UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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

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

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
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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. The EPA has concluded that the existing annual primary $PM_{2.5}$ 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 proposing to revise the existing standard to provide increased public health protection. Specifically, the EPA Administrator is proposing to revise the level of the standard within the range of 9-10 $\mu g/m^3$, while soliciting comment on levels down to 8 $\mu g/m^3$ and up to 11 $\mu g/m^3$. The primary 24-hour $PM_{2.5}$ standard provides protection against exposures to short-term "peak" concentrations of $PM_{2.5}$ in ambient air. The EPA Administrator is proposing to retain the primary 24-hour $PM_{2.5}$ standard at its current level of 35 $\mu g/m^3$ and is soliciting comment on revising the level of the standard to as low as 25 $\mu g/m^3$.

The EPA has also concluded that the existing secondary PM standards are requisite to protect public welfare from known or anticipated effects and is proposing to retain the secondary standards for PM. Specifically, for the secondary annual $PM_{2.5}$ standard, the EPA Administrator is proposing to retain the existing standard of 15.0 $\mu g/m^3$. For the secondary 24-hour $PM_{2.5}$ standard, the EPA Administrator is proposing to retain the existing standard of 35 $\mu g/m^3$; however, the Administrator is soliciting comment on revising the level of the standard to as low as 25 $\mu g/m^3$. For the secondary 24-hour PM_{10} standard, the EPA Administrator is proposing to retain the existing standard of 150 $\mu g/m^3$.

Overview of the Regulatory Impact Analysis

Per Executive Orders 12866 and 13563 and the guidelines of the Office of Management and Budget's (OMB) Circular A-4, in this Regulatory Impact Analysis (RIA) we are analyzing the proposed annual and current 24-hour alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$, as well as 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 the proposed annual standard level of 10 $\mu g/m^3$ (i.e., 10/30 $\mu g/m^3$). Because the EPA is proposing that the current secondary PM standards be retained, we did not evaluate alternative secondary standard levels. The RIA includes the following chapters: Chapter 2: Emissions, Air Quality Modeling and Methods; Chapter 3: Control Strategies and $PM_{2.5}$ Emissions Reductions; Chapter 4: Engineering Cost Analysis and Social Costs; Chapter 5: Benefits Analysis Approach and Results; Chapter 6: Environmental Justice Impacts; 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 particulate matter NAAQS (12/35 $\mu g/m^3$). 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 proposed particulate matter NAAQS in late 2024. 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]

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 and analysis of a limited number of illustrative control strategies that states might adopt to implement a proposed 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 proposed 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

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

standards of 12/35 μg/m^3. From that analytical baseline, we estimate $PM_{2.5}$ emissions reductions needed to reach the proposed 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 direct 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 μg/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 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 control measures to nonpoint (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. The estimated $PM_{2.5}$ emissions reductions from these control applications do not fully account for all the emissions reductions needed to reach the proposed 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 3.2.6, we discuss the remaining air quality

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[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 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. The 2032 projections include wildfire emissions at their 2016 levels, but these emissions were not targeted for control.

challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$; the areas include a county in Pennsylvania affected by local sources, 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 local source-to-monitor impacts, 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 2016 and 2032. The projections reflect SO_2 and NO_X emissions decreases between 2016 and 2032 -- over this period (1) NO_X emissions are projected to decrease by 3.8 million tons (40 percent), with the greatest reductions from mobile source and EGU emissions inventory sectors, and (2) SO_2 emissions are projected to decrease by 1 million tons (38 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 2016 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.[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

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[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 2016 and 2032 CMAQ modeling.

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 proposed and more stringent alternative standard levels relative to the current standards. The analytical baseline reflects, among other existing regulations, the Revised Cross-State Air Pollution Rule Update, the Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026, the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: EGUs, and the Mercury and Air Toxics Standards. 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	2,298
CA	6,907
Total	9,205

Eighteen counties need $PM_{2.5}$ emissions reductions to meet the current standards in 2032 – 9 counties in California and 9 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 in Northern 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 Alternative Standard Levels Analyzed

We apply regional $PM_{2.5}$ air quality ratios to estimate $PM_{2.5}$ DVs at air quality monitor locations and then again to estimate the emissions reductions needed to reach the proposed 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 µg/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.

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[4] The 18 counties require primary PM emissions reductions to meet the current standards of 12/35 µg/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.

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 alternative standard levels analyzed are listed in Chapter 2, Table 2-1. We estimated the emissions reductions needed to just meet the 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 alternative 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 alternative standard levels. For each alternative standard level, Table ES-2 also includes an area's percent of the total estimated emissions reductions needed nationwide to reach that alternative standard level in all locations. For example, for the proposed standard level of 10/35 $\mu g/m^3$, California's 10,128 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 alternative standard levels analyzed. Figure ES-2 shows the counties projected to exceed the annual and 24-hour 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. 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 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 $\mu g/m^3$ in 2032

Area	10/35	10/30	9/35	8/35
Northeast	1,068	1,221	6,996	30,843
Southeast	474	474	4,088	18,028
West	820	7,852	3,078	9,708
CA	10,128	12,230	17,750	28,293
Total	12,490	21,776	31,912	86,872

Area	10/35	10/30	9/35	8/35
Northeast	9%	6%	22%	36%
Southeast	4%	2%	13%	21%
West	7%	36%	10%	11%
CA	81%	56%	56%	33%

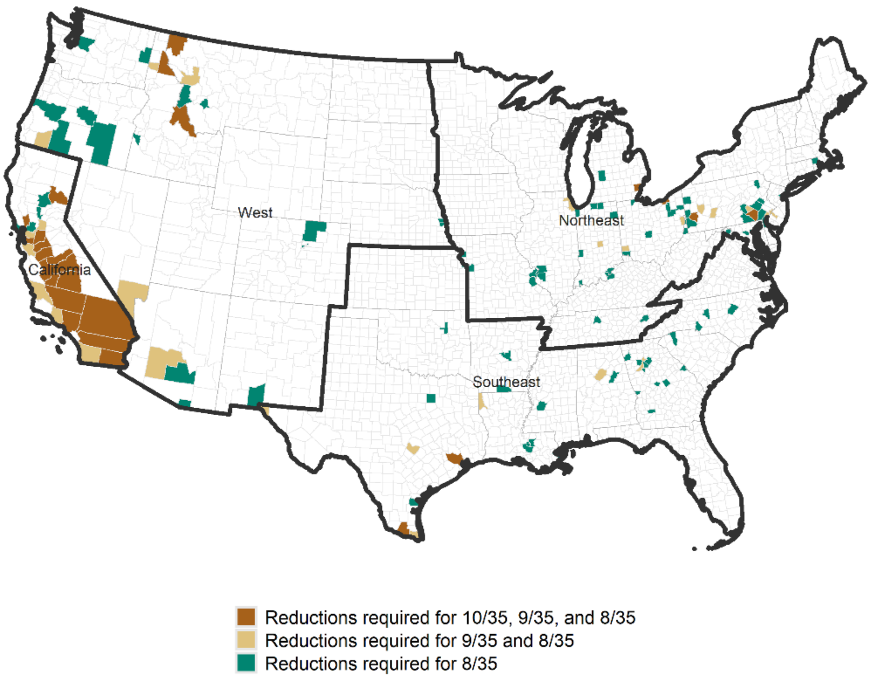

Figure ES-2 Counties Projected to Exceed in Analytical Baseline for Alternative Standard Levels of 10/35 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$

For each alternative standard level, 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 alternative standard level, in each geographic area that need $PM_{2.5}$ emissions reductions from the analytical baseline.

- 10/35 µg/m^3-- *24 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 2 counties in the southeast, 3 counties in the west, and 15 counties in California.
- 10/30 µg/m^3-- *47 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 2 counties in the southeast, 23 counties in the west, and 18 counties in California.
- 9/35 µg/m^3 -- *51 counties* need $PM_{2.5}$ emissions reductions. This includes 14 counties in the northeast, 8 counties in the southeast, 8 counties in the west, and 21 counties in California.
- 8/35 µg/m^3 -- *141 counties* need $PM_{2.5}$ emissions reductions. This includes 57 counties in the northeast, 35 counties in the southeast, 24 counties in the west, and 25 counties in California.

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

We identified control measures 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 control technologies or measures 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 control measures 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

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[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.

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.

By area, Table ES-3 includes a summary of the estimated emissions reductions from control applications for the 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. See Chapter 3, Tables 3-5 through 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 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 (tons/year)

	$PM_{2.5}$ Emissions Reductions			
Area	**10/35**	**10/30**	**9/35**	**8/35**
Northeast	1,070	1,222	6,334	19,142
Northeast (Adjacent Counties)	0	0	1,737	15,440
Southeast	475	475	3,040	12,212
Southeast (Adjacent Counties)	0	0	194	4,892
West	224	2,206	947	4,711
CA	1,792	2,481	2,958	4,925
Total	3,561	6,384	15,210	61,321

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 Control Technologies and Measures

The estimated $PM_{2.5}$ emissions reductions from the control strategies do not fully account for all the emissions reductions needed to reach the proposed 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 alternative standards analyzed. See Chapter 3, Table 3-9 for an additional summary of estimated emissions reductions still needed. Figure ES-3 and Figure ES-4 show the counties that still need emissions reductions after control applications for the proposed alternative standard levels of 10/35 µg/m^3 and 9/35 µg/m^3. 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 3.2.6 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 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 $\mu g/m^3$ in 2032 (tons/year)

Region	10/35	10/30	9/35	8/35
Northeast	0	0	238	6,741
Southeast	0	0	994	4,780
West	595	5,651	2,132	5,023
CA	8,336	9,749	14,793	23,368
Total	8,931	15,400	18,157	39,912

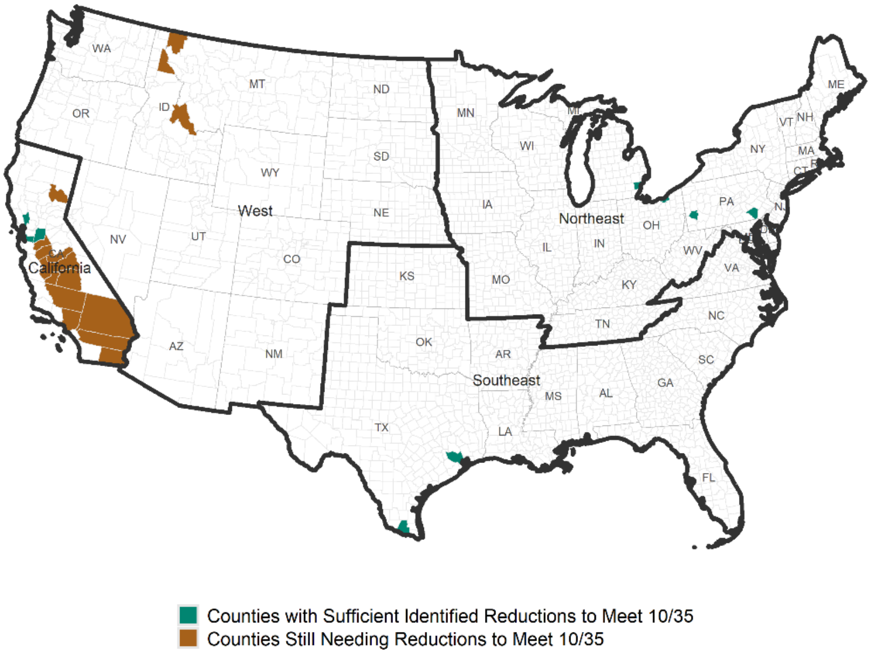

Figure ES-3 Counties that Still Need $PM_{2.5}$ Emissions Reductions for Proposed Alternative Standard Level of 10/35 $\mu g/m^3$

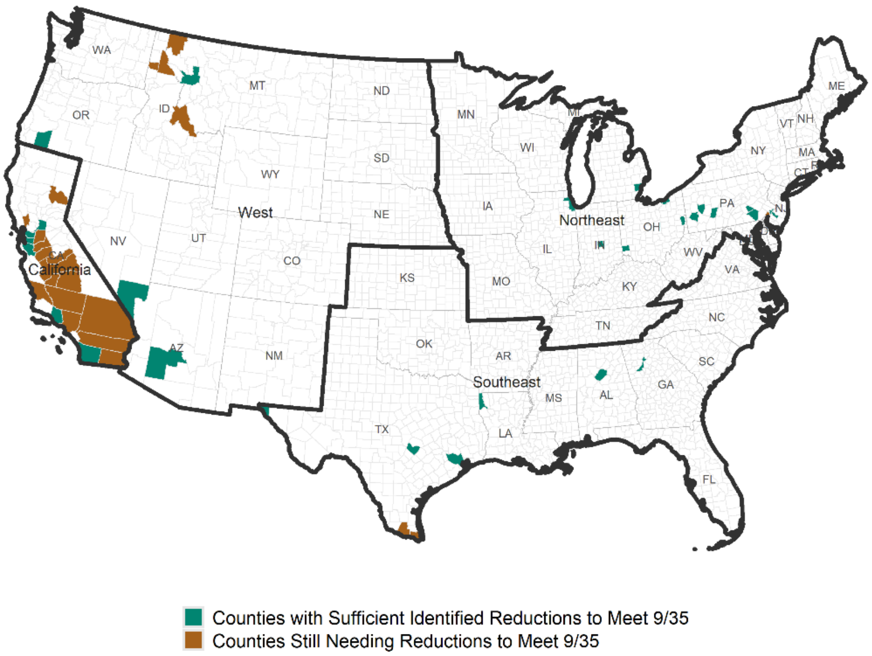

Figure ES-4 **Counties that Still Need $PM_{2.5}$ Emissions Reductions for Proposed Alternative Standard Level of 9/35 µg/m^3**

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 measure and the interest rate incorporated into a capital recovery factor. Annualized costs represent an equal stream of yearly costs over the period the control technology 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 alternative standard levels analyzed. See Chapter 4, Tables 4-2 through

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 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	10/35	10/30	9/35	8/35
Northeast	$7.3	$12.8	$183.5	$560.2
Northeast (Adjacent Counties)	$0	$0	$22.3	$539.7
Southeast	$4.1	$4.1	$50.4	$250.6
Southeast (Adjacent Counties)	$0	$0	$18.2	$186.5
West	$19.0	$150.0	$34.2	$121.8
CA	$64.1	$90.4	$84.7	$162.9
Total	$94.5	$257.2	$393.3	$1,821.7

For the proposed alternative standard level of 10/35 μg/m³, the majority of the estimated costs are incurred in California because 15 of the 24 counties that need emissions reductions are located in California. Looking at the more stringent alternative standard level of 10/30 μg/m³, in the west an additional 20 counties need emissions reductions and estimated costs increase significantly; estimated costs for the proposed alternative standard level of 9/35 μg/m³ are higher than for 10/35 μg/m³ but lower than for 10/30 μg/m³ in this area. For alternative standard levels of 9/35 μg/m³ and 8/35 μg/m³, 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/m³ and 8/35 μg/m³.

In the northeast and southeast when we applied the emissions reductions from adjacent counties, we applied 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. Application of this ratio contributes to the higher estimated cost estimates for alternative standard levels of 9/35 μg/m³ and 8/35 μg/m³.

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 a health impact function (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 each of the 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 each of the alternative standard levels, both nationally and by region, thereby allowing the comparison of cost and benefits of the application of the illustrative controls. As mentioned above and discussed in Chapter 3, Section 3.2.5, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the proposed 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 3.2.6, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 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 proposed 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 Alternative Primary $PM_{2.5}$ Standard Levels for 2032 (95% Confidence Interval)

Avoided Mortality[a]	**10/35 µg/m³**	**10/30 µg/m³**	**9/35 µg/m³**	**8/35 µg/m³**
Pope III et al., 2019 (adult mortality ages 18-99 years)	1,700 (1,200 to 2,100)	1,900 (1,400 to 2,400)	4,200 (3,000 to 5,300)	9,200 (6,600 to 12,000)
Wu et al., 2020 (adult mortality ages 65-99 years)	810 (710 to 900)	920 (810 to 1,000)	2,000 (1,800 to 2,200)	4,400 (3,900 to 4,900)
Woodruff et al., 2008 (infant mortality)	1.6 (-0.99 to 4.0)	1.8 (-1.1 to 4.6)	4.7 (-3.0 to 12)	11 (-6.9 to 28)
Avoided Morbidity	**10/35 µg/m³**	**10/30 µg/m³**	**9/35 µg/m³**	**8/35 µg/m³**
Hospital admissions—cardiovascular (age > 18)	140 (100 to 170)	150 (110 to 190)	310 (230 to 400)	660 (480 to 840)
Hospital admissions—respiratory	93 (31 to 150)	100 (35 to 170)	210 (74 to 350)	460 (160 to 740)
ED visits--cardiovascular	260 (-100 to 610)	290 (-110 to 670)	630 (-240 to 1,500)	1,400 (-530 to 3,200)
ED visits—respiratory	490 (95 to 1,000)	530 (100 to 1,100)	1,200 (240 to 2,600)	2,700 (540 to 5,700)
Acute Myocardial Infarction	29 (5.9 to 17)	32 (19 to 45)	67 (39 to 94)	143 (83 to 200)
Cardiac arrest	15 (-5.9 to 33)	16 (-6.6 to 37)	34 (-14 to 76)	72 (-29 to 160)
Hospital admissions--Alzheimer's Disease	360 (270 to 440)	390 (300 to 480)	850 (640 to 1,000)	1,900 (1,500 to 2,400)
Hospital admissions--Parkinson's Disease	48 (25 to 70)	54 (28 to 79)	120 (63 to 180)	270 (140 to 390)
Stroke	55 (14 to 94)	61 (16 to 110)	130 (33 to 220)	270 (71 to 470)
Lung cancer	65 (20 to 110)	73 (22 to 120)	150 (46 to 250)	320 (99 to 530)
Hay Fever/Rhinitis	15,000 (3,500 to 25,000)	16,000 (4,000 to 28,000)	35,000 (8,500 to 60,000)	75,000 (18,000 to 130,000)
Asthma Onset	2,200 (2,100 to 2,300)	2,500 (2,400 to 2,600)	5,400 (5,100 to 5,600)	11,000 (11,000 to 12,000)
Asthma symptoms – Albuterol use	310,000 (-150,000 to 750,000)	350,000 (-170,000 to 850,000)	740,000 (-360,000 to 1,800,000)	1,600,000 (-780,000 to 3,900,000)
Lost work days	110,000 (97,000 to 130,000)	130,000 (110,000 to 150,000)	270,000 (230,000 to 310,000)	580,000 (490,000 to 660,000)
Minor restricted-activity days	680,000 (550,000 to 800,000)	750,000 (610,000 to 890,000)	1,600,000 (1,300,000 to 1,900,000)	3,400,000 (2,700,000 to 4,000,000)

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 Alternative Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 μg/m³ (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	$20 + B	$43 + B	$95 + B
7% discount rate	$16 + B	$18 + B	$39 + B	$86 + 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	$9.6 + B	$21 + B	$46 + B
7% discount rate	$7.6 + B	$8.6 + B	$19 + B	$41 + 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 ES-8 Estimated Monetized Benefits by Region of the Control Strategies for the Alternative Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 µg/m^3 (billions of 2017$)

Benefits Estimate	Region	10 µg/m^3 Annual & 35 µg/m^3 24-hour	10 µg/m^3 Annual & 30 µg/m^3 24-hour	9 µg/m^3 Annual & 35 µg/m^3 24-hour	8 µg/m^3 Annual & 35 µg/m^3 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	***California***	$13 + B	$14 + B	$17 + B	$23 + B
	Northeast	$2.3 + B	$2.6 + B	$15 + B	$40 + B
	Southeast	$1.8 + B	$1.8 + B	$8.8 + B	$22 + B
	West	$0.018 + B	$1.1 + B	$2.2 + B	$11 + B
7% discount rate	***California***	$12 + B	$13 + B	$16 + B	$21 + B
	Northeast	$2 + B	$2.3 + B	$13 + B	$36 + B
	Southeast	$1.6 + B	$1.6 + B	$7.9 + B	$20 + B
	West	$0.016 + B	$1 + B	$2 + B	$9.5 + 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	***California***	$6.5 + B	$6.9 + B	$8.4 + B	$11 + B
	Northeast	$1.1 + B	$1.3 + B	$7.3 + B	$19 + B
	Southeast	$0.84 + B	$0.84 + B	$4.1 + B	$10 + B
	West	$0.0092 + B	$0.56 + B	$1.1 + B	$5.1 + B
7% discount rate	***California***	$5.8 + B	$6.2 + B	$7.5 + B	$10 + B
	Northeast	$1 + B	$1.2 + B	$6.6 + B	$17 + B
	Southeast	$0.75 + B	$0.75 + B	$3.6 + B	$9.2 + B
	West	$0.0082 + B	$0.5 + B	$0.97 + B	$4.6 + 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.

