0	2.4	3.2	6.8
		Standards	0.2	0.1	0.0	7.7	0.2	0.1	0.7	9.3	1.3	0.6	0.8	13.8	3.1	2.7	3.7	21.7
	American Indian	Controls	0.1	0.0	0.0	4.1	0.1	0.0	0.3	4.8	1.3	0.4	0.6	5.3	2.8	2.4	2.1	6.4
		Standards	0.1	0.0	0.0	8.8	0.1	0.0	0.8	10.4	1.2	0.4	0.6	15.0	2.9	2.4	2.4	22.5
	Asian	Controls	0.1	0.0	0.0	4.7	0.1	0.0	0.1	5.1	1.8	2.2	0.5	7.1	4.2	6.7	3.3	9.1
		Standards	0.1	0.0	0.0	8.4	0.1	0.0	0.2	9.1	1.4	2.2	0.5	15.4	4.4	6.7	3.6	24.3
	Black	Controls	0.3	0.0	0.0	5.3	0.3	0.0	0.1	5.9	2.7	0.5	0.9	7.3	5.7	3.0	5.8	8.7
		Standards	0.3	0.0	0.0	10.4	0.3	0.0	0.3	11.3	2.2	0.5	1.0	17.8	5.9	3.0	6.6	26.6
	Hispanic	Controls	0.1	0.4	0.0	5.1	0.1	0.4	0.2	5.5	1.5	1.5	1.1	6.2	4.0	3.7	4.6	7.3
		Standards	0.1	0.4	0.0	11.1	0.1	0.4	0.5	12.2	1.3	2.2	1.1	18.3	4.2	5.7	5.3	26.7
Pope 2019 (18-99)	Reference	Controls	0.2	0.1	0.0	4.1	0.2	0.1	0.4	4.7	1.6	0.6	0.8	5.8	3.4	2.7	3.4	7.4
		Standards	0.2	0.1	0.0	8.2	0.2	0.1	0.7	9.7	1.4	0.7	0.8	14.7	3.5	2.9	3.9	22.9
	Hispanic	Controls	0.1	0.4	0.0	5.3	0.1	0.4	0.3	5.6	1.6	1.6	1.2	6.5	4.1	4.0	4.8	7.6
		Standards	0.1	0.4	0.0	11.4	0.1	0.4	0.5	12.6	1.3	2.3	1.2	18.8	4.3	6.0	5.6	27.4
	NH American Indian	Controls	0.1	0.0	0.0	3.2	0.1	0.0	0.3	4.2	1.0	0.2	0.5	4.3	2.0	2.1	1.7	5.4
		Standards	0.1	0.0	0.0	6.9	0.1	0.0	0.8	8.9	0.8	0.2	0.5	12.1	2.1	2.1	1.9	18.7
	NH Asian	Controls	0.1	0.0	0.0	4.6	0.1	0.0	0.2	5.1	1.7	2.0	0.6	7.1	4.0	6.5	3.3	9.0
		Standards	0.1	0.0	0.0	8.2	0.1	0.0	0.3	9.1	1.3	2.1	0.6	15.3	4.2	6.5	3.7	24.1
	NH Black	Controls	0.3	0.0	0.0	5.2	0.3	0.0	0.1	5.8	2.7	0.6	1.0	7.3	5.7	3.1	5.9	8.6
		Standards	0.3	0.0	0.0	10.3	0.3	0.0	0.2	11.1	2.2	0.6	1.0	17.5	5.9	3.1	6.8	26.2
	NH White	Controls	0.2	0.0	0.0	3.2	0.2	0.0	0.5	4.0	1.4	0.4	0.7	5.0	2.9	2.3	3.1	6.8
		Standards	0.2	0.0	0.0	6.5	0.2	0.0	0.7	8.4	1.3	0.4	0.8	12.2	3.1	2.3	3.6	20.0

Figure 6-39 Heat Map of Regional Percent Reductions (%) in Average Mortality Rate Reductions Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Revised and Alternative PM NAAQS Levels in 2032 (NH, Non-Hispanic)

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CHAPTER 7: LABOR IMPACTS

Overview

This chapter discusses baseline employment in some of the industries potentially affected by this rule. As economic activity shifts in response to a regulation, typically there will be a mix of declines and gains in employment in different parts of the economy over time and across regions. To present a complete picture, an employment impact analysis will describe the potential positive and negative changes in employment levels. Significant challenges arise, however, when trying to evaluate the employment effects due to an environmental regulation and separate them from employment effects due to a wide variety of other concurrent economic changes, including such important macroeconomic events as the coronavirus pandemic, or the state of the macroeconomy generally. Despite these challenges, the economics literature provides a constructive framework and empirical evidence that sheds light on the labor impacts of environmental regulation. To simplify, we focus on potential impacts on labor demand related to compliance behavior. Environmental regulation may also have important effects on labor supply through changes in worker health and productivity (Graff Zivin and Neidell, 2018).

7.1 Labor Impacts

Economic theory of labor demand indicates that employers affected by environmental regulation may increase their demand for some types of labor, decrease demand for other types, or for still other types, not change it at all (Morgenstern et al. 2002, Deschênes 2018, Berman and Bui 2001). To study labor demand impacts empirically, a growing literature has compared employment levels at facilities subject to an environmental regulation to employment levels at similar facilities not subject to that environmental regulation; some studies find no employment effects, and others find significant differences. For example, see (Berman and Bui 2001), (Greenstone 2002), (Ferris, Shadbegian and Wolverton 2014), and (Curtis 2018, 2020).

A variety of conditions can affect employment impacts of environmental regulation, including baseline labor market conditions and employer and worker characteristics such as occupation and industry. This baseline labor analysis is illustrative and focused on potential labor impacts in the emissions inventory sectors and industries that may apply end-of-pipe and area source controls, as identified in Chapter 3. We present information on baseline characteristics of labor markets in the affected emissions inventory sectors: non-electric generating unit (non-EGU) point, oil and gas point, non-point (area), residential wood combustion, and area fugitive dust. Baseline information presented includes employment levels, recent trends in employment, and labor intensity of production. We do not have detailed information on the industries that may require pollution controls, and in which states they may be required. Thus, the presentation of nationwide baseline information is merely suggestive of employment conditions in the industries that might be affected.

Table 7-1 presents baseline employment for industries that fall into the emissions inventory sectors of non-EGU point, oil and gas point, residential wood combustion, and area fugitive dust. The table shows national employment levels in 2021 and the percent change in employment over the ten years from 2011 to 2021 for the industries, and their corresponding North American Industry Classification System (NAICS) codes, identified as potentially affected industries under each emissions inventory sector. Non-EGU point sources include emissions units in the cement and concrete product manufacturing, basic chemical manufacturing, pulp, paper, and paperboard mills, iron and steel mills and ferroalloy manufacturing, non-ferrous metals production and processing, petroleum and coal products manufacturing, and mining industries. The oil and gas point emissions inventory sector includes oil and gas extraction. The residential wood combustion emissions inventory sector reflects HVAC and commercial refrigeration equipment manufacturing, and hardware, and plumbing and heating equipment supplies merchant wholesalers as both of those industries include establishments engaged in manufacturing and repairing heating equipment, including wood stoves, fireplaces, and wood furnaces. Because potential controls that could reduce fugitive road dust include applying asphalt or concrete to roadbeds or roadsides, we include asphalt paving, roofing, and saturated materials under the area fugitive dust emissions inventory sector.

Table 7-1 Baseline Industry Employment

Potentially Affected Industries by Emissions Inventory Sector and by Industry	NAICS	Employment in 2021 (thousands)	Percent Change in Employment 2011-2021
Non-EGU Point			
Cement and Concrete Product Manufacturing	3273	194.6	18
Basic Chemical Manufacturing	3251	147.9	4
Pulp, Paper, and Paperboard Mills	3221	88.2	-19
Iron and Steel Mills and Ferroalloy Manufacturing	3311	80.5	-14
Non-ferrous Metal (except Aluminum) Production and Processing	3314	57.3	-6
Petroleum and Coal Products Manufacturing	3241	105.4	-6
Mining (except Oil and Gas)	212	177.6	-20
Oil and Gas Point			
Oil and Gas Extraction	211	118.3	-32
Residential Wood Combustion			
Ventilation, Heating, Air Conditioning and Commercial Refrigeration Equipment Manufacturing	3334	136.2	5
Hardware, and Plumbing and Heating Equipment Supplies Merchant Wholesalers	4237	294.5	24
Area Fugitive Dust			
Asphalt Paving, Roofing, and Saturated Materials Manufacturing	32412	N/A[a]	N/A