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 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.

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[6] 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 proposed rulemaking, as well as the nature of known and potential exposures and impacts. For the proposal, we quantitatively evaluate the potential for disparities in $PM_{2.5}$ exposures and mortality effects across different demographic populations under illustrative control strategies associated with implementation of the current standard (12/35 $\mu g/m^{3,}$ or baseline) and potential 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 totals, changes, and proportional changes in 1) exposures, in terms of annual average $PM_{2.5}$ 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

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[6] U.S. Environmental Protection Agency (EPA), 2015. Guidance on Considering Environmental Justice During the Development of Regulatory Actions.

nationally than the reference (overall) population, both in terms of aggregated average exposure and across the distribution of air quality. Specifically, Hispanics, Asians, Blacks, and those less educated (no high school) have higher national annual exposures, 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, the Hispanic population is estimated to experience the highest exposures, both on average and across $PM_{2.5}$ concentration distributions, of all demographic groups analyzed. These disproportionalities are also observed at the regional level, though to different extents.

In response to the second question, while a lower standard level would be predicted to reduce $PM_{2.5}$ exposures and mortality rates across all demographic groups, disparities seen in the baseline are also reflected in the standard levels under consideration. 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, Hispanics, Asians, and those less educated are estimated to see greater proportional reductions in $PM_{2.5}$ concentrations than reference populations under all alternative standard levels evaluated, with proportional reductions increasing as the alternative standard levels decrease. However, exposures in the Black population are estimated to proportionally decrease on par with exposures in reference population. Considering the four geographic regions (northeast, southeast, west, and California), proportionally greater reductions in $PM_{2.5}$ concentrations experienced by Asian, Hispanic, and less educated populations are most notable in the southeast and California, whereas $PM_{2.5}$ concentration reductions among Black populations tend to be proportionally larger than among the reference population in California, the west, and the northeast, especially under the proposed alternative standard level of 9/35 $\mu g/m^3$ and the more stringent alternative standard level of 8/35 $\mu g/m^3$. In Section 6.6.2.2 we provide some 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 (question 1). Black populations are estimated to have the highest national and regional $PM_{2.5}$-attributable mortality rates, both on average and across population distributions. Differential $PM_{2.5}$ exposures for this population in some parts of the country, which may contribute to higher magnitude concentration-response relationships between exposure and premature mortality, as well as other underlying health factors that may increase susceptibility to adverse outcomes among Black populations. Health disparities associated with the baseline scenario are also predicted for the proposed and more stringent standard levels (question 2), although as the alternative standard levels become increasingly stringent, differences in mortality rates across demographic groups decline, particularly for the proposed and more stringent alternative standard levels evaluated (9/35 $\mu g/m^3$ and 8/35 $\mu g/m^3$) (question 3).

ES.2 Qualitative Assessment of the Remaining Air Quality Challenges

For the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 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 and Figure ES-4). As discussed in Chapters 2 and 3, the remaining air quality challenges for the proposed alternative standard levels can be grouped into the following “bins”: Delaware County, Pennsylvania, 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 proposed alternative standard levels.

Table ES-9 Summary of Counties by Bin that Still Need Emissions Reductions for Proposed Alternative Primary Standard Levels of 10/35 μg/m^3 and 9/35 μg/m^3

Bin	Area	Counties[a] for 10/35 mg/m^3	Additional Counties[a] for 9/35 mg/m^3
Delaware County, Pennsylvania	Northeast	--	Delaware County, PA
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	Benewah County, ID
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) Riverside County, CA (SCAQMD) San Bernardino County, CA (SCAQMD) Stanislaus County, CA (SJVAPCD) Tulare County, CA (SJVAPCD)	Napa County, CA (BAAQMD) San Joaquin County, CA (SJVAPCD) San Luis Obispo 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 have no identified $PM_{2.5}$ emissions reductions because available controls were applied for the current standard of 12/35 μg/m^3 and additional controls were not available: Imperial, Kern, Kings, Lemhi, Plumas, Riverside, San Bernardino, Shoshone, and Tulare.

The characteristics of the air quality challenges for these areas include features of local source-to-monitor impacts, 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 3.2.6.

For Delaware County, Pennsylvania, a more detailed local analysis of the local source emissions reductions impacts is needed. For the border areas that may be influenced by cross-border emissions, more detailed analyses of international transport emissions are 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 are needed. In addition, more detailed analyses are 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.

Lastly, 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 control measures 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) is needed given the magnitude of emissions from these sources in these areas. Further, more detailed analyses are 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 Results of Benefit-Cost Analysis

As discussed above and in Chapter 3, Section 3.2.5, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the proposed 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 3.2.6, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$. The EPA calculates the monetized net benefits of the proposed alternative standard levels by subtracting the estimated monetized compliance costs from the estimated monetized benefits in 2032. These estimates do not fully account for all of the emissions reductions needed to reach the proposed and more stringent alternative standard levels. In 2032, the monetized net benefits of the proposed alternative standard level of 10/35 $\mu g/m^3$ are approximately \$8.4 billion and \$17 billion using a 3 percent real discount rate for the benefits estimates, and the monetized net benefits of the proposed alternative standard level of 9/35 $\mu g/m^3$ are approximately $20 billion and $43 billion using a 3 percent real discount rate for the benefits estimates (in 2017$). The benefits are associated with two point estimates from two different epidemiologic studies discussed in more detail in Chapter 5, Section 5.3.3. Table ES-10 presents a summary of these impacts for the proposed alternative standard levels and the 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 Alternative Standard Levels of 10/35 μg/m³, 10/30 μg/m³, 9/35 μg/m³, and 8/35 μg/m³ in 2032 for the U.S. (millions of 2017$)

	10/35	10/30	9/35	8/35
Benefits[a]	$8,500 and $17,000	$9,600 and $20,000	$21,000 and $43,000	$46,000 and $95,000
Costs[b]	$95	$260	$390	$1,800
Net Benefits	$8,400 and $17,000	$9,300 and $19,000	$20,000 and $43,000	$44,000 and $93,000

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.

[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 5.3.4 and 5.3.5).

[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 proposed alternative standard levels, annual benefits and costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed 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 proposed alternative standard level of 10/35 μg/m³ the PV of the net benefits, in 2017$ and discounted to 2022, is $200 billion when using a 3 percent discount rate and $90 billion when using a 7 percent discount rate. The EAV is $13 billion per year when using a 3 percent discount rate and $8.5 billion when using a 7 percent discount rate. For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 9/35 μg/m³ the PV of the net benefits, in 2017$ and discounted to 2022, is $490 billion when using a 3 percent discount rate and $220 billion when using a 7 percent discount rate. The EAV is $33 billion per year when using a 3 percent discount rate and $21 billion when using a 7 percent discount rate. The comparison of benefits and costs in PV and EAV terms for the proposed alternative standard levels can be found in Table ES-11 and Table ES-12. Estimates in the tables 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 Proposed Primary Alternative Standard Level of 10/35 μg/m^3 (millions of 2017$, 2032-2051, discounted to 2022 using 3 and 7 percent discount rates)

	Benefits[a]		Costs[b]		Net Benefits	
Year	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
2032	$13,000	$8,000	$70	$48	$13,000	$7,900
2033	$13,000	$7,500	$68	$45	$13,000	$7,400
2034	$12,000	$7,000	$66	$42	$12,000	$6,900
2035	$12,000	$6,500	$64	$39	$12,000	$6,500
2036	$12,000	$6,100	$63	$37	$11,000	$6,100
2037	$11,000	$5,700	$61	$34	$11,000	$5,700
2038	$11,000	$5,300	$59	$32	$11,000	$5,300
2039	$11,000	$5,000	$57	$30	$10,000	$4,900
2040	$10,000	$4,600	$56	$28	$10,000	$4,600
2041	$9,900	$4,300	$54	$26	$9,900	$4,300
2042	$9,700	$4,100	$52	$24	$9,600	$4,000
2043	$9,400	$3,800	$51	$23	$9,300	$3,800
2044	$9,100	$3,500	$49	$21	$9,100	$3,500
2045	$8,800	$3,300	$48	$20	$8,800	$3,300
2046	$8,600	$3,100	$47	$19	$8,500	$3,100
2047	$8,300	$2,900	$45	$17	$8,300	$2,900
2048	$8,100	$2,700	$44	$16	$8,000	$2,700
2049	$7,900	$2,500	$43	$15	$7,800	$2,500
2050	$7,600	$2,400	$41	$14	$7,600	$2,300
2051	$7,400	$2,200	$40	$13	$7,400	$2,200
Present Value	**$200,000**	**$91,000**	**$1,100**	**$540**	**$200,000**	**$90,000**
Equivalent Annualized Value	**$13,000**	**$8,500**	**$72**	**$51**	**$13,000**	**$8,500**

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 5-7, 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 5.3.4 and 5.3.5).

[b] The costs are annualized using a 7 percent interest rate.

Table ES-12 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs, Benefits, and Net Benefits of the Control Strategies Applied Toward the Proposed Primary Alternative Standard Level of 9/35 $\mu g/m^3$ (millions of 2017$, 2032-2051, discounted to 2022 using 3 and 7 percent discount rates)

	Benefits[a]		Costs[b]		Net Benefits	
Year	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
2032	$32,000	$20,000	$290	$200	$32,000	$20,000
2033	$31,000	$18,000	$280	$190	$31,000	$18,000
2034	$30,000	$17,000	$280	$170	$30,000	$17,000
2035	$29,000	$16,000	$270	$160	$29,000	$16,000
2036	$29,000	$15,000	$260	$150	$28,000	$15,000
2037	$28,000	$14,000	$250	$140	$27,000	$14,000
2038	$27,000	$13,000	$250	$130	$27,000	$13,000
2039	$26,000	$12,000	$240	$120	$26,000	$12,000
2040	$25,000	$11,000	$230	$120	$25,000	$11,000
2041	$25,000	$11,000	$220	$110	$24,000	$11,000
2042	$24,000	$10,000	$220	$100	$24,000	$9,900
2043	$23,000	$9,400	$210	$95	$23,000	$9,300
2044	$23,000	$8,800	$210	$89	$22,000	$8,700
2045	$22,000	$8,200	$200	$83	$22,000	$8,100
2046	$21,000	$7,700	$190	$78	$21,000	$7,600
2047	$21,000	$7,200	$190	$72	$20,000	$7,100
2048	$20,000	$6,700	$180	$68	$20,000	$6,600
2049	$19,000	$6,300	$180	$63	$19,000	$6,200
2050	$19,000	$5,800	$170	$59	$19,000	$5,800
2051	$18,000	$5,500	$170	$55	$18,000	$5,400
Present Value	**$490,000**	**$220,000**	**$4,500**	**$2,300**	**$490,000**	**$220,000**
Equivalent Annualized Value	**$33,000**	**$21,000**	**$300**	**$210**	**$33,000**	**$21,000**

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 5-7, 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 5.3.4 and 5.3.5).

[b] The costs are annualized using a 7 percent interest rate.

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CHAPTER 1: OVERVIEW AND BACKGROUND

Overview of the Proposal

On June 10, 2021, the Environmental Protection Agency (EPA) announced its decision to reconsider the 2020 Particulate Matter (PM) National Ambient Air Quality Standards (NAAQS) final action. In this reconsideration, the EPA has concluded that the existing annual primary $PM_{2.5}$ standard for PM, set at a level of 12.0 µg/m^3, is not requisite to protect public health with an adequate margin of safety. The EPA Administrator is proposing to revise the level of the standard within the range of 9-10 µg/m^3, while soliciting comment on levels down to 8 µg/m^3 and up to 11 µg/m^3. The primary 24-hour $PM_{2.5}$ standard provides protection against exposures to short-term "peak" concentrations of $PM_{2.5}$ in ambient air. The EPA Administrator is proposing to retain primary 24-hour $PM_{2.5}$ standard at its current level of 35 µg/m^3 and is soliciting comment on revising the level of the standard to as low as 25 µg/m^3.

The EPA has also concluded that the existing secondary PM standards are requisite to protect public welfare from known or anticipated effects and is proposing to retain the secondary standards for PM. Specifically, for the secondary annual $PM_{2.5}$ standard, the EPA Administrator is proposing to retain the existing standard of 15.0 µg/m^3. For the secondary 24-hour $PM_{2.5}$ standard, the EPA Administrator is proposing to retain the existing standard of 35 µg/m^3; however, the Administrator is soliciting comment on revising the level of the standard to as low as 25 µg/m^3. For the secondary 24-hour PM_{10} standard, the EPA Administrator is proposing to retain the existing standard of 150 µg/m^3. The docket for the proposed 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 proposed annual and current 24-hour alternative standard levels of 10/35 µg/m^3 and 9/35 µg/m^3, as well as the following two more stringent alternative standard levels: (1) an 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) an alternative 24-hour standard level of 30 µg/m^3 in combination with the proposed annual standard level of 10 $\mu g/m^3$ (i.e., 10/30 $\mu g/m^3$). The RIA presents estimated costs and benefits of the control strategies analyzed for the proposed 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]

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 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 proposed 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

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

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 3.2.6 discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$; the areas include a county in Pennsylvania affected by local sources, 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 local source-to-monitor impacts, 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 and 13563.

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, regardless 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 proposed rule preamble, and below we briefly discuss requirements of Orders 12866 and 13563 and the guidelines of the Office of Management and Budget (OMB) Circular A-4 (U.S. OMB, 2003).

In accordance with Executive Orders 12866 and 13563 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 $PM_{2.5}$ alternative 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 proposed standard and one less stringent than the proposed standard. The Agency is proposing to revise the current annual $PM_{2.5}$ standards to a level within the range of 9-10 $\mu g/m^3$ and is soliciting comment on an alternative annual standard level down to 8 $\mu g/m^3$ and a level up to 11 $\mu g/m^3$. The Agency is also proposing to retain the current 24-hour standard of 35 $\mu g/m^3$ and is soliciting comment on an alternative 24-hour standard level of 25 $\mu g/m^3$. In this RIA, we are analyzing the proposed annual and current 24-hour alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$, as well as 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 the proposed 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 proposed standards. States—not the EPA—will implement the proposed 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 proposed 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 control measures 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 proposed standards will not be realized until specific control measures 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 proposed 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 proposed 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 proposed particulate matter NAAQS in late 2024. 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 proposed $PM_{2.5}$ 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 measures. 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 proposed standards by the attainment date, the state would need to identify additional emissions control measures in its SIP to meet attainment requirements.

1.3.1 Establishing the Baseline for Evaluation of Proposed and Alternative Standards

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 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 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 standard. Additional emissions reductions achieved as a result of state and local agency regulations and voluntary programs are reflected to the

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[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.

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 2016v2 emissions modeling platform titled *Preparation of Emissions Inventories for the 2016v2 North American Emissions Modeling Platform* (U.S. EPA, 2022b). 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.

- Revised Cross-State Air Pollution Rule Update (RCU), (U.S. EPA, 2021)
- The Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: EGUs (U.S. EPA, 2015)
- Mercury and Air Toxics Standards (U.S. EPA, 2011)
- Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026 (U.S. EPA, U.S. DOT, 2020)
- Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 (U.S. EPA, U.S. DOT, 2016)
- Tier 3 Motor Vehicle Emission and Fuel Standards (U.S. EPA, 2014)

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 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 control technologies. The technologies and 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 proposed alternative standard levels. We quantified an array of mortality and morbidity effects using the BenMAP-CE tool (U.S. EPA 2018), 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 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 proposed 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 proposed 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 proposed 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 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 2016-based modeling platform with the Community Multiscale Air Quality (CMAQ) model. The modeling platform paired a 2016 CMAQ simulation with a corresponding CMAQ simulation with emissions representative of 2032 that reflect 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 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 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 2016 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 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 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 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 2016 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 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.

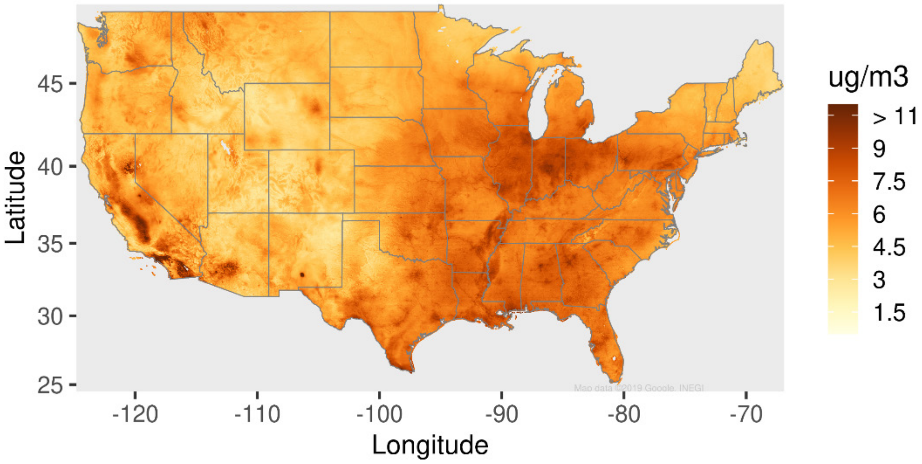

Figure 2-1 **Annual Average $PM_{2.5}$ Concentrations over the U.S. in 2019 Based on the Hybrid Satellite Modeling Approach of van Donkelaar et al. (2021)**

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 98th 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).

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

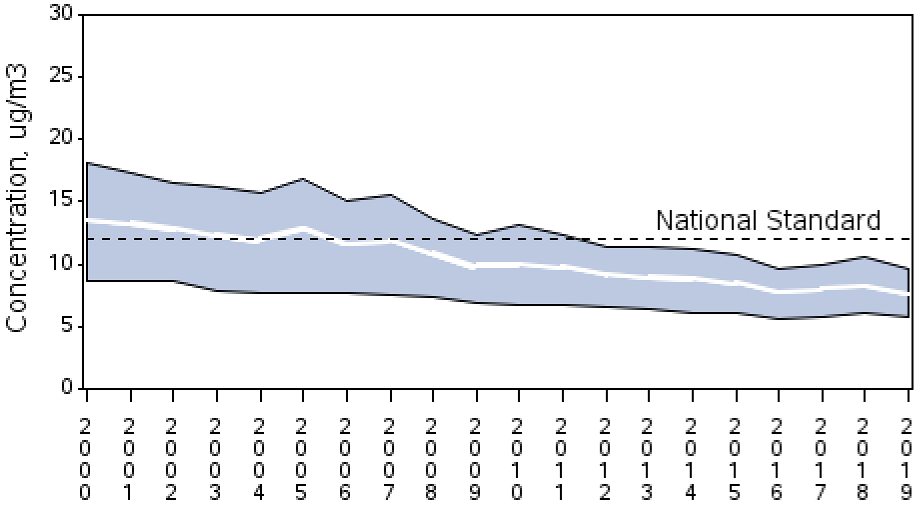

Figure 2-2 **Seasonally Weighted Annual Average $PM_{2.5}$ Concentrations in the U.S. from 2000 to 2019 (406 sites)**

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

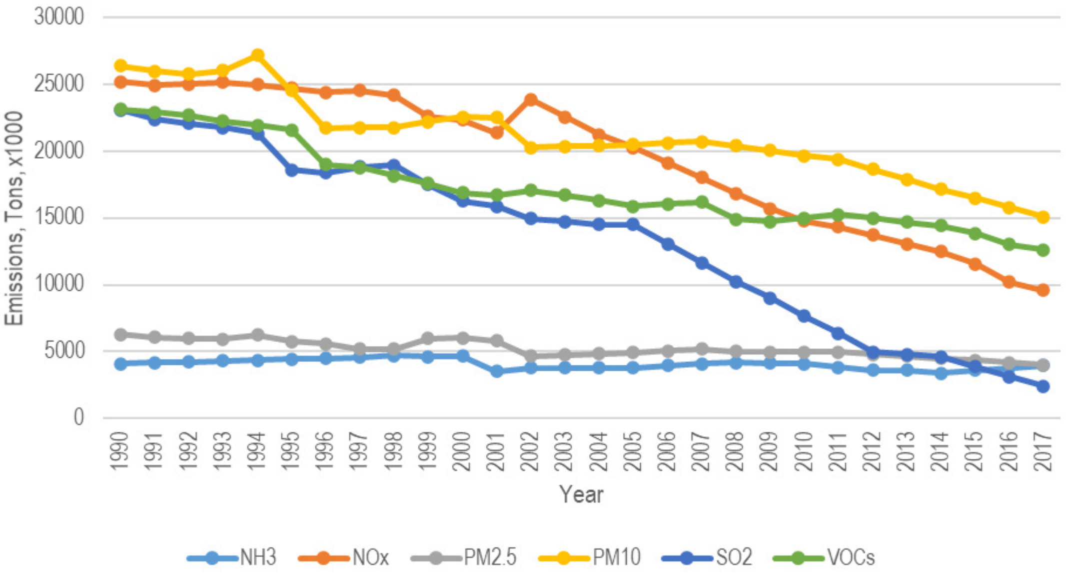

Figure 2-3 **National Emission Trends of $PM_{2.5}$, PM_{10}, and Precursor Gases from 1990 to 2017**

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 2016 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 2016 to 2032, anthropogenic NOx emissions are projected to decrease by 3.8 million tons (40%), with the greatest reductions from mobile-source sectors (nonroad and onroad) and EGUs. SO_2 emissions are projected to decrease by 1 million tons (38%), with the greatest reductions from the EGU sector. For primary $PM_{2.5}$, emissions are relatively flat from 2016 to 2032, with a decrease of 100k tons (3%) 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).

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[2] Prescribed burning emissions were held constant at 2016 levels in the model projections, although these emissions could potentially change in the future.

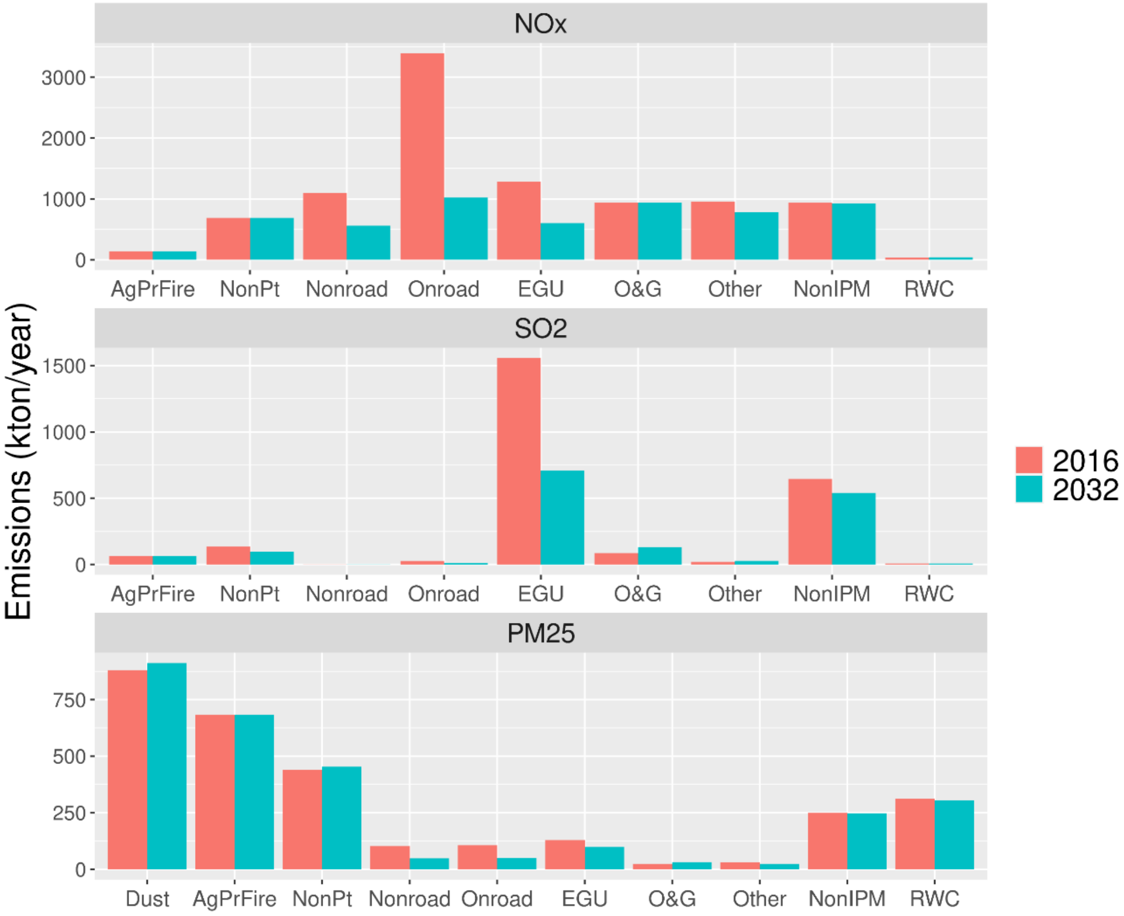

Figure 2-4 Annual Anthropogenic Source Sector Emission Totals (1000 tons per year) for NOx, SO_2, and $PM_{2.5}$ for 2016 and 2032

Note that AgPrFire: agricultural and prescribed fire; Nonpt: non-point area sources; O&G: oil and gas; Other: airports, commercial marine vehicles, rail, and solvents; NonIPM: 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 alternative standards levels considered in the RIA, whereas concentrations surrounding the urban core are below the 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 (e.g., Appendix 2A.5), 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.

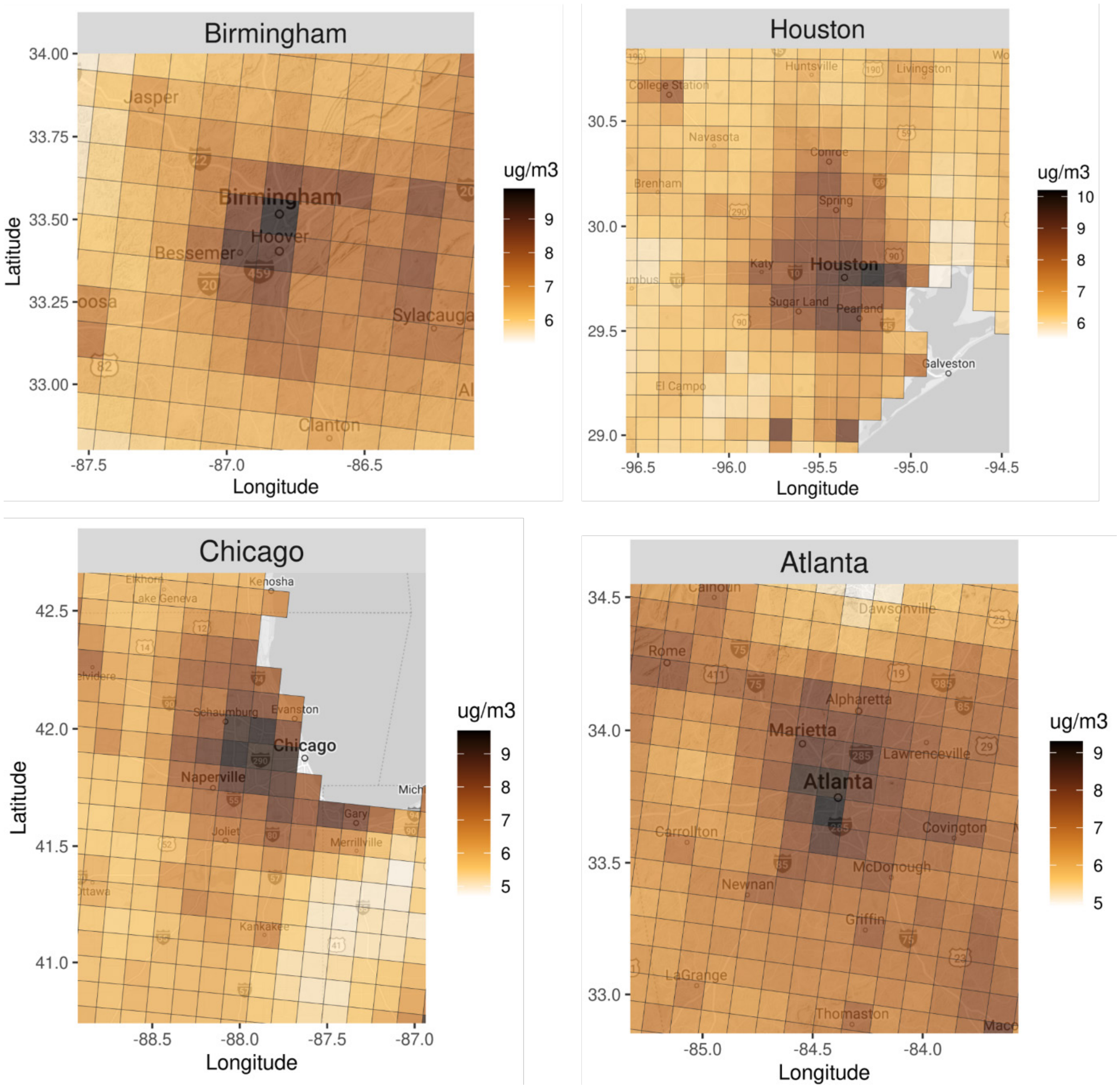

Figure 2-5 Gridded $PM_{2.5}$ Concentrations over Selected Urban Areas Based on the 2032 Modeling Case Described Below with the Enhanced Voronoi Neighbor Averaging Approach

2.2 Modeling $PM_{2.5}$ in the Future

To evaluate the incremental costs and benefits of meeting the alternative $PM_{2.5}$ standard levels proposed 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 2016-based modeling platform with the Community Multiscale Air Quality (CMAQ) model (www.epa.gov/cmaq). The modeling platform paired a 2016 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 2016 and for a case with emissions representative of 2032. Other than the differences in emissions inventories for the 2016 and 2032 CMAQ simulations, all other model inputs specified for the 2016 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 2016 to provide a reference simulation for the 2032 air quality projection. The geographic extents of the outer and inner air quality modeling domains are shown in Figure 2-6. The outer domain covers the 48 contiguous states along with most of Canada and Mexico using a horizontal resolution of 36 x 36 km. Air quality modeling for the 36-km domain was used to provide chemical boundary conditions for the simulation on the nested 12-km domain 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 2016 version 2 emissions modeling platform (USEPA, 2022b), which included emissions for 2016 and the projected 2032 case. Meteorological data were based on a 2016 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.

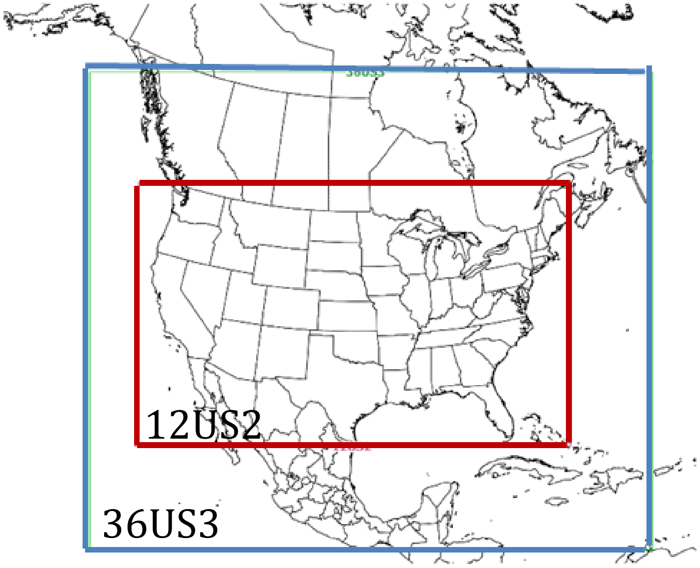

Figure 2-6 Map of the Outer 36US3 (36 x 36 km Horizontal Resolution) and Inner 12US2 (12 x 12 km Horizontal Resolution) Modeling Domains

2.2.1.2 Emission Inventory

The future-year emission inventory is projected from the 2016 version 2 emissions modeling platform. The projected emission case is labeled 2032, although the emission projections are based on a combination of projection years[3]. The development of the 2016 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 2016v2 North American Emissions Modeling Platform* (USEPA, 2022b). 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 Summer 2021 version of the Integrated Planning Model (IPM) (USEPA, 2021). 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 the 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

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[3] 2032: non-road, 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 at 2016 levels in CA, OR, and WA), and solvents; 2030: EGUs, US commercial marine vehicles, rail, and livestock; 2028: most Canada and Mexico emissions; 2016: fertilizer, fires, biogenics, and fugitive dust (other than paved road)

[4] Emissions reductions from the Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards (2021) and 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 these rules, any potential impacts are likely to be small. Updated air quality modeling will be conducted for a final PM NAAQS RIA.

Rule (MATS) finalized in 2011, and other finalized rules. Full documentation and results of the Summer 2021 Reference Case for EGUs are available at https://www.epa.gov/power-sector-modeling/results-using-epas-power-sector-modeling-platform-v6-summer-2021-reference.

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

- 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.

Note that the Boiler MACT is assumed to be fully implemented by 2016 except for North Carolina, in which it was fully implemented by 2017. 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 Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026 (March 2020); Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 (October 2016); Tier 3 Vehicle Emission and Fuel Standards Program (March 2014) and other finalized rules. A full discussion of the future year base inventory is provided in USEPA (2022b). 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 2016 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 2016 simulation are within or close to the ranges found in other recent applications. These model performance results provide confidence that our use of the 2016 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 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 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 2016 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 (2016) 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) version 1.8 (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 2014-2018 period centered on the 2016 CMAQ modeling period were used in projecting $PM_{2.5}$ DVs. $PM_{2.5}$ species measurements from the IMPROVE and CSN networks during 2015–2017 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 2014-2018 $PM_{2.5}$ 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-concentration cutoff of 61 μg m^{-3} was identified based the 99.9th percentile value from all daily $PM_{2.5}$ concentrations across all sites in the long-term AQS observations (2002-2018).

Step 2. Specific states and months where wildfires frequently occur were screened for instances of monitors exceeding the cutoff concentration. Potential wildfire periods were identified as those with $PM_{2.5}$ concentrations above the cutoff concentration in June-October in CA, WA, OR, MT, ID, and CO.

Step 3. For potential wildfire periods, the presence of visible wildfire smoke was examined using satellite imagery from NASA's Worldview platform (https://worldview.earthdata.nasa.gov). Timeseries of $PM_{2.5}$ concentrations at individual sites were also examined to confirm that the $PM_{2.5}$ enhancements are temporally consistent with wildfire events.

Step 4. For wildfire periods confirmed by the satellite imagery and timeseries analysis, $PM_{2.5}$ concentrations above the cutoff concentration of 61 μg m^{-3} occurring during the identified wildfire episode window at impacted sites were excluded. If the satellite imagery and timeseries analysis did not corroborate the wildfire event, data from the period were retained.

Step 5. In addition to the screening criteria above, data for the Camp Fire in northern CA during November 2018 and the Appalachian Fires in NC, TN, and GA during November 2016 were evaluated for exclusion if concentrations exceeded the extreme value threshold of 61 μg m^{-3}. These large fire episodes produced obvious $PM_{2.5}$ concentration impacts across multiple monitors and were clearly evident in the 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 concentration of 61 μg m^{-3} was applied as the cutoff value across all sites for New Year's Eve and the Fourth of July.

The excluded site-day combinations represent a small fraction (0.4%) of the total site-day combinations for the flagged sites. Since the cutoff value (61 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 and Alternative Standard Levels

To estimate the tons of emissions reductions needed to reach attainment of the existing and proposed 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, USEPA, 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 and alternative standards.

2.3.1 Developing Air Quality Ratios

In the illustrative control strategy analysis in the RIA, the 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 (e.g., Appendix 2A.5), 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.

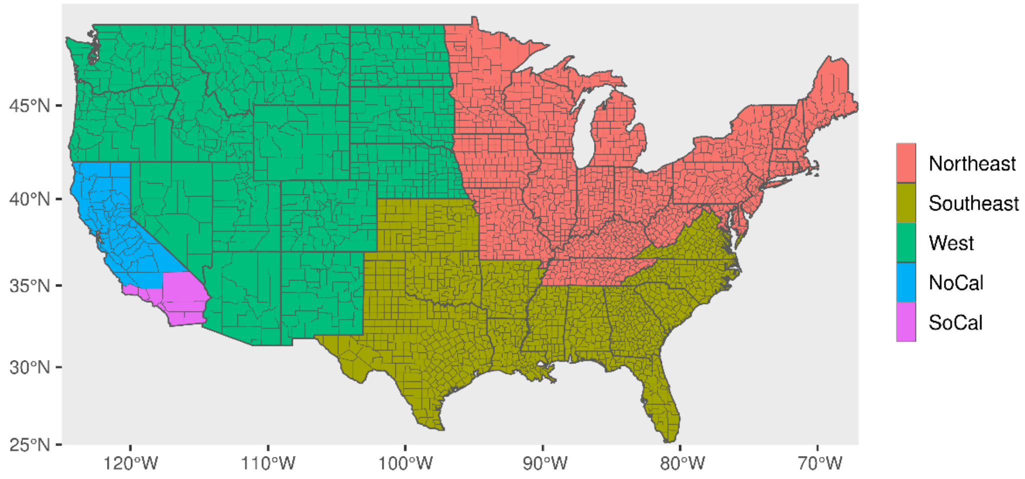

Figure 2-7 Regional Groupings for Calculating Air Quality Ratios

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 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 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 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 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, Utah, 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 three counties (Los Angeles, San Bernardino, and Imperial) exceed only the annual standard. Los Angeles and San Bernardino are in the South Coast Air Basin along with Riverside County, which exceeds both the annual and 24-hour standard.

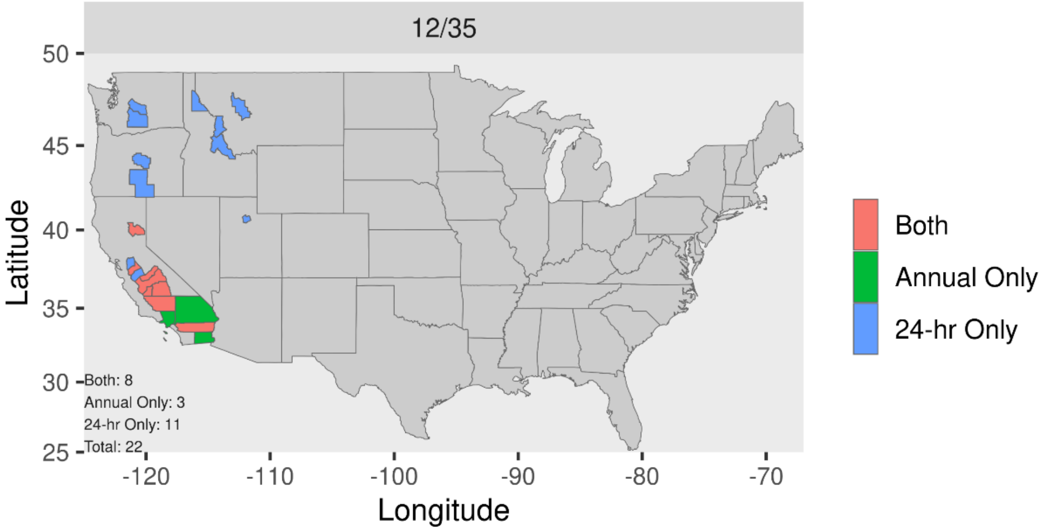

Figure 2-8 **Counties with Projected 2032 $PM_{2.5}$ DVs that Exceed the 24-Hour (24-hr Only), Annual (Annual Only) or Both (Both) Existing Standards (12/35 µg m^{-3})**

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 annual $PM_{2.5}$ DV in Kern County is 14.54 µg m^{-3} at site 06-029-0016 after applying the 75% NOx emission reduction to the 2032 DVs in SJV. The annual air quality ratio for primary $PM_{2.5}$ emissions in Northern California is 3.15 µg m^{-3} per 1000 tons. Therefore, to meet an annual standard of 12 µg m^{-3}, a total of 794 tons of primary $PM_{2.5}$ emissions is needed (i.e., (14.54-12.04)/3.15 x 1000). The highest 24-hour $PM_{2.5}$ DV in Kern County is 40.4 μg m^{-3} at site 06-029-0010 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 1000 tons. Therefore, to meet a 24-hour standard of 35 μg m^{-3}, a total of 502 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (40.4-35.4)/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 794 tons of primary $PM_{2.5}$ emission reductions are needed to meet the 12/35 standard combination (i.e., the maximum of 794 tons and 502 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} (i.e., 14.54 - (794 x 3.15 / 1000)) and the adjusted 24-hour DV is 32.5 μg m^{-3} (40.4 – (794 x 9.97 / 1000)).

2.3.3 Emission Reductions to Meet Alternative Standards

$PM_{2.5}$ DVs in the 12/35 analytical baseline exceed the levels of the 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 alternative standard levels.