Note: NAICS is North American Industry Classification System. The source of the information is the U.S. Bureau of Labor Statistics and is available at https://www.bls.gov/emp/data/industry-out-and-emp.htm and Detailed industries: hours and employment at https://www.bls.gov/productivity/tables/.
[a] N/A – not available. The U.S. Bureau of Labor Statistics only provides information at the 4-digit NAICS code. By Standard Industrial Classification (SIC) code, we located information on employment for paving, surfacing and tamping equipment operators (47-2071), which is briefly discussed below.

Cement and concrete product manufacturing, hardware and plumbing and heating equipment supplies merchant wholesalers, and mining are the largest industries in terms of number people employed. The basic chemical manufacturing and ventilation, heating, air conditioning and commercial refrigeration equipment manufacturing industries also have high employment. Each of the industries has had different trends in employment over the past decade. Cement and concrete product manufacturing and hardware and plumbing and heating equipment supplies merchant wholesalers have had sizable increases in employment over the past decade, while pulp, paper, and paperboard mills, oil and gas extraction, and mining have experienced a decline in employment over the last decade.

Under the area fugitive dust emissions inventory sector, potential controls that could reduce fugitive road dust include applying asphalt or concrete to roadbeds or roadsides, i.e., shoulders. Associated with these controls, the overall employment for paving, surfacing and tamping equipment operators in 2022 was 41,470.[1] The industry with the highest concentration of employment in paving, surfacing and tamping equipment operators is highway, street and bridge construction which employs 14,480 workers. Texas, New York, Florida, California, and Illinois are the states with the highest employment levels in paving, surfacing and tamping equipment operators.

Understanding the relative use of labor and capital in potentially affected industries can shed light on potential labor impacts. Many of these manufacturing industries are capital intensive. We rely on three public sources to get a range of estimates of employment per output by industry. Two of the public sources are provided by the U.S. Census Bureau: the Economic Census (EC) and the Annual Survey of Manufacturers (ASM). The EC is conducted every 5 years and although it was most recently conducted in 2022, the data are not available yet. The latest set of data from the EC is 2017. The ASM is an annual subset of the EC and is based on a sample of establishments. The latest set of data from the ASM is from 2021. Both sets of U.S. Census Bureau data provide detailed industry data, providing estimates at the 4-digit NAICS level. The data sets provide separate estimates of the number of employees and the value of shipments at the 4-digit NAICS, which we convert to a ratio in this analysis. The third public source that gives an estimate of employment per output by industry is the U.S. Bureau of Labor Statistics (BLS). Table 7-2 provides estimates of employment per $1 million of products sold by the industry for each data source in 2017$. While the ratios are not the same, they are similar across time for each data source. Cement and concrete products manufacturing and ventilation, heating, air conditioning and commercial refrigeration equipment manufacturing appear to be the most labor-intensive industries.

[1] The source of the information is the U.S. Bureau of Labor Statistics and is available at (https://www.bls.gov/oes/current/oes472071.htm).

Table 7-2 Employment per $1 Million Output (2017$) by Industry (4-digit NAICS)

	Source of Estimate		
Emissions Inventory Sector and Industry Sector	**BLS**	**Economic Census**	**ASM**
Non-EGU Point			
Cement and Concrete Product Manufacturing	3.22	2.92	2.81
Basic Chemical Manufacturing	0.81	0.68	0.64
Pulp, and Paper, and Paperboard Mills	1.15	1.24	1.33
Iron and Steel Mills and Ferroalloy Manufacturing	0.98	0.97	0.67
Non-ferrous Metals (except Aluminum) Production and Processing	1.25	1.21	0.94
Petroleum and Coal Products Manufacturing	N/A	0.20	0.31
Mining (except Oil and Gas)	N/A	2.02	N/A
Oil and Gas Point			
Oil and Gas Extraction	N/A	0.54	N/A
Residential Wood Combustion			
Ventilation, Heating, Air Conditioning and Commercial Refrigeration Equipment Manufacturing	3.08	3.04	3.23
Hardware, and Plumbing and Heating Equipment Supplies Merchant Wholesalers	N/A	1.39	N/A
Area Fugitive Dust			
Asphalt Paving, Roofing, and Saturated Materials Manufacturing	N/A	1.12	1.19

Note: N/A – not available. The source of the information is the U.S. Bureau of Labor Statistics: BLS and is available at https://www.bls.gov/emp/data/industry-out-and-emp.htm.

In general, there are significant challenges when evaluating the employment effects due to an environmental regulation. Employment effects associated with a regulation must be assessed while considering a wide variety of dynamic economic and social factors that also influence employment in the U.S. economy. In addition to these challenges, the EPA does not have detailed information on the industries that may require pollution controls for this rule. Thus, the EPA did not estimate potential employment impacts associated with this rule. However, to provide information about baseline conditions in relevant employment markets that might experience incremental impacts, this chapter presented employment levels, trends, and labor intensities of production in potentially affected industries.

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CHAPTER 8: COMPARISON OF BENEFITS AND COSTS

Overview

As discussed in Chapter 1, the Agency is revising the current annual $PM_{2.5}$ standard to a level of 9 $\mu g/m^3$. The Agency is also retaining the current 24-hour standard of 35 $\mu g/m^3$. OMB Circular A-4 requires analysis of one potential alternative standard level more stringent than the revised standard and one less stringent than the revised standard. In this Regulatory Impact Analysis (RIA), we are analyzing the revised annual and current 24-hour standard levels of 9/35 $\mu g/m^3$, as well as the following less and more stringent alternative standard levels: (1) a less stringent alternative annual standard level of 10 $\mu g/m^3$ in combination with the current 24-hour standard (i.e.,10/35 $\mu g/m^3$), (2) a more stringent alternative annual standard level of 8 $\mu g/m^3$ in combination with the current 24-hour standard (i.e., 8/35 $\mu g/m^3$), and (2) a more stringent alternative 24-hour standard level of 30 $\mu g/m^3$ in combination with an annual standard level of 10 $\mu g/m^3$ (i.e., 10/30 $\mu g/m^3$). Because the EPA is not changing the current secondary $PM_{2.5}$ standards at this time, as well as retaining the primary and secondary PM_{10} standards, we did not evaluate alternative levels of those standards in this RIA. The docket for the rulemaking is EPA-HQ-OAR-2015-0072.

The analyses in this RIA rely on national-level data (emissions inventory and control measure information) for use in national-level assessments (air quality modeling, control strategies, environmental justice, and benefits estimation). However, the ambient air quality issues being analyzed are highly complex and local in nature, and the results of these national-level assessments therefore contain uncertainty. It is beyond the scope of this RIA to develop detailed local information for the areas being analyzed, including populating the local emissions inventory information, obtaining local information to increase the resolution of the air quality modeling, and obtaining local information on emissions controls, all of which would reduce some of the uncertainty in these national-level assessments. For example, having more refined data would be ideal for agricultural dust and burning, prescribed burning, and non-point (area) sources due to their large contribution to primary $PM_{2.5}$ emissions and the limited availability of emissions controls.[1] In addition, for residential wood combustion emissions, people will respond differently to the various regulations and incentives offered for controlling $PM_{2.5}$ emissions from wood burning, making it important to identify the right balance of controls for each area. The estimated benefits and costs associated with applying emissions controls are incremental to a baseline of attaining the current primary annual and 24-hour $PM_{2.5}$ standards of 12/35 $\mu g/m^3$ in ambient air and incorporate air quality improvements achieved through the projected implementation of existing regulations.