Exceedances of the 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, six counties in the east, three in the northwest, and fifteen 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-three counties have 24-hr DVs greater than 30 μg m^{-3} with annual DVs less than 10 μg m^{-3}, and eleven counties exceed both the 24-hr and annual standards. For the 9/35 case, twenty-two counties exceed the annual standard in the Eastern U.S., compared with six for the 10/35 and 10/30 cases. The total number of counties exceeding the standards increases from 51 to 141 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.

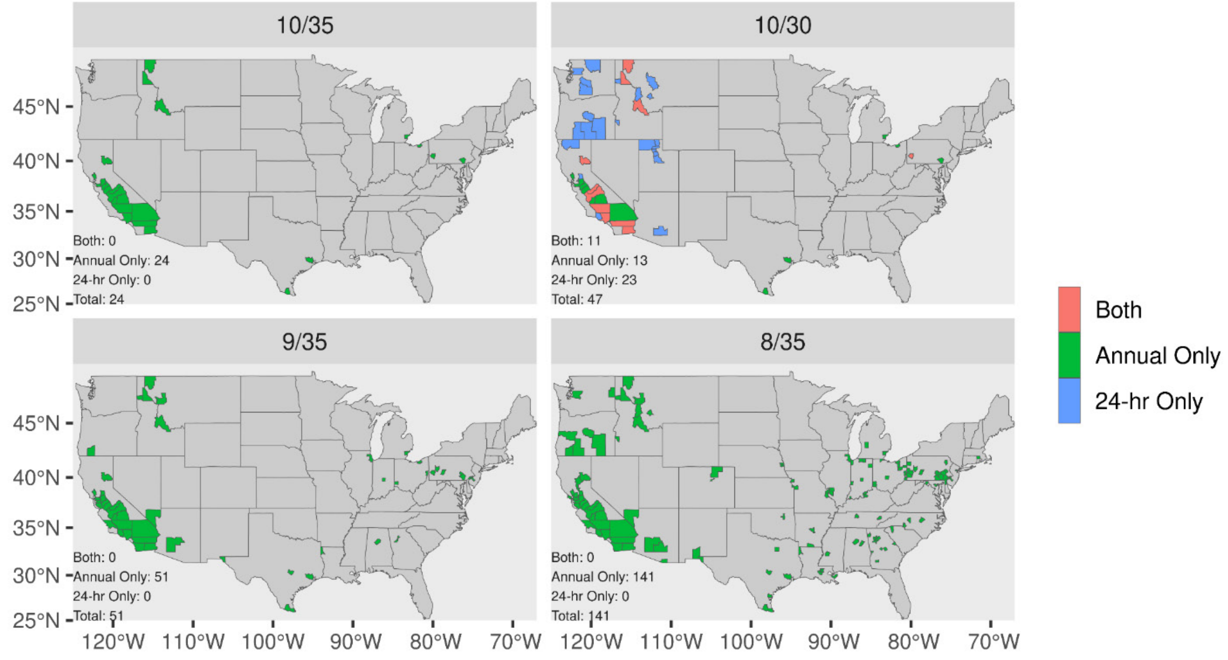

Figure 2-9 Counties with $PM_{2.5}$ DVs that Exceed Alternative Annual (Annual Only), 24-Hour (24-hr Only), or Both (Both) Standards in the 12/35 Analytical Baseline

The primary $PM_{2.5}$ emission reductions needed to meet the 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 alternative standards is available in section 2A.3.4.2 of Appendix 2A.

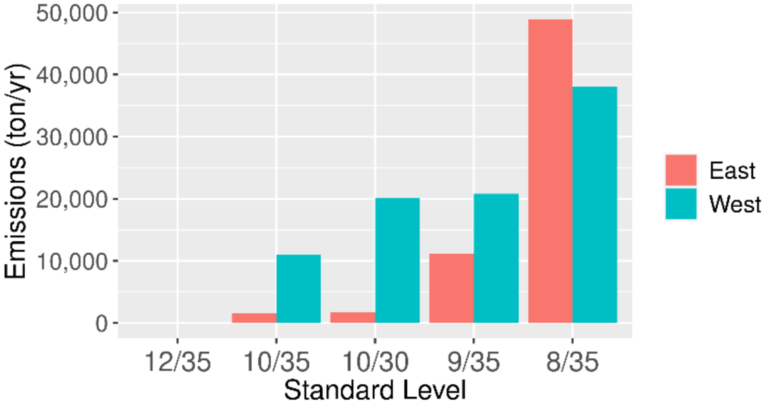

Figure 2-10 **Total Primary $PM_{2.5}$ Emission Reductions Needed to Meet the Alternative Standard Levels of 10/35, 10/30, 9/35, and 8/35 Relative to the 12/35 Analytical Baseline in the Eastern and Western U.S.**

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 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 local source-to-monitor impacts, 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 an area in Pennsylvania affected by local sources. 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 Delaware County, PA

$PM_{2.5}$ concentrations at the Chester monitor (site ID: 42-045-0002) in Delaware County, Pennsylvania appear to be strongly influenced by one or two nearby facilities. As described in the PA Department of Environmental Protection (PADEP) 2014 Annual Ambient Air Monitoring Network Plan (PADEP, 2014), the Chester monitor is located on the property of Evonik Degussa Corporation (Figure 2-11). The neighboring PQ Corporation produces sodium silicate and provides it to Evonik Degussa Corporation to undergo a drying process. Speciation data discussed in the 2014 monitoring plan demonstrated an anomalously high amount of silicon at the Chester speciation monitor that suggests $PM_{2.5}$ concentrations are strongly influenced by local emissions from the PQ and Evonik facilities. To confirm the source influence, additional $PM_{2.5}$ monitoring was performed at the Marcus Hook site about 2.5 miles from the Chester site. In PADEP's 2018 monitoring plan (PADEP, 2018), the state concluded that local sources are impacting the Chester monitoring site based on comparison of $PM_{2.5}$ concentrations from the Chester and Marcus Hook sites. Our 2032 DV projections are consistent with a local source influence on the Chester monitor. For instance, the annual 2032 DV at Chester is 9.96 $\mu g\ m^{-3}$ and is 8.61 $\mu g\ m^{-3}$ at the Marcus Hook site about 2.5 miles away. Given the local nature of the source-to-monitor influence at the Chester site, controllable emissions likely exist at the facilities to resolve the air quality issue. However, specifically quantifying the impacts of the near-monitor controls would require a detailed local analysis beyond the scope of the national RIA.

Figure 2-11 Location of the Chester Site in Relation to the Evonik Degussa and PQ Corporation Facilities

Source: PADEP, 2018

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 2-12). 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 12.45 $\mu g\ m^{-3}$ in Calexico, 9.13 $\mu g\ m^{-3}$ in Brawley, and 8.02 $\mu g\ m^{-3}$ 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, CARB, 2018b).

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 2-13 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 2-14). 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

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[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.

California. However, a detailed local analysis beyond the scope of the RIA would be needed to evaluate this possibility.

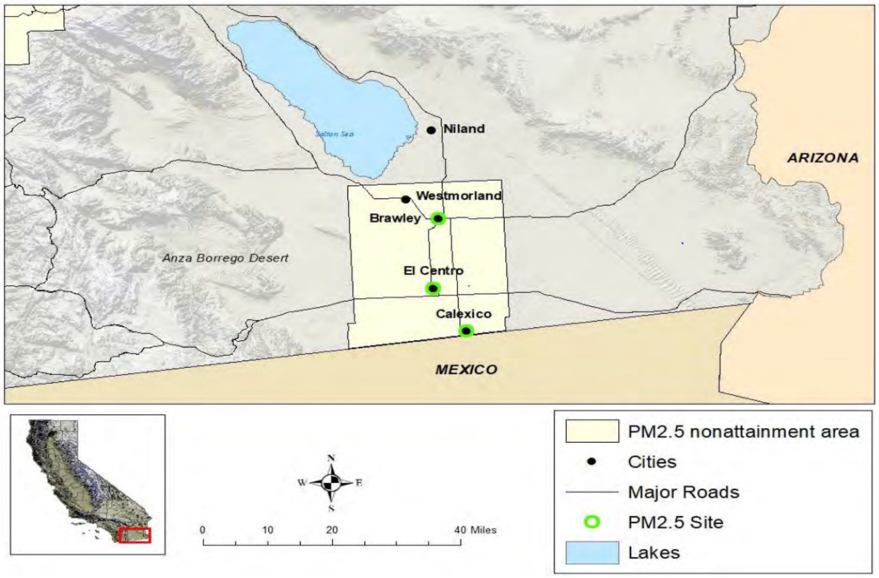

Figure 2-12 Imperial County and the Nonattainment Area

Source: CARB, 2018a

Figure 2-13 Nighttime Aerial View of Calexico, CA and Mexicali, MX

Source: CARB, 2018b

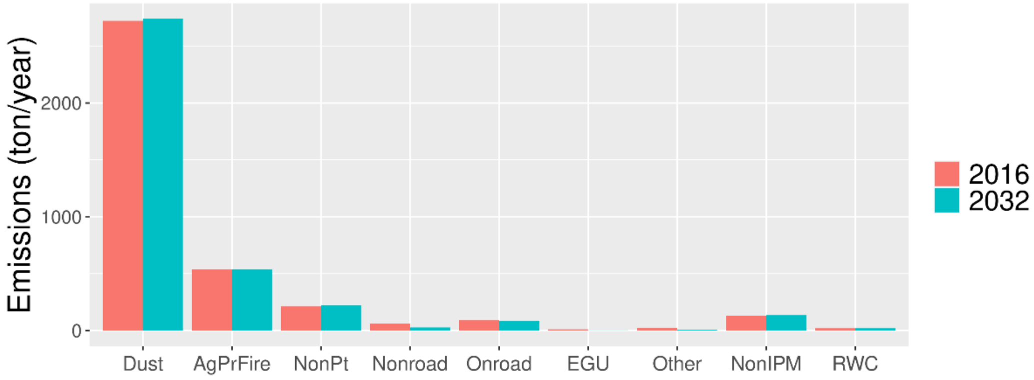

Figure 2-14 **Annual Source Sector Emission Totals (1000 tons per year) for $PM_{2.5}$ for 2016 and 2032 in Imperial County**

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: 9.75 μg m^{-3}) and Hidalgo (2032 annual DV: 10.30 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 2-15), 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 2016 and 2032 modeling cases (Figure 2-16). Paved-road dust emissions are projected to increase in these counties between 2016 and 2032 due to projected increases in the vehicle miles travelled. Non-point (area source) emissions are also projected to increase due to population-based emission projection factors. Increases in dust and non-point emissions from 2016 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 2-16). 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 international transport to projected exceedances in this area.

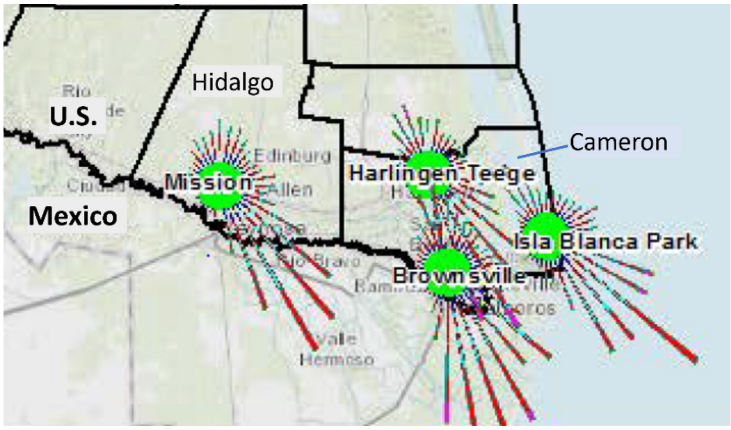

Figure 2-15 Location of Mission and Brownsville Monitors in Hidalgo and Cameron County, respectively, with Annual Wind Patterns from Meteorological Measurements

Source: TCEQ, 2015

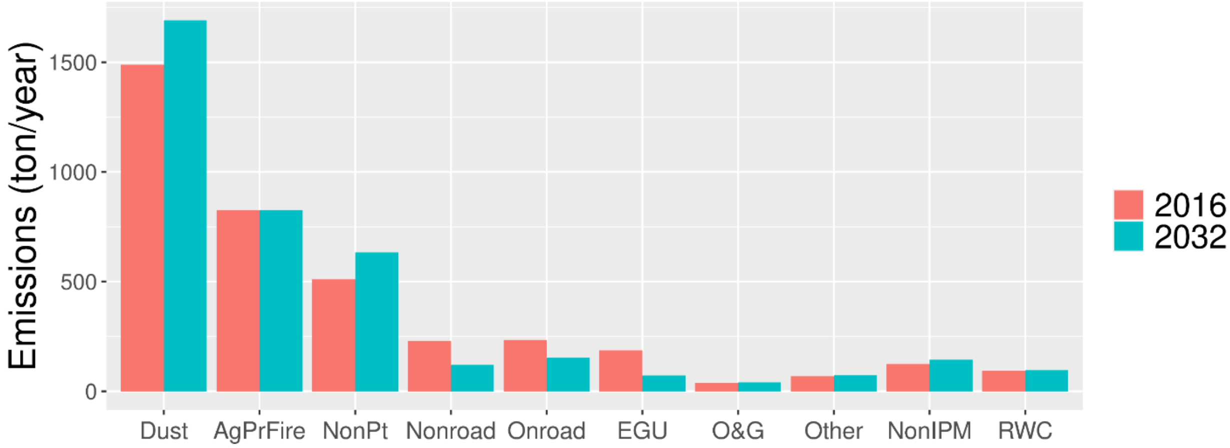

Figure 2-16 **Annual Source Sector Emission Totals (1000 tons per year) for $PM_{2.5}$ for 2016 and 2032 in Cameron and Hidalgo County Combined**

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 2-17). 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 2-18. The Libby nonattainment area for the 1997 $PM_{2.5}$ NAAQS and the city of Libby are shown within Lincoln County, MT in Figure 2-19.

Figure 2-17 Air Pollution Layer Associated with a Temperature Inversion in Missoula, MT in November 2018

Source: Tommy Martino, Missoulian[6]

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[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.

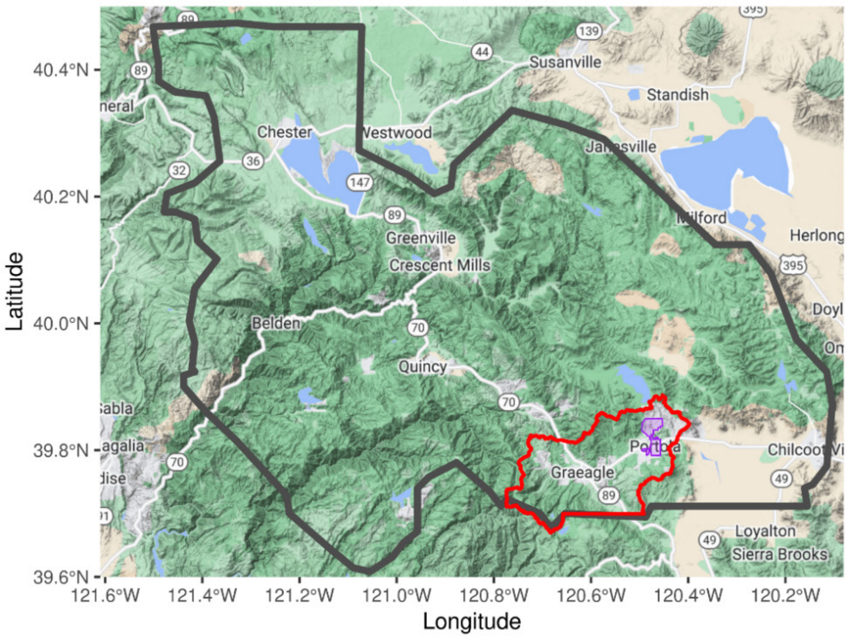

Figure 2-18 **Plumas County, CA (Grey), Portola Nonattainment Area (Red), and City of Portola (Purple)**

Source: Map Data ©2022 Google.

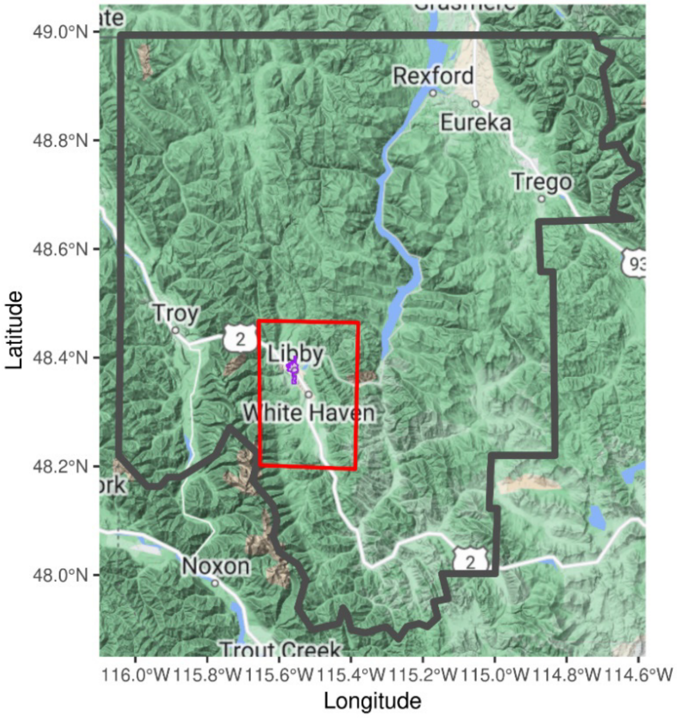

Figure 2-19 **Lincoln County, MT (Grey), Libby Nonattainment Area (Red), and City of Libby (Purple)**

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 Benewah, ID. The populations of the relevant cities within these counties range from 1,913 to 3,182 (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 with lower cutoff concentrations and broader temporal screening of wildfire influence were performed to explore the potential for wildfire impacts to affect attainment of the standards. The sensitivity projections (Table 2-

2) suggest that the elevated concentrations in Benewah County may be driven largely by wildfires and that annual DVs in Lemhi, Shoshone, and Lincoln could be up to 0.8 to 1 μg m^{-3} lower if detailed analyses led to additional data exclusion. 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 I[b] (μg m^{-3})	Annual 2032 DV Alternative Fire Screening II[c] (μg m^{-3})
Plumas, CA	Portola (1,913)	14.52	14.49	14.23
Lincoln, MT	Libby (2,845)	11.08	10.79	10.04
Shoshone, ID	Pinehurst (1,620)	11.04	10.57	10.10
Lemhi, ID	Salmon (3,182)	11.03	10.59	10.21
Benewah, ID	St. Maries (2,465)	9.61	8.83	8.58

[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 cutoff concentration of 25 μg m^{-3} (rather than the default value of 61 μg m^{-3})

[c] Screening based on a cutoff concentration of 20 μg m^{-3} (rather than the default value of 61 μg m^{-3}) and inclusion of all days in June-October (rather than the flagged fire periods alone).

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 two relatively isolated counties (San Luis Obispo and Napa).

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 2-10) 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.

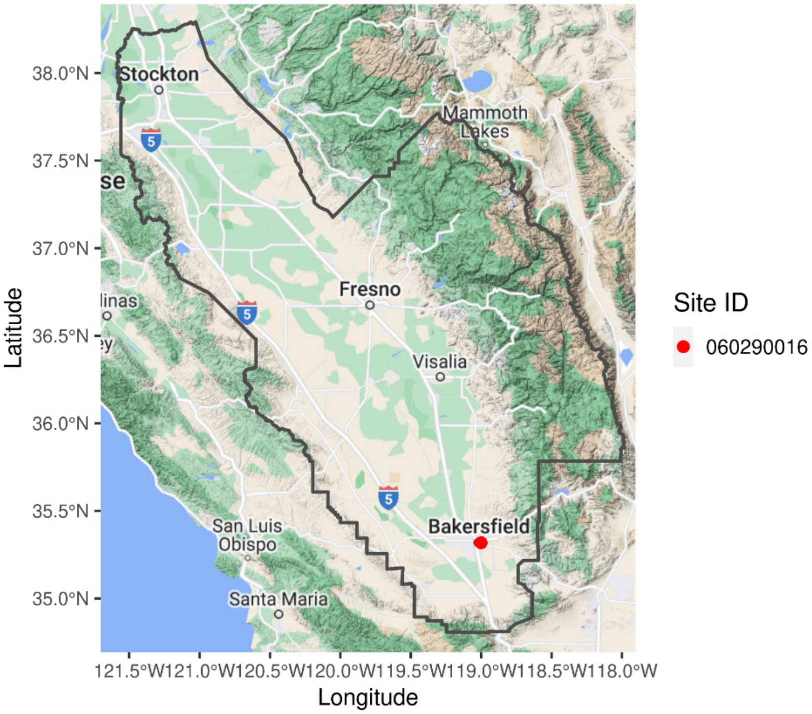

Figure 2-20 **San Joaquin Valley Nonattainment Area and Location of Highest $PM_{2.5}$ Monitor in Bakersfield (06-029-0016)**

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 2-21. 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 2-22; 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).