8.1 Results

The EPA prepared an illustrative control strategy analysis to estimate the costs and human health benefits associated with the control strategies applied toward reaching the revised and less and more stringent alternative $PM_{2.5}$ standard levels. The control strategies presented in this RIA are an illustration of one possible set of control strategies states might choose to implement toward meeting the revised standard levels. States, not the EPA, will implement the revised NAAQS and will ultimately determine appropriate emissions control strategies. This section summarizes the results of the analyses.

As shown in Chapter 4, the estimated costs associated with the control strategies for the revised standard levels of 9/35 $\mu g/m^3$ are approximately $594 million in 2032 (2017$, 7 percent interest rate).[2] As shown in Chapter 5, the estimated monetized benefits associated with these control strategies for the revised standard levels of 9/35 $\mu g/m^3$ are approximately $20 billion and $42 billion in 2032 (2017$, based on a real discount rate of 7 percent).[3] The benefits are associated with two point estimates from two different epidemiologic studies discussed in more detail in Chapter 5, Section 5.2.3. It is expected

[1] Examples of area source emissions include area fugitive dust, residential wood combustion, and commercial cooking emissions.

[2] When calculating the annualized costs, we prefer to use the interest rates faced by firms; however, we do not know what those rates are.

[3] As indicated in Chapter 5, we assume that there is a "cessation" lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure, which affects the valuation of mortality benefits at different discount rates. Similarly, we assume there is a cessation lag between the change in PM exposures and both the development and diagnosis of lung cancer.

that some costs and benefits will begin occurring before 2032, as states begin implementing controls to attain earlier or to show progress towards attainment.

As discussed in Chapter 3, Section 3.2.4, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California. In Chapter 2, Section 2.4 and Chapter 3, Section 3.2.5, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the revised standard levels of 9/35 μg/-m^3. The EPA calculates the monetized net benefits of the revised and alternative standard levels by subtracting the estimated monetized compliance costs from the estimated monetized benefits in 2032. The estimates of costs and benefits do not fully account for all of the emissions reductions needed to reach the revised and less and more stringent alternative standard levels. In 2032, the monetized net benefits of the revised standard levels of 9/35 μg/m^3 are approximately \$22 billion and \$46 billion using a 3 percent real discount rate for the benefits estimates (in 2017\$). The benefits are associated with two point estimates from two different epidemiologic studies discussed in more detail in Chapter 5, Section 5.2.3. Table 8-1 presents a summary of these impacts for the revised standard levels and the less and more stringent alternative standard levels for 2032.

Table 8-1 Estimated Monetized Benefits, Costs, and Net Benefits of the Control Strategies Applied Toward Primary Revised and Alternative Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3, and 8/35 μg/m^3 in 2032 for the U.S. (millions of 2017\$)

	10/35	**10/30**	**9/35**	**8/35**
Benefits[a]	\$8,500 and \$17,000	\$10,000 and \$21,000	\$22,000 and \$46,000	\$48,000 and \$99,000
Costs[b]	\$200	\$340	\$590	\$1,500
Net Benefits	\$8,300 and \$17,000	\$9,900 and \$21,000	\$22,000 and \$46,000	\$46,000 and \$97,000

Notes: Rows may not appear to add correctly due to rounding.
We focus results to provide a snapshot of costs and benefits in 2032, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.
The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the revised and less and more stringent alternative standard levels in some counties in the northeast, southeast, west, and California.
[a] We assume that there is a cessation lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure, which affects the valuation of mortality benefits at different discount rates. Similarly, we assume there is a cessation lag between

the change in PM exposures and both the development and diagnosis of lung cancer. The benefits are associated with two point estimates from two different epidemiologic studies, and we present the benefits calculated at a real discount rate of 3 percent. The benefits exclude additional health and welfare benefits that could not be quantified (see Chapter 5, Sections 5.2.4 and 5.2.5).

[b] The costs are annualized using a 7 percent interest rate.

As part of fulfilling analytical guidance with respect to E.O. 12866, the EPA presents estimates of the present value (PV) of the monetized benefits and costs over the twenty-year period 2032 to 2051. To calculate the present value of the social net benefits of the revised and alternative standard levels, annual benefits and costs are discounted to 2023 at 3 percent and 7 percent discount rates as recommended by OMB's Circular A-4. The EPA also presents the equivalent annualized value (EAV), which represents a flow of constant annual values that, had they occurred in each year from 2032 to 2051, would yield a sum equivalent to the PV. The EAV represents the value of a typical cost or benefit for each year of the analysis, in contrast to the 2032-specific estimates.

For the twenty-year period of 2032 to 2051, for the revised standard levels of 9/35 $\mu g/m^3$ the PV of the costs, in 2017$ and discounted to 2023, is $7 billion when using a 3 percent discount rate and $3.7 billion when using a 7 percent discount rate. The EAV is $470 million per year when using a 3 percent discount rate and $350 million when using a 7 percent discount rate. The costs in PV and EAV terms for the revised and alternative standard levels can be found in Table 8-2 and Table 8-3.

Table 8-2 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs of the Control Strategies Applied Toward the Primary Revised and Alternative Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³ 8/35 μg/m³ (millions of 2017$, 2032-2051, discounted to 2023, 3 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$160	$260	$460	$1,200
2033	$150	$250	$440	$1,100
2034	$150	$250	$430	$1,100
2035	$140	$240	$420	$1,100
2036	$140	$230	$400	$1,000
2037	$130	$220	$390	$990
2038	$130	$220	$380	$960
2039	$130	$210	$370	$940
2040	$120	$210	$360	$910
2041	$120	$200	$350	$880
2042	$120	$190	$340	$860
2043	$110	$190	$330	$830
2044	$110	$180	$320	$810
2045	$110	$180	$310	$780
2046	$100	$170	$300	$760
2047	$100	$170	$290	$740
2048	$97	$160	$280	$720
2049	$94	$160	$280	$700
2050	$91	$150	$270	$680
2051	$89	$150	$260	$660
Present Value	$2,400	$4,000	$7,000	$18,000
Equivalent Annualized Value	$160	$270	$470	$1,200

Table 8-3 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs of the Control Strategies Applied Toward the Primary Revised and Alternative Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³ 8/35 μg/m³ (millions of 2017$, 2032-2051, discounted to 2023, 7 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$110	$180	$320	$820
2033	$100	$170	$300	$760
2034	$96	$160	$280	$710
2035	$90	$150	$260	$670
2036	$84	$140	$250	$620
2037	$79	$130	$230	$580
2038	$73	$120	$220	$540
2039	$69	$120	$200	$510
2040	$64	$110	$190	$480
2041	$60	$100	$180	$440
2042	$56	$94	$160	$420
2043	$52	$88	$150	$390
2044	$49	$82	$140	$360
2045	$46	$77	$130	$340
2046	$43	$72	$130	$320
2047	$40	$67	$120	$300
2048	$37	$63	$110	$280
2049	$35	$59	$100	$260
2050	$33	$55	$96	$240
2051	$30	$51	$89	$230
Present Value	$1,200	$2,100	$3,700	$9,300
Equivalent Annualized Value	$120	$200	$350	$870

For the twenty-year period of 2032 to 2051, for the revised standard levels of 9/35 μg/m³ the PV of the benefits, in 2017$ and discounted to 2023, is $540 billion when using a 3 percent discount rate and $290 billion when using a 7 percent discount rate. The EAV is $36 billion per year when using a 3 percent discount rate and $27 billion when using a 7 percent discount rate. The benefits in PV and EAV terms for the revised and alternative standard levels can be found in Table 8-4 and Table 8-5.