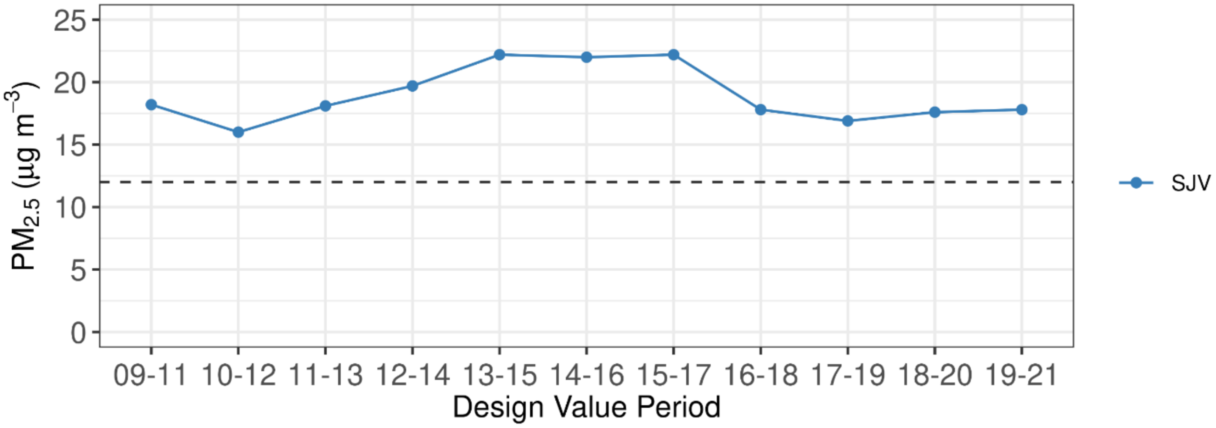

Figure 2-21 **Recent Annual $PM_{2.5}$ DVs at the Highest SJV Monitor for Design Value Periods (e.g., 11-13: 2011-2013). Dashed line is the 2012 Annual $PM_{2.5}$ NAAQS Level (12 µg m^{-3})**

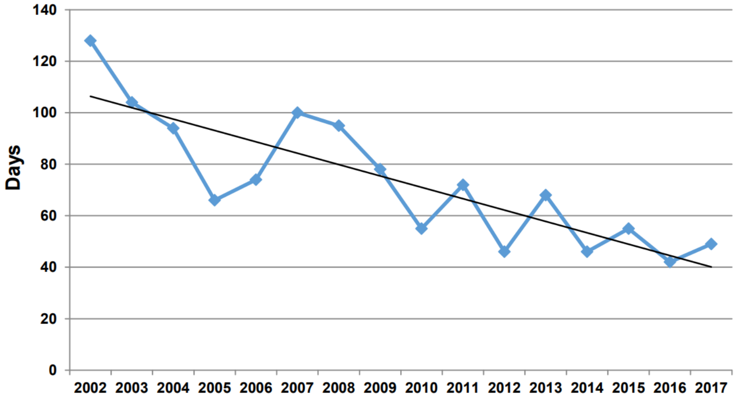

Figure 2-22 **Decrease in the Number of Days SJV Exceeded the 24-hr NAAQS Level (35 µg m^{-3})**

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 2-23. $PM_{2.5}$ emissions are largest from agricultural dust from the production of crops and livestock, agricultural burning, paved and unpaved road dust, and prescribed burning. Wildfire also contributed 22,000 tons of $PM_{2.5}$ emissions to SJV based on 2016 levels.

The highest projected 2032 annual DV in SJV is 16.20 $\mu g\ m^{-3}$ 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.

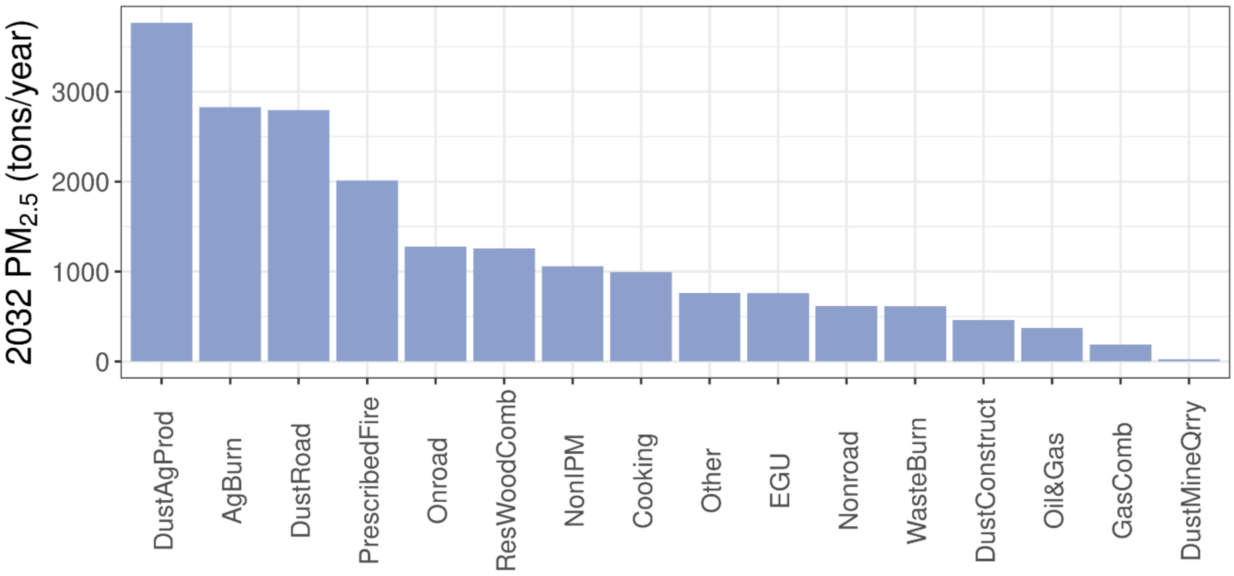

Figure 2-23 Annual Source Sector $PM_{2.5}$ Emission Totals in SJV Counties for 2032 Modeling Case

Note that DustAgProd: Dust from Agricultural Production; AgBurn: Open Agricultural Burning; DustRoad: Paved and Unpaved Road Dust; NonIPM: 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 22,000 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 2-24). 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 12.73 µg m^{-3} (site ID: 06-037-4008) and is 14.10 µg m^{-3} in Riverside (site ID: 06-065-8005) and 14.96 µg m^{-3} in San Bernardino (site ID: 06-071-0027).

Figure 2-24 South Coast Air Basin Nonattainment Area and Locations of Highest $PM_{2.5}$ Monitors in Los Angeles (06-037-4008), 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 2-25). 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 are commercial and residential cooking, onroad mobile sources, and paved and unpaved road dust (Figure 2-26). $PM_{2.5}$ 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.

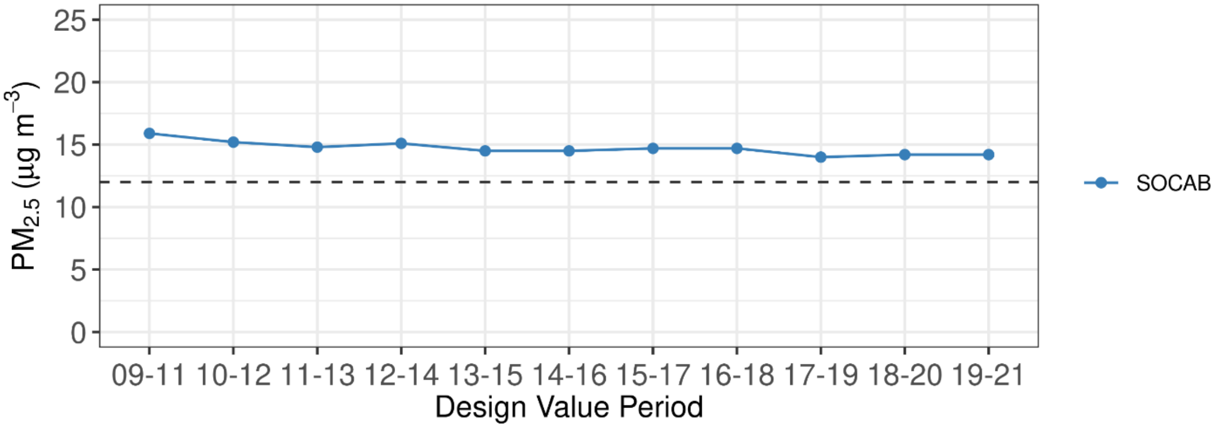

Figure 2-25 **Recent Annual $PM_{2.5}$ DVs at the Highest South Coast Monitor for Design Value Periods (e.g., 11-13: 2011-2013). Dashed line is the 2012 Annual $PM_{2.5}$ NAAQS Level (12 $\mu g\ m^{-3}$)**

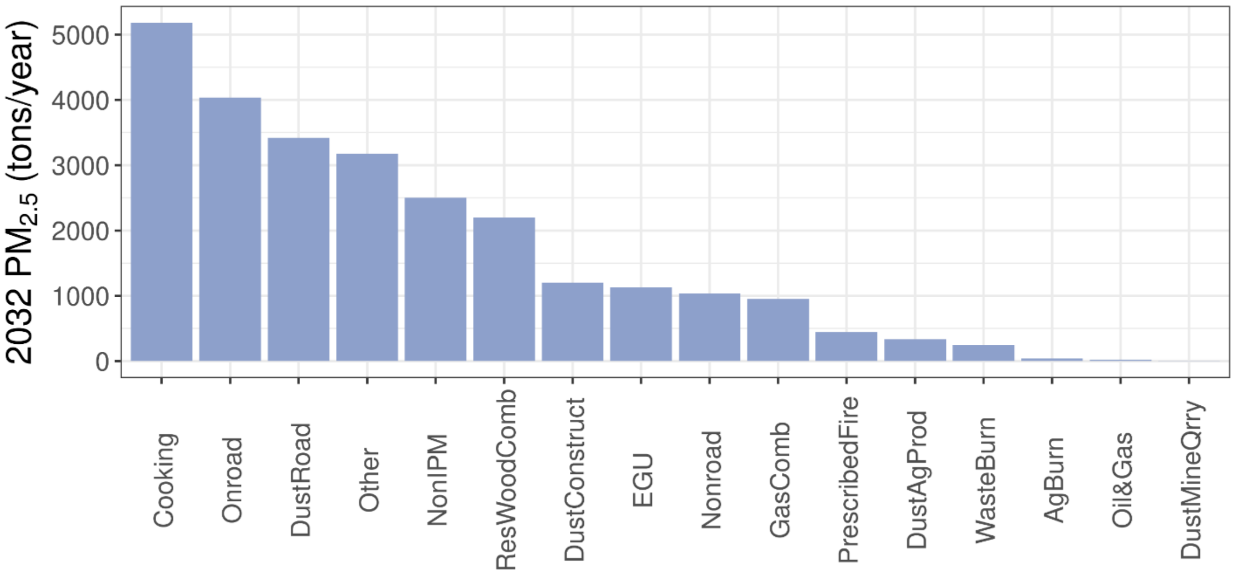

Figure 2-26 **Annual Source Sector $PM_{2.5}$ Emission Totals in the SoCAB Counties for 2032 Modeling Case**

Note: See Figure 2-23 for Label Definitions. Wildfire emissions (Not Shown) are 8,000 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 San Luis Obispo and Napa, CA

The RIA analysis identified challenges in meeting the 9/35 standard at the Arroyo Grande site (06-079-2007) in San Luis Obispo County. Local sources and wildfires could be the main contributors to $PM_{2.5}$ concentrations at this site based on the coastal situation and surrounding mountains (Figure 2-27). In recent years, the $PM_{2.5}$ DVs have decreased at the Arroyo Grande site such that the annual $PM_{2.5}$ DVs for the 2018-2020 and 2019-2021 periods are 8.0 and 7.7 μg m^{-3}, respectively (Figure 2-28). The projected 2032 annual DV (9.63 μg m^{-3}) is based on monitoring from the 2014-2018 period and does not capture the recent air quality improvements. Based on the ambient data for the two most recent DV periods, the Arroyo Grande site may not require additional emission reductions to meet alternative standard levels.

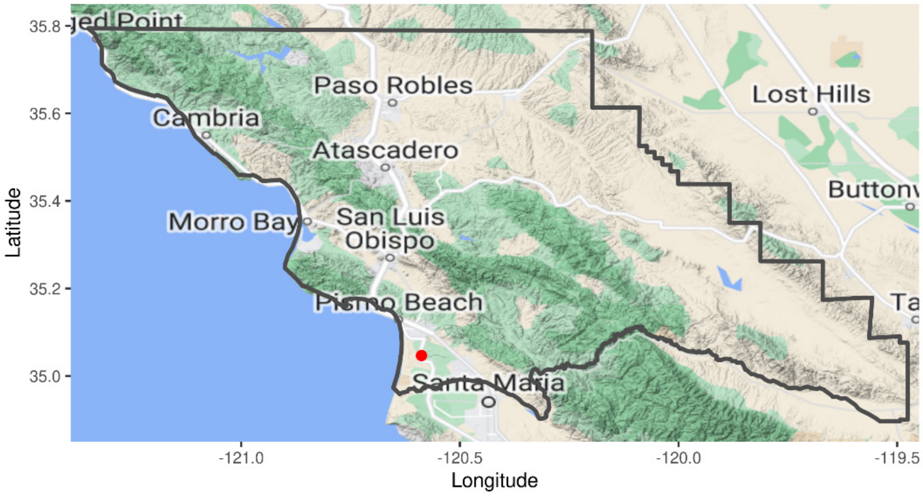

Figure 2-27 San Luis Obispo County and Location of Highest $PM_{2.5}$ Monitor in Arroyo Grande (06-079-2007)

Source: Map Data ©2022 Google.

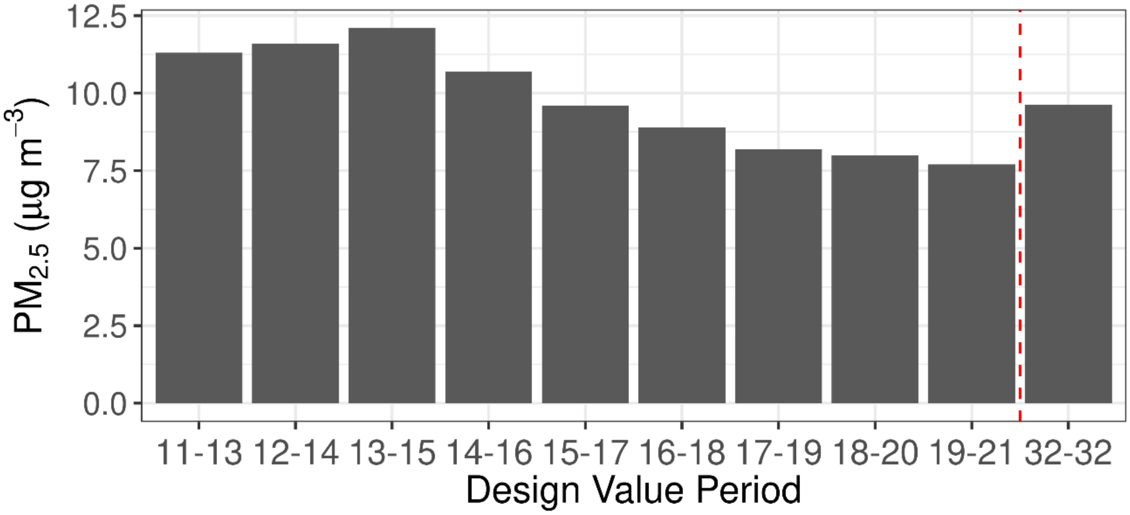

Figure 2-28 **Recent and Projected Annual $PM_{2.5}$ DVs at the Arroyo Grande Monitor (06-079-2007) in San Luis Obispo County for DV Periods (e.g., 11-13: 2011-2013; 32-32: Projected 2032 DV)**

The RIA analysis also identified challenges in meeting alternative standard levels in Napa County. The projected 2032 annual DV at the highest-DV site in Napa (06-055-0003) is 10.09 µg m^{-3}. Since the site is located in a valley (Figure 2-29), $PM_{2.5}$ concentrations may have relatively large contributions from local emission sources. Contributions from regional sources in the Bay Area, Central Valley, and wildfire are also possible. For instance, severe wildfires occurred in Napa during the Wine Country Fires in Fall 2017. A previous study reported that modeled concentrations of carbonaceous $PM_{2.5}$ at the Napa site were underestimated, often by a factor of two to three (BAAQMD, 2009). The analysis suggested that carbonaceous $PM_{2.5}$ emissions, possibly from wood burning, may have been strongly underrepresented in the Napa emission inventory. Additional work to develop local emission inventories and modeling for the area would be needed to identify appropriate emission reductions in Napa.

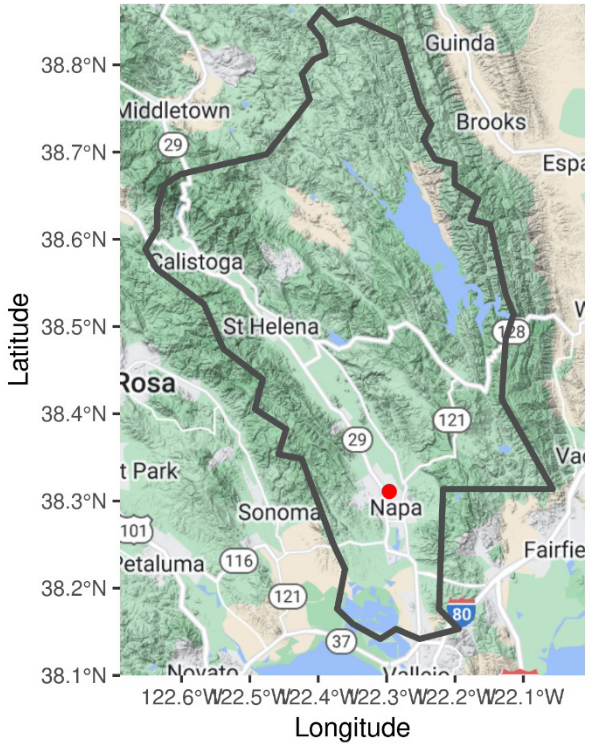

Figure 2-29 Napa County and Location of $PM_{2.5}$ Monitor (06-055-0003)

Source: Map Data ©2022 Google.

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

National $PM_{2.5}$ concentration fields corresponding to meeting the existing 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 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.

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, version 1.8, 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 2015-2017 period were interpolated to the spatial grid using inverse distance-squared-weighting of monitored concentrations that were further weighted by the ratio of the 2016 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 2016.

Step 2. The 2016 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 2016. 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 2-30.

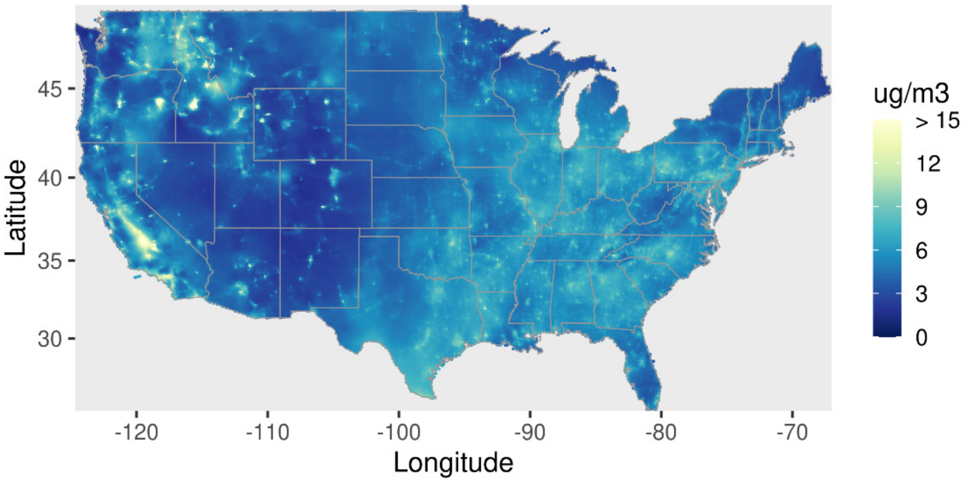

Figure 2-30 **$PM_{2.5}$ Concentration for 2032 based on eVNA Method**

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 the county non-highest monitors, the difference in $PM_{2.5}$ DVs was estimated by proportionally adjusting 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, 2012b).

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.

An example of a spatial field for the incremental change in $PM_{2.5}$ concentration between the 2032 case and the case of meeting the existing standard combination, 12/35, is shown in Figure 2-31. Additional details on the method for developing $PM_{2.5}$ concentration fields are available in section 2A.4 of Appendix 2A.

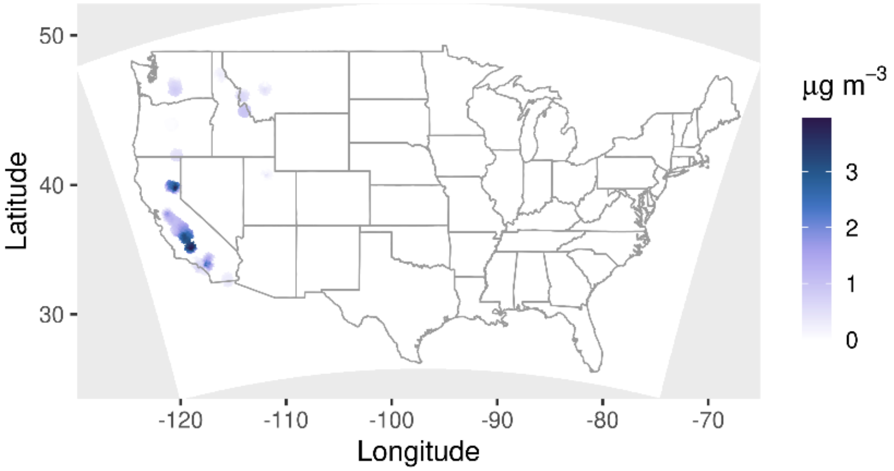

Figure 2-31 $PM_{2.5}$ Concentration Improvement Associated with Meeting 12/35 Relative to the 2032 case

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APPENDIX 2A: ADDITIONAL AIR QUALITY MODELING INFORMATION

Overview

A 2016-based modeling platform was used to project future-year air quality for 2032 to identify areas that would exceed the existing and potential 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 2016 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 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 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 2016 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 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 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.
6. As a sensitivity analysis, estimate the influence on $PM_{2.5}$ DVs of emission reductions beyond the 2032 modeling that are expected to occur due to EGU retirements and other factors became known or on-the-books after the EGU emissions projections were conducted for the 2032 CMAQ modeling. [1]

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[1] The EGU fleet information for the case used in the 2032 CMAQ modeling (i.e., NEEDS v6 Summer 2021 Reference Case) and the case that informed the sensitivity analysis (i.e., NEEDS v6 rev: 1-24-22) are both available here: https://www.epa.gov/power-sector-modeling/national-electric-energy-data-system-needs-v6.

In the remainder of this Appendix, the 2016 air quality model configuration and simulation are described and evaluated in Section 2A.1. The projection of air quality from 2016 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. The development of the $PM_{2.5}$ concentration fields is described in Section 2A.4. Finally, the sensitivity analysis for EGU emission reductions beyond the 2032 CMAQ modeling case is described in section 2A.6.

2A.1 2016 CMAQ Modeling

CMAQ modeling was performed for 2016 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 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 2016 to provide a reference simulation for the 2032 air quality projection. The geographic extents of the outer and inner air quality modeling domains are shown in Figure 2A-1. The outer domain covers the 48 contiguous states along with most of Canada and Mexico with a horizontal resolution of 36 x 36 km. Air quality modeling for the 36-km domain was used to provide chemical boundary conditions for the nested 12-km domain simulation, which was used in projecting air quality to the future. Both model domains have 35 vertical layers with a top at about 17.6 km (50 millibars). The chemical boundary and initial conditions for the 36-km modeling domain were developed with version 3.1.1 of the hemispheric CMAQ model (https://www.epa.gov/cmaq/hemispheric-scale-applications). The simulations included 10 days of model spin-up in December 2015 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 2016 emissions modeling platform as described in detail previously (USEPA, 2022). 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 2016 meteorology.

The 2016 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 (Morrison et al., 2005, 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, 2019c).

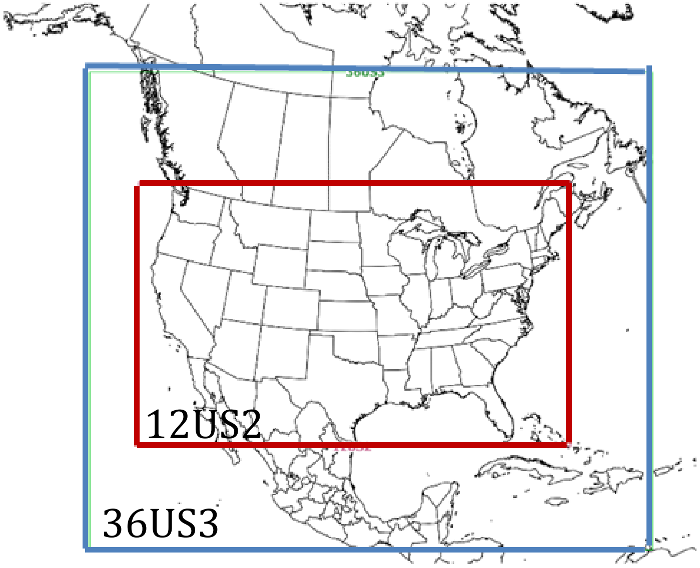

Figure 2A-1 **Map of the Outer 36US3 (36 x 36 km Horizontal Resolution) and Inner 12US2 (12 x 12 km Horizontal Resolution) Modeling Domains Used for the PM NAAQS RIA**

2A.1.2 Model Performance Evaluation

CMAQ predictions were evaluated by comparison with observations from U.S. monitoring networks in 2016. 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 μg m^{-3} or 24-hour DVs greater than 30 μg m^{-3}. For regions in the eastern U.S., normalized mean biases (NMBs) are within 15% and Pearson correlation coefficients are 0.58 or greater for all regions, except for the South (r=0.37). In western regions, the model is generally biased low compared with observations, with NMBs ranging from -16% in the Northwest to -30% in the Southwest. 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 13% in eastern regions and correlation coefficients are 0.55 or greater in four of the five regions. In the western regions, NMB ranged from 8.0% in the Northwest to -25.9% in the Northern Rockies and Plains and correlation coefficients ranged from 0.10 to 0.43.

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 ±16% for all regions except the Northwest (NMB: 64%) at CSN sites and within ±23% for all regions except the Northwest (NMB: 41%) 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 <0.25 μg m^{-3} for both networks in the Northwest. Correlation coefficients over the annual period for sulfate predictions and observations were greater than 0.56 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 ±18% at CSN sites and within ±30% at IMPROVE sites. Nitrate predictions are biased low in the West at CSN (NMB: -48.8%) and IMPROVE (NMB: -24.8%) 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 0.59 to 0.79 at CSN sites and 0.52 to 0.75 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 ±30% for six of the nine regions at CSN sites and seven 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 five 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 four 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 is within ±17% at CSN sites and within ±25% at IMPROVE sites for all regions except the Northwest. As mentioned above, overpredictions of $PM_{2.5}$ species concentrations in the Northwest may be associated with challenges in modeling the mixing height near the coast, wildfire influence, and other factors. Correlation coefficients for the EC predictions and observations over the annual period were greater than 0.5 in seven of the nine regions for CSN and IMPROVE sites. Spatially, EC predictions tend to be biased slightly low through much of the US with predictions biased high along the coast of the Northeast and Northwest (Figure 2A-4 and 2A-5).

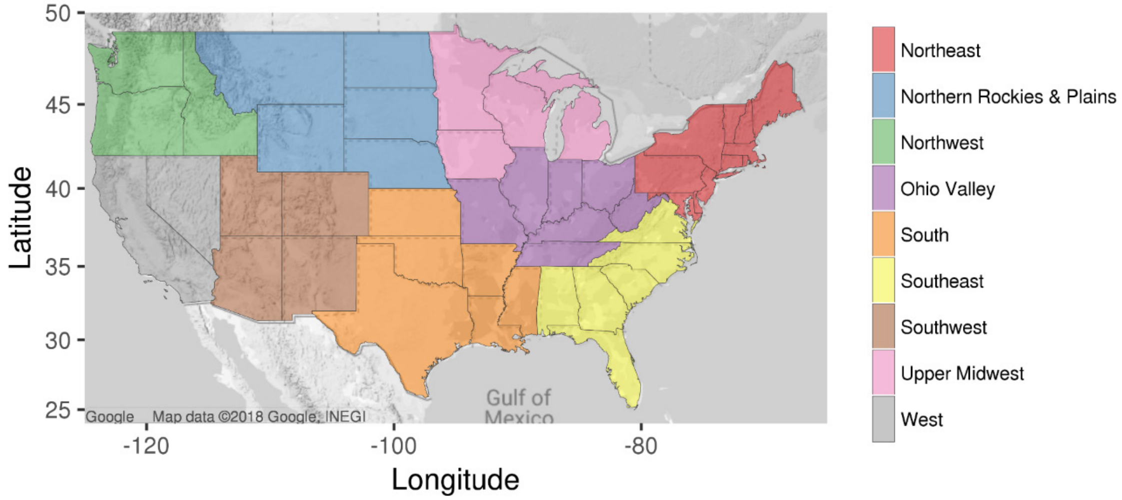

Figure 2A-2 U.S. Climate Regions (Karl and Koss, 1984) Used in the CMAQ Model Performance Evaluation

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
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

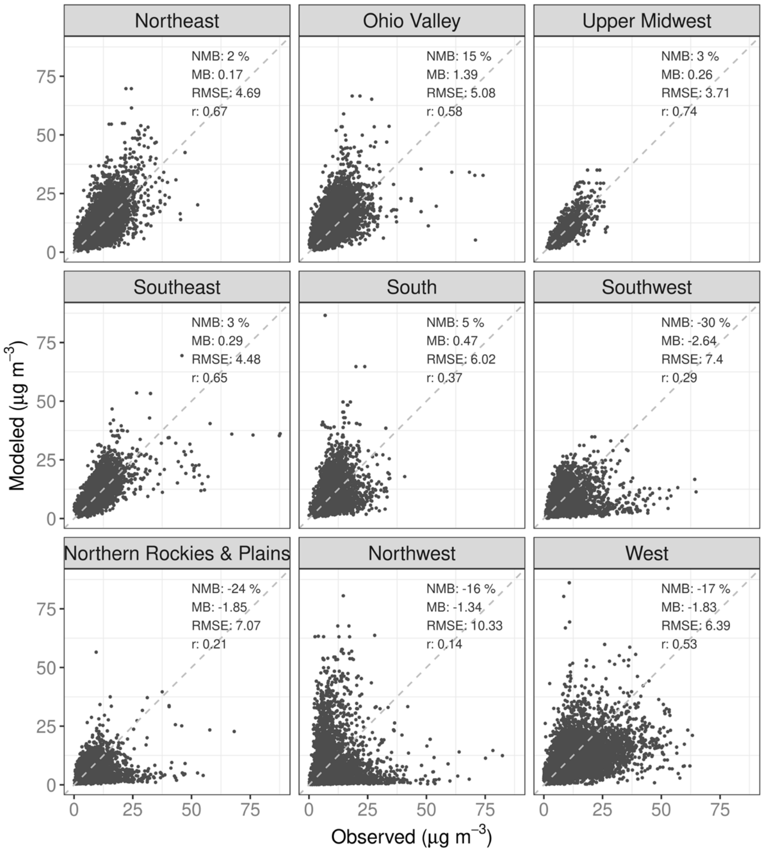

Figure 2A-3 **Comparison of CMAQ Predictions of $PM_{2.5}$ and Observations at AQS Sites for County Highest $PM_{2.5}$ Monitors with 2032 $PM_{2.5}$ DVs Greater than 8/30**

Table 2A-2 CMAQ Performance Statistics for PM$_{2.5}$ at AQS Sites in 2016

Region	Season	N	Avg. Obs. (μg m^{-3})	Avg. Mod. (μg m^{-3})	MB (μg m^{-3})	NMB (%)	RMSE (μg m^{-3})	NME (%)	*r*
Northeast	Winter	13305	8.32	10.16	1.84	22.1	5.95	47.6	0.65
	Spring	13491	6.86	7.41	0.56	8.1	3.85	39.0	0.69
	Summer	13636	7.20	6.61	-0.58	-8.1	3.45	35.3	0.56
	Fall	13413	6.72	7.94	1.22	18.1	4.90	46.8	0.65
	Annual	53845	7.27	8.02	0.75	10.3	4.63	42.3	0.64
Southeast	Winter	10996	7.37	8.47	1.09	14.8	5.26	41.8	0.48
	Spring	11218	8.05	7.60	-0.45	-5.6	3.47	29.9	0.60
	Summer	11501	8.01	6.59	-1.43	-17.8	3.55	32.6	0.51
	Fall	11454	8.88	8.69	-0.19	-2.2	5.28	32.9	0.63
	Annual	45169	8.09	7.83	-0.26	-3.2	4.47	34.0	0.55
Ohio Valley	Winter	10729	8.47	10.61	2.15	25.4	5.50	44.8	0.57
	Spring	10739	7.76	8.42	0.66	8.6	4.65	39.3	0.47
	Summer	10753	8.54	8.36	-0.18	-2.0	3.93	32.7	0.49
	Fall	10761	8.92	10.48	1.56	17.5	5.67	40.2	0.62
	Annual	42982	8.42	9.47	1.05	12.5	4.99	39.3	0.55
Upper Midwest	Winter	6638	8.19	9.62	1.43	17.4	5.07	42.6	0.65
	Spring	6556	7.04	7.53	0.48	6.9	7.98	44.2	0.30
	Summer	6253	6.02	6.00	-0.02	-0.4	3.35	39.9	0.52
	Fall	6863	6.42	7.65	1.23	19.2	4.29	45.2	0.65
	Annual	26310	6.93	7.73	0.80	11.5	5.46	43.1	0.52
South	Winter	7935	6.93	8.35	1.42	20.4	4.77	46.1	0.53
	Spring	8266	8.00	7.21	-0.79	-9.9	4.23	35.6	0.51
	Summer	7974	9.02	6.20	-2.81	-31.2	5.39	45.6	0.35
	Fall	7951	7.96	8.40	0.44	5.5	4.52	37.0	0.57
	Annual	32126	7.98	7.53	-0.44	-5.6	4.74	41.0	0.43
Southwest	Winter	5373	8.12	6.59	-1.53	-18.9	8.45	58.1	0.39
	Spring	5447	4.77	5.16	0.39	8.3	4.07	52.7	0.32
	Summer	5548	6.35	3.99	-2.36	-37.2	4.63	49.6	0.28
	Fall	5574	5.58	5.08	-0.50	-9.0	4.35	49.5	0.42
	Annual	21942	6.20	5.19	-1.00	-16.2	5.64	52.9	0.37
N. Rockies & Plains	Winter	5006	5.80	3.60	-2.21	-38.0	6.77	62.9	0.29
	Spring	5238	5.22	4.04	-1.17	-22.5	15.61	61.9	0.11
	Summer	5267	6.55	4.32	-2.23	-34.0	34.38	66.1	0.09
	Fall	5065	4.58	4.46	-0.12	-2.6	6.55	63.8	0.22
	Annual	20576	5.54	4.11	-1.43	-25.9	19.66	63.8	0.10
Northwest	Winter	9961	7.90	6.18	-1.72	-21.8	8.67	70.3	0.24
	Spring	10059	4.23	5.42	1.19	28.1	4.88	64.3	0.45
	Summer	9884	4.72	6.37	1.65	34.9	8.29	69.0	0.44
	Fall	9864	5.63	6.32	0.69	12.2	6.67	69.0	0.39
	Annual	39768	5.62	6.07	0.45	8.0	7.28	68.5	0.32
West	Winter	10915	9.47	7.53	-1.94	-20.5	6.83	47.0	0.61
	Spring	11124	6.79	5.99	-0.79	-11.7	3.80	39.3	0.57
	Summer	11516	9.24	7.46	-1.78	-19.3	9.73	43.8	0.25
	Fall	11097	8.64	7.15	-1.50	-17.3	6.24	43.8	0.47
	Annual	44652	8.54	7.03	-1.50	-17.6	7.01	43.8	0.43

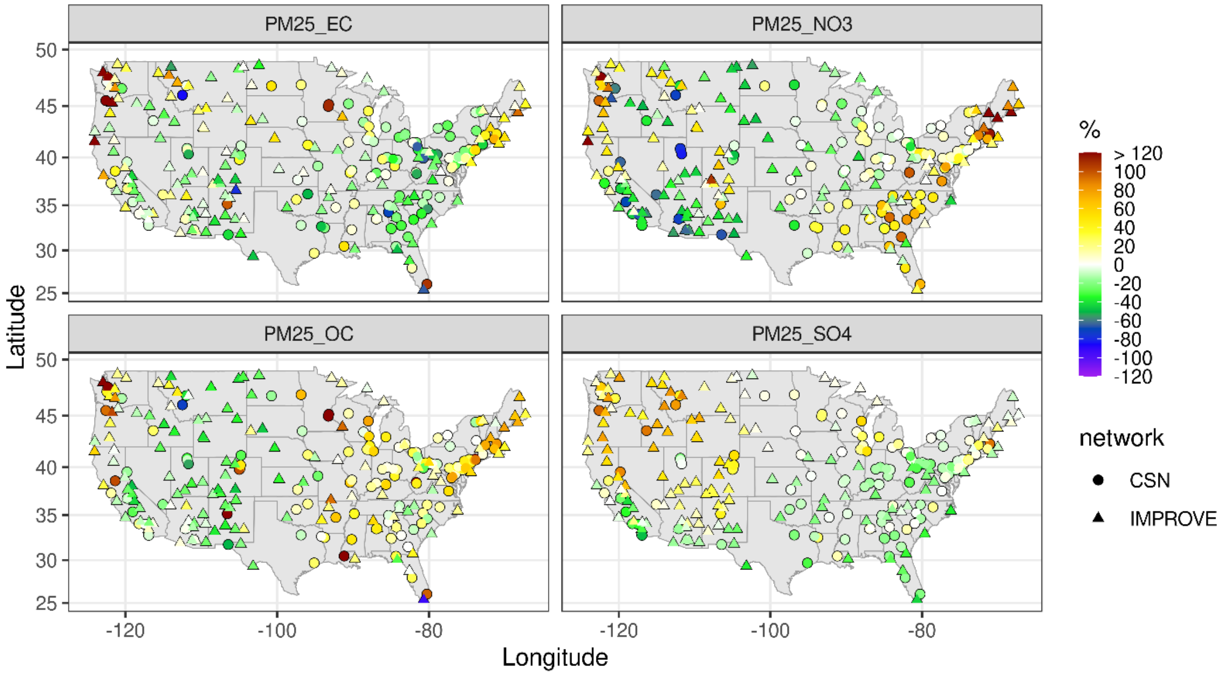

Figure 2A-4 NMB in 2016 CMAQ Predictions of $PM_{2.5}$ Components at CSN and IMPROVE Sites