Table 8-4 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Benefits of the Control Strategies Applied Toward the Primary Revised and Alternative Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3 8/35 μg/m^3 (millions of 2017$, 2032-2051, discounted to 2023, 3 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$13,000	$16,000	$35,000	$76,000
2033	$13,000	$16,000	$34,000	$73,000
2034	$13,000	$15,000	$33,000	$71,000
2035	$12,000	$15,000	$32,000	$69,000
2036	$12,000	$14,000	$31,000	$67,000
2037	$12,000	$14,000	$31,000	$65,000
2038	$11,000	$13,000	$30,000	$63,000
2039	$11,000	$13,000	$29,000	$62,000
2040	$11,000	$13,000	$28,000	$60,000
2041	$10,000	$12,000	$27,000	$58,000
2042	$10,000	$12,000	$26,000	$56,000
2043	$9,700	$12,000	$26,000	$55,000
2044	$9,400	$11,000	$25,000	$53,000
2045	$9,100	$11,000	$24,000	$52,000
2046	$8,900	$11,000	$23,000	$50,000
2047	$8,600	$10,000	$23,000	$49,000
2048	$8,300	$10,000	$22,000	$47,000
2049	$8,100	$9,700	$21,000	$46,000
2050	$7,900	$9,400	$21,000	$44,000
2051	$7,600	$9,200	$20,000	$43,000
Present Value	$210,000	$250,000	$540,000	$1,200,000
Equivalent Annualized Value	$14,000	$17,000	$36,000	$78,000

Table 8-5 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Benefits of the Control Strategies Applied Toward the Primary Revised and Alternative Standard Levels of 10/35 μg/m^3, 10/30 μg/m^3, 9/35 μg/m^3 8/35 μg/m^3 (millions of 2017$, 2032-2051, discounted to 2023, 7 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$9,500	$11,000	$25,000	$54,000
2033	$8,900	$11,000	$24,000	$50,000
2034	$8,300	$10,000	$22,000	$47,000
2035	$7,800	$9,300	$21,000	$44,000
2036	$7,300	$8,700	$19,000	$41,000
2037	$6,800	$8,100	$18,000	$38,000
2038	$6,300	$7,600	$17,000	$36,000
2039	$5,900	$7,100	$16,000	$33,000
2040	$5,500	$6,600	$15,000	$31,000
2041	$5,200	$6,200	$14,000	$29,000
2042	$4,800	$5,800	$13,000	$27,000
2043	$4,500	$5,400	$12,000	$26,000
2044	$4,200	$5,100	$11,000	$24,000
2045	$3,900	$4,700	$10,000	$22,000
2046	$3,700	$4,400	$9,800	$21,000
2047	$3,400	$4,100	$9,100	$19,000
2048	$3,200	$3,900	$8,500	$18,000
2049	$3,000	$3,600	$8,000	$17,000
2050	$2,800	$3,400	$7,400	$16,000
2051	$2,600	$3,200	$7,000	$15,000
Present Value	$110,000	$130,000	$290,000	$610,000
Equivalent Annualized Value	$10,000	$12,000	$27,000	$57,000

For the twenty-year period of 2032 to 2051, for the revised standard levels of 9/35 μg/m^3 the PV of the net benefits, in 2017$ and discounted to 2023, is $540 billion when using a 3 percent discount rate and $280 billion when using a 7 percent discount rate. The EAV is $36 billion per year when using a 3 percent discount rate and $27 billion when using a 7 percent discount rate. The comparison of benefits and costs in PV and EAV terms for the revised standard levels can be found in Table 8-6. Estimates in the table are presented as rounded values.

Table 8-6 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs, Benefits, and Net Benefits of the Control Strategies Applied Toward the Revised Primary Alternative Standard Levels of 9/35 µg/m³ (millions of 2017$, 2032-2051, discounted to 2023 using 3 and 7 percent discount rates)

	Benefits[a]		Costs[b]		Net Benefits	
Year	3%	7%	3%	7%	3%	7%
2032	$35,000	$25,000	$460	$320	$35,000	$25,000
2033	$34,000	$24,000	$440	$300	$34,000	$23,000
2034	$33,000	$22,000	$430	$280	$33,000	$22,000
2035	$32,000	$21,000	$420	$260	$32,000	$20,000
2036	$31,000	$19,000	$400	$250	$31,000	$19,000
2037	$31,000	$18,000	$390	$230	$30,000	$18,000
2038	$30,000	$17,000	$380	$220	$29,000	$17,000
2039	$29,000	$16,000	$370	$200	$28,000	$15,000
2040	$28,000	$15,000	$360	$190	$28,000	$14,000
2041	$27,000	$14,000	$350	$180	$27,000	$14,000
2042	$26,000	$13,000	$340	$160	$26,000	$13,000
2043	$26,000	$12,000	$330	$150	$25,000	$12,000
2044	$25,000	$11,000	$320	$140	$25,000	$11,000
2045	$24,000	$10,000	$310	$130	$24,000	$10,000
2046	$23,000	$9,800	$300	$130	$23,000	$9,600
2047	$23,000	$9,100	$290	$120	$22,000	$9,000
2048	$22,000	$8,500	$280	$110	$22,000	$8,400
2049	$21,000	$8,000	$280	$100	$21,000	$7,900
2050	$21,000	$7,400	$270	$96	$21,000	$7,300
2051	$20,000	$7,000	$260	$89	$20,000	$6,900
Present Value	$540,000	$290,000	$7,000	$3,700	$540,000	$280,000
Equivalent Annualized Value	$36,000	$27,000	$470	$350	$36,000	$27,000