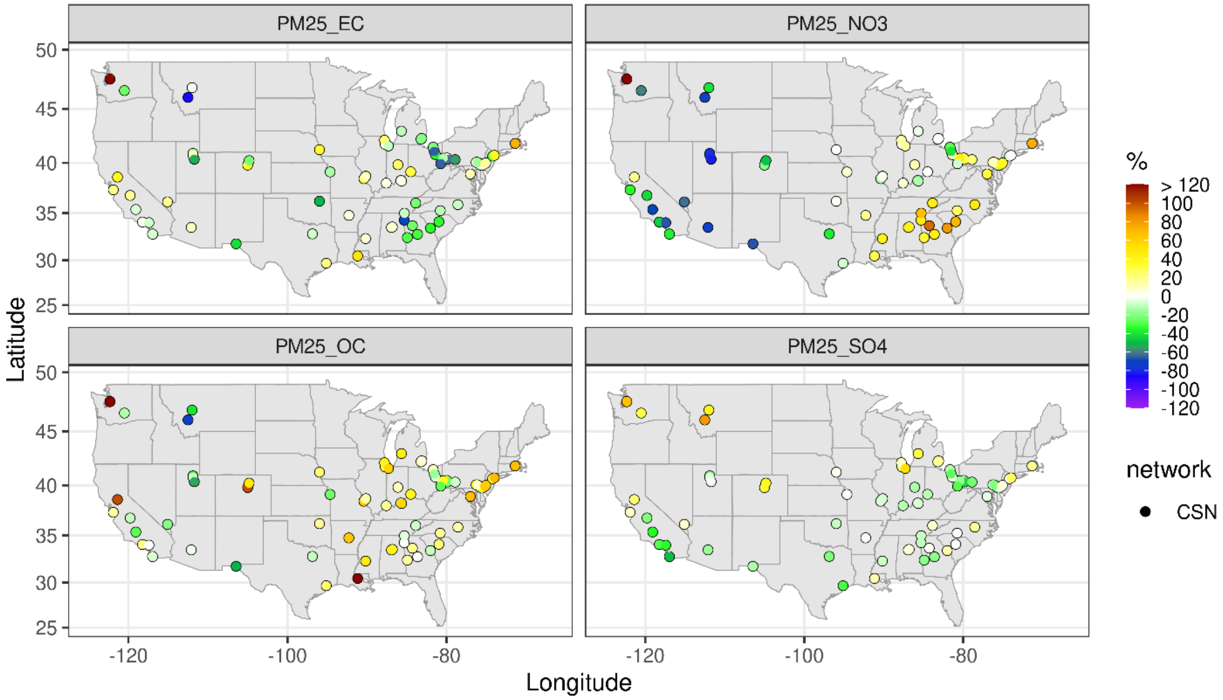

Figure 2A-5 NMB in 2016 CMAQ Predictions of $PM_{2.5}$ Components at CSN and IMPROVE Sites for Monitors in Counties with 2032 $PM_{2.5}$ DVs Greater than 8/30

Table 2A-3 CMAQ Performance Statistics for $PM_{2.5}$ Sulfate at CSN and IMPROVE Sites in 2016

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	696	1.04	1.06	0.02	1.6	0.87	43.0	0.29
		Spring	741	0.92	1.02	0.10	10.8	0.51	38.4	0.59
		Summer	736	1.16	0.98	-0.18	-15.5	0.51	28.7	0.79
		Fall	705	0.88	0.96	0.09	9.8	0.55	36.7	0.70
		Annual	2878	1.00	1.01	0.00	0.5	0.62	36.3	0.57
	IMPROVE	Winter	349	0.72	0.67	-0.05	-7.3	0.29	30.3	0.70
		Spring	387	0.73	0.72	-0.01	-1.6	0.29	26.8	0.76
		Summer	396	0.70	0.62	-0.08	-11.9	0.34	32.2	0.83
		Fall	375	0.58	0.57	-0.01	-1.9	0.26	30.4	0.84
		Annual	1507	0.68	0.65	-0.04	-5.8	0.30	29.9	0.80
Southeast	CSN	Winter	456	0.93	1.02	0.09	9.5	0.44	35.4	0.64
		Spring	490	1.11	1.08	-0.03	-2.8	0.48	30.9	0.56
		Summer	463	1.11	0.89	-0.22	-19.6	0.49	32.0	0.54
		Fall	447	0.95	0.97	0.02	1.9	0.36	25.7	0.72
		Annual	1856	1.03	0.99	-0.04	-3.5	0.45	31.0	0.60
	IMPROVE	Winter	342	0.95	0.85	-0.10	-10.6	0.44	35.0	0.61
		Spring	379	1.24	0.97	-0.27	-21.6	0.61	30.6	0.45
		Summer	394	1.21	0.77	-0.44	-36.3	0.61	41.0	0.58
		Fall	366	1.04	0.86	-0.17	-16.8	0.39	26.9	0.72
		Annual	1481	1.12	0.86	-0.25	-22.6	0.53	33.6	0.56
Ohio Valley	CSN	Winter	510	1.34	1.14	-0.20	-15.0	0.81	35.3	0.52
		Spring	526	1.19	1.21	0.02	1.7	0.61	34.2	0.43
		Summer	515	1.65	1.50	-0.15	-9.0	0.86	30.5	0.67
		Fall	499	1.23	1.22	-0.01	-0.9	0.62	31.0	0.67
		Annual	2050	1.35	1.27	-0.09	-6.3	0.74	32.7	0.61
	IMPROVE	Winter	192	1.07	0.89	-0.18	-16.7	0.49	30.9	0.69
		Spring	213	1.16	0.95	-0.22	-18.6	0.53	28.9	0.56
		Summer	211	1.48	1.12	-0.36	-24.5	0.67	33.9	0.73
		Fall	202	1.27	1.04	-0.23	-17.8	0.50	28.1	0.80
		Annual	818	1.25	1.00	-0.25	-19.8	0.55	30.6	0.72
Upper Midwest	CSN	Winter	278	1.03	1.10	0.07	7.0	0.53	33.8	0.73
		Spring	292	0.93	1.15	0.22	24.1	0.47	39.5	0.71
		Summer	275	1.04	1.08	0.04	3.5	0.47	33.4	0.82
		Fall	280	0.76	1.00	0.24	31.7	0.56	48.3	0.77
		Annual	1125	0.94	1.08	0.14	15.4	0.51	38.1	0.75
	IMPROVE	Winter	194	0.76	0.71	-0.05	-6.9	0.30	27.6	0.83
		Spring	208	0.76	0.75	-0.01	-1.4	0.32	30.3	0.71
		Summer	210	0.68	0.59	-0.10	-14.3	0.32	31.0	0.88
		Fall	210	0.63	0.61	-0.01	-1.8	0.34	35.3	0.79
		Annual	822	0.71	0.66	-0.04	-6.1	0.32	30.9	0.81
South	CSN	Winter	258	0.99	1.12	0.12	12.5	0.63	39.9	0.60
		Spring	273	1.16	1.08	-0.08	-7.3	0.84	38.6	0.63
		Summer	264	1.49	1.07	-0.42	-28.3	0.81	39.9	0.46
		Fall	257	1.31	1.24	-0.07	-5.3	0.61	32.0	0.67
		Annual	1052	1.24	1.12	-0.11	-9.2	0.73	37.5	0.56
	IMPROVE	Winter	212	0.75	0.78	0.03	4.2	0.38	34.2	0.73
		Spring	242	0.97	0.80	-0.17	-17.1	0.65	38.5	0.60
		Summer	221	1.42	0.77	-0.65	-45.5	0.91	48.4	0.55
		Fall	234	1.10	0.89	-0.21	-19.1	0.51	33.1	0.73
		Annual	909	1.06	0.81	-0.25	-23.4	0.64	39.6	0.59
Southwest	CSN	Winter	189	0.50	0.51	0.01	1.9	0.72	74.3	0.19
		Spring	195	0.40	0.67	0.27	68.7	0.36	77.6	0.38
		Summer	192	0.70	0.49	-0.22	-30.7	0.45	45.2	0.13
		Fall	200	0.50	0.52	0.02	3.0	0.28	45.1	0.35

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	776	0.53	0.55	0.02	4.1	0.48	58.1	0.13
N. Rockies & Plains	IMPROVE	Winter	829	0.25	0.39	0.14	57.0	0.37	83.1	0.36
		Spring	909	0.39	0.62	0.23	60.3	0.35	70.8	0.47
		Summer	900	0.65	0.40	-0.25	-38.3	0.48	49.3	0.32
		Fall	877	0.47	0.40	-0.07	-14.7	0.30	45.4	0.38
		Annual	3515	0.44	0.45	0.01	3.1	0.38	57.7	0.28
	CSN	Winter	141	0.51	0.62	0.11	21.0	0.46	54.4	0.70
		Spring	145	0.54	0.65	0.11	20.5	0.32	45.7	0.68
		Summer	135	0.54	0.55	0.01	1.5	0.29	37.5	0.79
		Fall	139	0.47	0.55	0.08	17.5	0.30	43.8	0.80
		Annual	560	0.51	0.59	0.08	15.2	0.35	45.4	0.73
Northwest	IMPROVE	Winter	542	0.32	0.42	0.10	31.3	0.29	66.1	0.73
		Spring	573	0.38	0.50	0.13	34.0	0.25	53.3	0.67
		Summer	603	0.36	0.40	0.04	10.0	0.21	42.2	0.54
		Fall	574	0.34	0.40	0.06	17.7	0.26	48.8	0.70
		Annual	2292	0.35	0.43	0.08	22.9	0.25	52.0	0.67
	CSN	Winter	129	0.30	0.57	0.27	92.1	0.51	119.4	0.21
		Spring	135	0.38	0.73	0.36	93.6	0.47	97.7	0.64
		Summer	135	0.50	0.60	0.10	20.8	0.34	53.8	0.44
		Fall	134	0.34	0.59	0.24	70.7	0.42	93.6	0.39
		Annual	533	0.38	0.62	0.24	64.0	0.44	86.3	0.38
West	IMPROVE	Winter	405	0.15	0.26	0.11	75.6	0.20	97.5	0.65
		Spring	474	0.30	0.49	0.19	61.2	0.29	69.4	0.73
		Summer	488	0.35	0.39	0.04	11.8	0.23	48.9	0.45
		Fall	471	0.24	0.33	0.09	38.0	0.24	71.2	0.62
		Annual	1838	0.27	0.37	0.11	40.5	0.24	66.2	0.62
	CSN	Winter	246	0.46	0.61	0.15	33.1	0.44	70.5	0.35
		Spring	257	0.76	0.80	0.04	5.1	0.53	49.5	0.44
		Summer	258	1.31	0.74	-0.58	-43.9	1.25	51.1	0.35
		Fall	235	0.77	0.65	-0.12	-16.1	0.52	47.2	0.49
		Annual	996	0.83	0.70	-0.13	-15.8	0.77	52.5	0.37
	IMPROVE	Winter	510	0.22	0.38	0.16	74.2	0.33	104.3	0.36
		Spring	549	0.51	0.61	0.10	20.5	0.36	53.8	0.39
		Summer	548	0.74	0.52	-0.22	-30.2	0.49	47.6	0.36
		Fall	527	0.47	0.44	-0.03	-6.0	0.30	47.1	0.45
		Annual	2134	0.49	0.49	0.00	0.3	0.38	55.2	0.39

Table 2A-4 CMAQ Performance Statistics for $PM_{2.5}$ Nitrate at CSN and IMPROVE Sites in 2016

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	696	1.72	2.44	0.72	42.1	1.55	61.7	0.74
		Spring	741	0.86	0.84	-0.01	-1.7	0.72	55.6	0.77
		Summer	736	0.32	0.21	-0.12	-36.2	0.30	62.2	0.52
		Fall	705	0.64	0.72	0.08	12.0	0.65	61.0	0.66
		Annual	2878	0.88	1.04	0.16	18.3	0.92	60.1	0.79
	IMPROVE	Winter	349	0.49	1.05	0.56	113.3	0.99	127.3	0.66
		Spring	387	0.32	0.32	0.00	1.3	0.40	65.7	0.61
		Summer	396	0.15	0.20	0.05	31.1	0.26	91.3	0.40
		Fall	375	0.22	0.30	0.07	32.1	0.35	82.5	0.57
		Annual	1507	0.29	0.45	0.16	55.2	0.56	96.6	0.62
Southeast	CSN	Winter	456	0.68	1.33	0.66	97.0	1.15	112.4	0.64
		Spring	490	0.37	0.37	-0.01	-1.5	0.41	63.1	0.60
		Summer	463	0.20	0.22	0.02	9.2	0.21	70.8	0.35
		Fall	450	0.33	0.43	0.11	32.8	0.46	76.6	0.62
		Annual	1859	0.39	0.58	0.19	48.4	0.66	87.6	0.68
	IMPROVE	Winter	342	0.49	0.63	0.14	27.5	0.50	70.9	0.60
		Spring	379	0.34	0.26	-0.08	-24.1	0.29	56.2	0.42
		Summer	394	0.19	0.19	0.01	4.1	0.16	59.5	0.44
		Fall	366	0.29	0.28	-0.01	-3.7	0.29	61.9	0.61
		Annual	1481	0.32	0.33	0.01	3.0	0.33	63.2	0.61
Ohio Valley	CSN	Winter	510	2.41	2.37	-0.04	-1.8	1.63	43.5	0.59
		Spring	526	0.91	0.87	-0.03	-3.5	1.04	64.7	0.44
		Summer	515	0.37	0.37	0.00	1.0	0.48	78.3	0.27
		Fall	499	0.82	0.84	0.02	2.7	0.81	58.4	0.59
		Annual	2050	1.13	1.11	-0.01	-1.1	1.08	53.4	0.69
	IMPROVE	Winter	192	1.31	1.07	-0.24	-18.5	1.15	55.2	0.54
		Spring	213	0.53	0.32	-0.21	-39.2	0.65	59.4	0.60
		Summer	211	0.19	0.18	-0.01	-5.5	0.21	68.0	0.32
		Fall	202	0.50	0.37	-0.13	-26.1	0.60	62.4	0.55
		Annual	818	0.62	0.47	-0.15	-23.5	0.72	58.6	0.64
Upper Midwest	CSN	Winter	278	2.76	2.72	-0.04	-1.5	1.54	37.6	0.75
		Spring	292	1.15	1.14	-0.01	-1.1	1.27	58.0	0.52
		Summer	275	0.35	0.36	0.01	3.8	0.55	85.8	0.27
		Fall	280	0.81	0.82	0.01	1.1	0.87	55.9	0.65
		Annual	1125	1.27	1.26	-0.01	-0.6	1.12	48.6	0.77
	IMPROVE	Winter	194	1.44	1.11	-0.34	-23.3	1.32	49.9	0.66
		Spring	208	0.58	0.35	-0.22	-38.3	0.78	58.6	0.67
		Summer	210	0.12	0.14	0.02	20.5	0.16	75.5	0.55
		Fall	210	0.33	0.27	-0.06	-18.1	0.50	65.4	0.52
		Annual	822	0.60	0.46	-0.14	-24.0	0.80	55.5	0.72
South	CSN	Winter	258	0.97	1.02	0.06	5.8	0.85	53.7	0.63
		Spring	273	0.35	0.30	-0.06	-16.1	0.36	61.9	0.52
		Summer	264	0.25	0.25	0.00	0.4	0.26	68.5	0.31
		Fall	257	0.35	0.37	0.02	6.3	0.38	69.0	0.46
		Annual	1052	0.48	0.48	0.00	1.0	0.51	60.0	0.68
	IMPROVE	Winter	212	0.81	0.65	-0.16	-19.3	0.73	54.1	0.63
		Spring	242	0.34	0.24	-0.10	-30.4	0.37	57.1	0.59
		Summer	221	0.21	0.14	-0.07	-35.1	0.17	57.5	0.42
		Fall	234	0.24	0.18	-0.06	-24.7	0.26	50.3	0.53
		Annual	909	0.39	0.30	-0.10	-24.8	0.43	54.6	0.68
Southwest	CSN	Winter	189	2.86	1.00	-1.86	-65.2	4.52	73.3	0.51
		Spring	195	0.48	0.30	-0.18	-37.9	0.54	55.2	0.66
		Summer	192	0.26	0.13	-0.13	-50.0	0.32	84.4	-0.09
		Fall	200	0.59	0.36	-0.23	-38.6	0.91	76.4	0.57

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	776	1.03	0.44	-0.59	-57.1	2.30	72.3	0.59
	IMPROVE	Winter	829	0.28	0.16	-0.12	-42.7	0.51	71.6	0.55
		Spring	909	0.17	0.14	-0.03	-19.5	0.15	56.3	0.27
		Summer	900	0.15	0.07	-0.09	-56.0	0.14	60.1	0.55
		Fall	877	0.12	0.09	-0.04	-29.2	0.13	59.3	0.44
		Annual	3515	0.18	0.11	-0.07	-37.5	0.28	63.2	0.52
N. Rockies & Plains	CSN	Winter	141	1.19	1.02	-0.17	-14.3	1.23	54.6	0.61
		Spring	145	0.50	0.36	-0.14	-28.3	0.53	53.5	0.78
		Summer	135	0.17	0.12	-0.05	-27.3	0.20	64.6	0.48
		Fall	139	0.31	0.34	0.02	7.1	0.45	70.3	0.58
		Annual	560	0.55	0.46	-0.08	-15.5	0.72	57.3	0.68
	IMPROVE	Winter	542	0.39	0.24	-0.15	-37.8	0.57	68.6	0.64
		Spring	573	0.16	0.13	-0.04	-23.4	0.22	67.4	0.33
		Summer	603	0.08	0.05	-0.03	-42.2	0.08	58.2	0.34
		Fall	574	0.11	0.11	0.00	2.0	0.17	76.6	0.45
		Annual	2292	0.18	0.13	-0.05	-29.1	0.31	68.3	0.63
Northwest	CSN	Winter	129	1.33	0.98	-0.35	-26.4	2.25	82.2	0.33
		Spring	135	0.38	1.09	0.70	183.8	2.08	211.6	0.56
		Summer	135	0.25	1.26	1.01	396.6	1.83	406.9	0.42
		Fall	134	0.51	0.95	0.44	86.7	1.21	142.4	0.19
		Annual	533	0.61	1.07	0.46	75.0	1.88	149.4	0.17
	IMPROVE	Winter	405	0.33	0.23	-0.10	-30.6	0.78	91.5	0.32
		Spring	474	0.15	0.26	0.11	75.0	0.77	113.7	0.56
		Summer	488	0.14	0.30	0.16	111.7	0.80	168.2	0.39
		Fall	471	0.17	0.23	0.07	39.5	0.52	108.8	0.39
		Annual	1838	0.19	0.26	0.07	34.1	0.73	114.8	0.27
West	CSN	Winter	246	3.02	1.41	-1.61	-53.4	3.59	61.7	0.66
		Spring	257	1.25	0.70	-0.55	-43.9	1.51	53.2	0.76
		Summer	258	1.16	0.74	-0.42	-36.3	1.18	51.3	0.64
		Fall	235	1.73	0.81	-0.92	-53.4	2.57	69.2	0.54
		Annual	996	1.78	0.91	-0.87	-48.8	2.39	60.2	0.67
	IMPROVE	Winter	510	0.50	0.36	-0.14	-28.2	0.94	60.4	0.80
		Spring	549	0.41	0.34	-0.07	-17.3	0.36	47.9	0.81
		Summer	548	0.34	0.28	-0.06	-17.5	0.38	55.1	0.45
		Fall	527	0.44	0.28	-0.15	-34.6	0.86	61.8	0.75
		Annual	2134	0.42	0.32	-0.10	-24.8	0.68	56.5	0.75

Table 2A-5 CMAQ Performance Statistics for $PM_{2.5}$ EC at CSN and IMPROVE Sites in 2016