Notes: Rows may not appear to add correctly due to rounding. The annualized present value of costs and benefits are calculated over a 20-year period from 2032 to 2051.
[a] The benefits values use the larger of the two avoided premature deaths estimates presented in Chapter 5, Table 5-5, and are discounted at a rate of 3 percent over the SAB-recommended 20-year segmented lag. The benefits exclude additional health and welfare benefits that could not be quantified (see Chapter 5, Sections 5.2.4 and 5.2.5).
[b] The costs are annualized using a 7 percent interest rate.

8.2 Limitations of Present Value Estimates

The net present value (NPV) estimates presented reflect the costs and benefits associated with the illustrative control strategies; as discussed in Chapter 3, Section 3.2.4, some areas still need emissions reductions after control applications for the alternative standards analyzed. Additionally, there are methodological complexities associated with calculating the NPV of a stream of costs and benefits for national ambient air quality standards. The estimated NPV can better characterize the stream of benefits and costs over a multi-year period; however, calculating the PV of improved air quality is generally quite data-intensive and costly. While NPV analysis allows evaluation of alternatives by summing the present value of all future costs and benefits, insights into how costs will occur over time are limited by underlying assumptions and data. Calculating a PV of the stream of future benefits also poses special challenges, which we describe below. Further, the results are sensitive to assumptions regarding the time period over which the stream of benefits is discounted.

To estimate engineering costs, the EPA employs the equivalent uniform annual cost (EUAC) method, which annualizes costs over varying lifetimes of controls applied in the analysis. Using the EUAC method results in a stream of annualized costs that is equal for each year over the lifetime of control, resulting in a value similar to the value associated with an amortized mortgage or other loan payment. Control equipment is often purchased by incurring debt rather than through a single up-front payment. Recognizing this led the EPA to estimate costs using the EUAC method instead of a method that mimics firms paying up front for the future costs of installation, maintenance, and operation of pollution control devices.

Further, because we do not know when a facility will stop using a control or change to another measure based on economic or other reasons, the EPA assumes the controls applied in the illustrative control strategies remain in service for their full useful life. As a result, the annualized cost of controls in a single future year is the same throughout the lifetimes of controls analyzed, allowing the EPA to compare the annualized control costs with the benefits in a single year for consistent comparison.

The theoretically appropriate approach for characterizing the PV of benefits is the life table approach. The life table, or dynamic population, approach explicitly models the year-to-year influence of air pollution on baseline mortality risk, population growth and the birth rate—typically for each year over the course of a 50- to 100-year period (U.S. EPA SAB, 2010; Miller, 2003). In contrast to the pulse approach that is employed in this analysis[4], a life table models these variables endogenously by following a population cohort over time. For example, a life table will "pass" the air pollution-modified baseline death rate

[4] The pulse approach assumes changes in air pollution in a single year and affects mortality estimates over a 20-year period.

and population from year to year; impacts estimated in year 50 will account for the influence of air pollution on death rates and population growth in the preceding 49 years.

Calculating year-to-year changes in mortality risk in a life table requires some estimate of the annual change in air quality levels. It is both impractical to model air quality levels for each year and challenging to account for changes in federal, state, and local policies that will affect the annual level and distribution of pollutants. For each of these reasons the EPA does not always report the PV of benefits for air rules but has instead pursued a pulse approach.

8.3 References

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