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	672	0.67	0.78	0.11	16.5	0.68	53.7	0.60
		Spring	736	0.58	0.55	-0.03	-4.8	0.44	43.2	0.58
		Summer	725	0.58	0.50	-0.08	-13.5	0.35	39.6	0.58
		Fall	725	0.62	0.70	0.07	11.9	0.56	47.9	0.58
		Annual	2858	0.61	0.63	0.02	2.9	0.52	46.3	0.58
	IMPROVE	Winter	373	0.19	0.28	0.09	46.4	0.17	62.3	0.83
		Spring	422	0.15	0.18	0.03	16.9	0.10	43.4	0.85
		Summer	423	0.16	0.17	0.01	4.6	0.09	39.1	0.82
		Fall	406	0.19	0.21	0.02	11.3	0.15	41.6	0.82
		Annual	1624	0.17	0.21	0.03	19.7	0.13	46.6	0.82
Southeast	CSN	Winter	392	0.59	0.58	-0.01	-1.3	0.36	41.6	0.60
		Spring	424	0.55	0.43	-0.13	-23.3	0.34	40.3	0.63
		Summer	388	0.43	0.41	-0.02	-5.0	0.30	47.9	0.41
		Fall	374	0.63	0.55	-0.08	-12.6	0.41	41.4	0.63
		Annual	1578	0.55	0.49	-0.06	-11.1	0.35	42.4	0.59
	IMPROVE	Winter	376	0.28	0.26	-0.02	-5.9	0.34	48.5	0.52
		Spring	416	0.32	0.21	-0.11	-34.4	0.66	50.0	0.29
		Summer	425	0.23	0.17	-0.06	-24.2	0.25	45.4	0.60
		Fall	395	0.36	0.26	-0.10	-28.0	0.26	38.3	0.85
		Annual	1612	0.30	0.23	-0.07	-24.2	0.42	45.2	0.51
Ohio Valley	CSN	Winter	498	0.49	0.57	0.07	15.1	0.33	45.0	0.64
		Spring	548	0.54	0.45	-0.09	-16.3	0.31	38.4	0.59
		Summer	523	0.61	0.47	-0.15	-24.0	0.35	39.6	0.44
		Fall	523	0.71	0.62	-0.09	-12.7	0.41	36.1	0.63
		Annual	2092	0.59	0.52	-0.06	-11.0	0.35	39.3	0.59
	IMPROVE	Winter	192	0.21	0.22	0.02	7.8	0.17	44.4	0.52
		Spring	213	0.22	0.17	-0.04	-19.4	0.16	40.5	0.36
		Summer	211	0.19	0.14	-0.05	-26.7	0.08	33.0	0.70
		Fall	202	0.31	0.24	-0.07	-23.6	0.18	34.1	0.68
		Annual	818	0.23	0.19	-0.04	-16.6	0.15	37.6	0.56
Upper Midwest	CSN	Winter	278	0.34	0.54	0.21	60.4	0.45	78.7	0.55
		Spring	285	0.46	0.47	0.01	2.4	0.39	49.1	0.52
		Summer	278	0.41	0.40	-0.01	-2.7	0.26	45.0	0.45
		Fall	279	0.47	0.52	0.06	12.3	0.32	47.6	0.69
		Annual	1120	0.42	0.48	0.07	15.6	0.36	53.7	0.53
	IMPROVE	Winter	220	0.15	0.20	0.06	40.8	0.14	56.1	0.79
		Spring	239	0.19	0.17	-0.03	-14.1	0.23	44.1	0.54
		Summer	237	0.18	0.14	-0.04	-21.5	0.12	42.0	0.81
		Fall	240	0.20	0.19	-0.02	-8.4	0.14	42.0	0.78
		Annual	936	0.18	0.17	-0.01	-3.9	0.16	45.2	0.66
South	CSN	Winter	226	0.63	0.58	-0.05	-7.6	0.35	39.7	0.60
		Spring	251	0.47	0.39	-0.08	-16.6	0.27	37.9	0.54
		Summer	208	0.43	0.41	-0.02	-4.9	0.30	51.2	0.36
		Fall	194	0.60	0.60	-0.01	-0.9	0.37	44.3	0.49
		Annual	879	0.53	0.49	-0.04	-7.7	0.32	42.6	0.55
	IMPROVE	Winter	212	0.15	0.14	-0.00	-2.1	0.11	43.2	0.68
		Spring	242	0.16	0.15	-0.02	-10.1	0.23	53.6	0.61
		Summer	219	0.11	0.08	-0.03	-24.9	0.07	44.6	0.63
		Fall	234	0.17	0.12	-0.06	-32.0	0.10	40.6	0.70
		Annual	907	0.15	0.12	-0.03	-17.5	0.14	45.7	0.63
Southwest	CSN	Winter	180	0.80	0.83	0.04	4.6	0.47	44.0	0.55
		Spring	194	0.30	0.44	0.14	48.7	0.27	64.3	0.66
		Summer	179	0.32	0.38	0.06	17.8	0.22	47.1	0.42
		Fall	187	0.54	0.63	0.09	15.8	0.36	49.0	0.62

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	740	0.49	0.57	0.08	16.9	0.34	49.1	0.66
	IMPROVE	Winter	829	0.15	0.12	-0.02	-15.1	0.17	47.3	0.86
		Spring	909	0.07	0.09	0.02	22.7	0.11	66.0	0.67
		Summer	894	0.10	0.09	-0.01	-11.8	0.09	51.2	0.63
		Fall	882	0.12	0.10	-0.02	-15.3	0.13	49.4	0.78
		Annual	3514	0.11	0.10	-0.01	-7.8	0.13	52.0	0.79
N. Rockies & Plains	CSN	Winter	124	0.27	0.25	-0.02	-8.1	0.52	92.1	0.09
		Spring	145	0.20	0.17	-0.03	-16.8	0.20	55.1	0.45
		Summer	161	0.22	0.18	-0.04	-18.2	0.16	43.2	0.45
		Fall	146	0.24	0.20	-0.05	-18.5	0.37	66.0	0.16
		Annual	576	0.23	0.20	-0.04	-15.5	0.33	64.1	0.20
	IMPROVE	Winter	540	0.05	0.06	0.01	18.5	0.08	78.6	0.37
		Spring	573	0.07	0.07	-0.01	-6.9	0.21	77.5	0.49
		Summer	601	0.10	0.14	0.03	32.5	0.42	82.1	0.27
		Fall	574	0.09	0.08	-0.01	-14.4	0.14	61.3	0.27
		Annual	2288	0.08	0.09	0.01	8.1	0.25	74.6	0.33
Northwest	CSN	Winter	132	0.76	1.05	0.29	38.4	1.07	83.4	0.42
		Spring	135	0.46	1.04	0.58	126.0	1.29	146.3	0.61
		Summer	129	0.41	1.11	0.70	171.2	1.19	175.7	0.49
		Fall	130	0.59	1.21	0.62	105.5	1.23	131.3	0.44
		Annual	526	0.56	1.10	0.55	98.7	1.20	126.0	0.45
	IMPROVE	Winter	425	0.08	0.13	0.04	51.8	0.32	104.5	0.79
		Spring	482	0.08	0.18	0.10	121.8	0.53	158.1	0.72
		Summer	488	0.15	0.29	0.14	90.2	0.66	153.2	0.35
		Fall	471	0.12	0.25	0.13	104.2	0.56	150.3	0.69
		Annual	1866	0.11	0.21	0.10	93.3	0.54	144.8	0.49
West	CSN	Winter	241	1.05	0.93	-0.12	-11.4	0.56	36.9	0.61
		Spring	253	0.41	0.50	0.09	22.1	0.27	45.0	0.76
		Summer	247	0.43	0.53	0.09	21.6	0.23	38.1	0.75
		Fall	235	0.67	0.76	0.09	13.9	0.37	39.8	0.67
		Annual	976	0.64	0.68	0.04	6.3	0.38	39.2	0.72
	IMPROVE	Winter	510	0.12	0.11	-0.01	-6.2	0.16	57.6	0.84
		Spring	546	0.08	0.09	0.02	20.5	0.09	65.8	0.74
		Summer	556	0.19	0.18	-0.01	-3.1	0.51	63.9	0.44
		Fall	527	0.15	0.16	0.01	6.4	0.20	60.4	0.68
		Annual	2139	0.13	0.14	0.00	2.4	0.29	61.9	0.55

Table 2A-6 CMAQ Performance Statistics for $PM_{2.5}$ OC at CSN and IMPROVE Sites in 2016

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	672	1.81	3.25	1.45	80.2	2.61	91.5	0.67
		Spring	736	1.56	2.24	0.68	43.5	1.51	58.8	0.64
		Summer	725	1.93	2.02	0.09	4.5	0.91	33.8	0.67
		Fall	725	1.84	2.67	0.84	45.7	1.76	60.6	0.69
		Annual	2858	1.78	2.53	0.75	42.1	1.78	60.2	0.65
	IMPROVE	Winter	373	0.75	1.64	0.89	119.3	1.32	122.4	0.81
		Spring	422	0.74	1.10	0.36	48.0	0.76	64.5	0.76
		Summer	423	1.19	1.19	0.00	0.0	0.70	37.3	0.67
		Fall	406	0.93	1.33	0.40	43.6	1.18	63.8	0.66
		Annual	1624	0.91	1.31	0.40	44.0	1.01	66.0	0.66
Southeast	CSN	Winter	392	2.03	2.97	0.94	46.3	1.99	61.8	0.66
		Spring	424	2.02	2.45	0.43	21.1	1.19	42.7	0.76
		Summer	388	1.92	2.33	0.42	21.8	1.01	38.5	0.72
		Fall	374	2.78	3.06	0.28	10.1	2.67	45.3	0.58
		Annual	1578	2.18	2.70	0.52	23.8	1.82	47.0	0.59
	IMPROVE	Winter	376	1.21	1.78	0.57	46.9	3.66	82.1	0.21
		Spring	416	4.04	1.71	-2.33	-57.6	40.44	81.9	0.15
		Summer	425	1.56	1.42	-0.14	-9.1	2.62	42.9	0.23
		Fall	395	2.03	1.99	-0.05	-2.4	2.27	45.6	0.58
		Annual	1612	2.23	1.72	-0.52	-23.2	20.69	66.6	0.10
Ohio Valley	CSN	Winter	498	1.61	2.59	0.98	61.1	1.76	72.6	0.62
		Spring	548	1.61	1.95	0.34	20.9	1.23	47.8	0.58
		Summer	523	1.88	1.91	0.03	1.5	0.85	32.8	0.56
		Fall	523	2.47	2.76	0.29	11.7	1.87	39.5	0.70
		Annual	2092	1.89	2.30	0.40	21.2	1.48	46.4	0.64
	IMPROVE	Winter	192	0.96	1.64	0.68	70.4	2.66	96.2	0.29
		Spring	213	1.12	1.49	0.37	33.0	3.23	66.4	0.20
		Summer	211	1.33	1.28	-0.05	-4.0	0.59	33.3	0.71
		Fall	202	1.84	2.02	0.18	9.5	2.05	50.4	0.60
		Annual	818	1.32	1.60	0.29	21.7	2.34	57.4	0.34
Upper Midwest	CSN	Winter	278	1.18	2.73	1.55	132.2	2.54	134.8	0.55
		Spring	285	1.56	2.22	0.66	42.1	2.08	72.2	0.38
		Summer	278	1.64	1.79	0.15	8.8	0.94	38.4	0.49
		Fall	279	1.58	2.21	0.64	40.4	1.41	55.5	0.74
		Annual	1120	1.49	2.24	0.75	50.2	1.85	70.8	0.44
	IMPROVE	Winter	220	0.60	1.25	0.65	107.6	1.11	111.6	0.70
		Spring	239	0.90	1.09	0.19	20.5	1.58	70.9	0.34
		Summer	237	1.18	0.92	-0.26	-21.8	0.58	38.2	0.54
		Fall	240	0.90	1.02	0.12	13.6	0.72	46.4	0.69
		Annual	936	0.90	1.07	0.17	18.4	1.07	60.2	0.42
South	CSN	Winter	226	2.19	2.86	0.67	30.5	2.08	64.4	0.55
		Spring	251	1.57	1.90	0.33	21.2	1.15	52.5	0.55
		Summer	208	1.68	2.07	0.39	23.3	1.45	56.0	0.55
		Fall	194	2.31	3.08	0.77	33.6	2.62	59.5	0.58
		Annual	879	1.92	2.45	0.53	27.6	1.87	58.6	0.57
	IMPROVE	Winter	212	0.74	1.10	0.36	48.7	1.25	69.2	0.63
		Spring	242	1.01	1.04	0.02	2.4	1.76	61.7	0.51
		Summer	219	1.09	0.88	-0.21	-19.4	0.67	46.2	0.73
		Fall	234	1.11	0.97	-0.14	-12.3	0.63	40.2	0.73
		Annual	907	0.99	1.00	0.00	0.4	1.19	52.7	0.52
Southwest	CSN	Winter	180	2.17	3.03	0.86	39.5	2.53	74.8	0.33
		Spring	194	0.92	1.49	0.57	62.2	1.27	83.2	0.37
		Summer	179	1.47	1.38	-0.09	-6.1	0.84	37.9	0.43
		Fall	187	1.53	2.02	0.49	32.1	1.40	67.9	0.47

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	740	1.51	1.97	0.46	30.5	1.63	65.7	0.43
N. Rockies & Plains	IMPROVE	Winter	829	0.52	0.50	-0.02	-4.3	0.80	48.1	0.77
		Spring	909	0.42	0.46	0.04	8.5	0.65	55.6	0.45
		Summer	894	0.86	0.62	-0.24	-27.6	0.76	50.4	0.53
		Fall	882	0.60	0.50	-0.10	-16.2	0.55	46.5	0.66
		Annual	3514	0.60	0.52	-0.08	-13.4	0.70	49.9	0.62
	CSN	Winter	124	1.05	1.10	0.05	4.5	1.93	95.2	0.12
		Spring	145	0.87	0.75	-0.12	-13.4	0.76	54.9	0.48
		Summer	161	1.45	0.87	-0.58	-40.0	1.05	47.2	0.49
		Fall	146	1.01	0.77	-0.24	-23.6	1.04	52.0	0.23
		Annual	576	1.11	0.87	-0.24	-21.9	1.24	59.6	0.25
Northwest	IMPROVE	Winter	540	0.30	0.34	0.05	15.5	0.42	70.0	0.36
		Spring	573	0.59	0.47	-0.12	-20.9	1.33	63.6	0.55
		Summer	601	1.22	1.03	-0.20	-16.0	3.17	58.2	0.25
		Fall	574	0.63	0.49	-0.14	-22.5	1.05	60.6	0.23
		Annual	2288	0.70	0.59	-0.11	-15.3	1.84	61.1	0.34
	CSN	Winter	132	2.54	4.33	1.80	70.9	4.33	98.1	0.45
		Spring	135	1.43	3.62	2.19	152.9	4.59	160.7	0.58
		Summer	129	1.55	3.83	2.28	147.0	3.58	153.7	0.48
		Fall	130	1.99	3.90	1.92	96.5	3.53	116.0	0.48
		Annual	526	1.88	3.92	2.05	109.1	4.04	126.3	0.45
West	IMPROVE	Winter	425	0.36	0.61	0.25	69.1	1.54	128.6	0.57
		Spring	482	0.54	0.82	0.28	51.8	1.81	93.3	0.53
		Summer	488	1.32	1.57	0.24	18.5	2.94	83.3	0.47
		Fall	471	0.77	1.28	0.51	66.8	2.43	116.9	0.55
		Annual	1866	0.76	1.08	0.32	42.3	2.26	98.6	0.44
	CSN	Winter	241	3.61	4.10	0.49	13.6	2.89	48.9	0.58
		Spring	253	1.52	1.85	0.32	21.3	1.10	44.5	0.64
		Summer	247	2.40	2.23	-0.17	-7.2	1.44	36.0	0.51
		Fall	235	2.77	3.10	0.33	11.9	1.96	43.7	0.62
		Annual	976	2.56	2.80	0.24	9.4	1.96	43.8	0.63
	IMPROVE	Winter	510	0.59	0.52	-0.07	-12.0	0.60	50.5	0.87
		Spring	546	0.62	0.51	-0.11	-17.5	0.48	46.7	0.61
		Summer	556	1.72	1.39	-0.33	-19.2	2.77	52.4	0.43
		Fall	527	1.07	1.00	-0.07	-6.7	1.22	50.0	0.64
		Annual	2139	1.01	0.86	-0.15	-14.7	1.58	50.6	0.54

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 2016 CMAQ simulation with a corresponding CMAQ simulation based on emissions representative of 2032. The 2032 emissions case accounts for factors including emission reductions between 2016 and 2032 from 'on-the-books' rules and has been described in detail previously (USEPA, 2022). Other than differences in the emissions inputs, all aspects of the 2032 CMAQ modeling were specified identical to the 2016 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 2016 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 (2016). RRFs are used in projecting air quality to help mitigate the influence of systematic biases in model predictions (e.g., systematic biases in the 2016 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) version 1.8 (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 2014-2018 period centered on the 2016 CMAQ modeling period. $PM_{2.5}$ species measurements from the IMPROVE and CSN networks during 2015–2017 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 2014-2018 $PM_{2.5}$ 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 major wildfire influence 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 61 $\mu g\ m^{-3}$ was identified based the 99.9th percentile value from all daily $PM_{2.5}$ concentrations across all sites in the long-term AQS observations (2002-2018).
2. Specific states and months were screened for instances of monitors exceeding the extreme value cutoff to identify potential periods of interest. States included for screening were CA, WA, OR, MT, ID, and CO. These states were selected due to the prevalence of wildfire in the western U.S. and the potential for NAAQS exceedances in these areas. States in the southwest were not included in part due to challenges in distinguishing wildfire influence from dust events. 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. For periods flagged under the previous step, the presence of visible wildfire smoke was corroborated using satellite imagery from NASA's Worldview platform (https://worldview.earthdata.nasa.gov) for the dates and geographic location identified. If corroboration with satellite imagery was not possible, the episode was not included. 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 wildfire periods confirmed with satellite imagery, all concentrations above the extreme value cutoff of 61 $\mu g\ m^{-3}$ occurring during the identified wildfire episode window at impacted sites were removed.
5. In addition to the evaluation criteria above, data corresponding to 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 61 $\mu g\ m^{-3}$. 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 61 $\mu g\ m^{-3}$ was applied as the cutoff across all sites for New Year's Eve and the Fourth of July.

A full list of episodes and counties that were evaluated for potential exclusion of monitor data due to influence from wildfire and fireworks is shown in Table 2A-7. Example satellite imagery and timeseries of $PM_{2.5}$ at impacted monitors for each episode are shown in Figures 2A-6 to 2A-14. The flagged day-site combinations represent 0.4% (767/200,201) of all possible day-site combinations for those sites. Not all days flagged for potential fire influence were excluded only those above the 61 $\mu g\ m^{-3}$ threshold.

Table 2A-7 Wildfire Episodes and Counties Where Data Were Screened for Exclusion if $PM_{2.5}$ Concentrations Exceeded the Extreme Value Threshold of 61 µg m^{-3}

Episode	Dates	Impacted County	State
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
North Bay/Wine Country Fires	Oct. 8-20, 2017	Napa	CA
		San Joaquin	CA
		Mendocino	CA
		Solano	CA
		Contra Costa	CA
		Lake	CA
		Sonoma	CA
		Marin	CA
		Alameda	CA
		Nevada	CA
		Mendocino	CA
Pacific Northwest/northern CA Fires of 2017	Aug. 1- Sept. 13, 2017	Benewah	ID
		Lemhi	ID
		Shoshone	ID

Episode	Dates	Impacted County	State
		Ada	ID
		Canyon	ID
		Bannock	ID
		Jackson	OR
		Lane	OR
		Josephine	OR
		Crook	OR
		Klamath	OR
		Harney	OR
		Flathead	MT
		Silver Bow	MT
		Lewis and Clark	MT
		Powder River	MT
		Fergus	MT
		Missoula	MT
		Ravalli	MT
		Lincoln	MT
		Yakima	WA
		Spokane	WA
		Clark	WA
		King	WA
		Pierce	WA
		Okanogan	WA
		Snohomish	WA
		Shasta	CA
		Tehama	CA
		Sonoma	CA
		Siskiyou	CA
Washington/Oregon Fires of 2018	July 14-Aug. 25, 2018	Spokane	WA
		Okanogan	WA
		Skagit	WA
		Whatcom	WA
		Snohomish	WA
		Kitsap	WA
		King	WA
		Clark	WA
		Pierce	WA
		Yakima	WA
		Jackson	OR
		Lake	OR
		Harney	OR
		Klamath	OR
		Josephine	OR
		Lane	OR

Episode	Dates	Impacted County	State
		Siskiyou	CA
Montana Fires of 2018	Aug. 13-Aug. 28, 2018	Lincoln	MT
		Missoula	MT
		Lewis and Clark	MT
		Yellowstone	MT
		Fergus	MT
		Flathead	MT
		Shoshone	ID
Montana/Washington/Idaho Fires of 2015	Aug. 15-Aug. 30, 2015	Missoula	MT
		Ravalli	MT
		Lincoln	MT
		Missoula	MT
		Flathead	MT
		Lewis and Clark	MT
		Powder River	MT
		Silver Bow	MT
		Fergus	MT
		Lemhi	ID
		Shoshone	ID
		Bannock	ID
		Clark	WA
416/Burro Fire Complex	June 8-13 2018	La Plata	CO
Butte Fire	Sept. 11-14, 2015	Calaveras	CA
		Placer	CA
Carr/Mendocino/Ferguson Fires	July 28-Aug. 18, 2018	Inyo	CA
		Mono	CA
		Shasta	CA
		Siskiyou	CA
		Calaveras	CA
		Tehama	CA
		Lake	CA
		Fresno	CA
		Tulare	CA
		Butte	CA
		Nevada	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

Episode	**Dates**	**Impacted County**	**State**
Fireworks	July 4-5 and Dec. 31-Jan. 1 (all years)	Walker	GA
		Clarke	GA
		Richmond	GA
		Hall	GA
		Greenville	SC
		Richland	SC
		Edgefield	SC
		Lexington	SC
		Charleston	SC
		Weber	UT
		Pierce	WA
		Snohomish	WA
		Clark	NV
		St. Louis City	MO
		Macomb	MI
		Marion	IN
		Lake	IN
		Allen	IN
		Cook	IL
		La Plata	CO
		Stanislaus	CA
		San Joaquin	CA
		San Bernardino	CA
		Riverside	CA
		Merced	CA
		Madera	CA
		Los Angeles	CA
		Kings	CA
		Kern	CA
		Inyo	CA
		Imperial	CA
		Fresno	CA
		Santa Cruz	AZ
		Maricopa	AZ

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

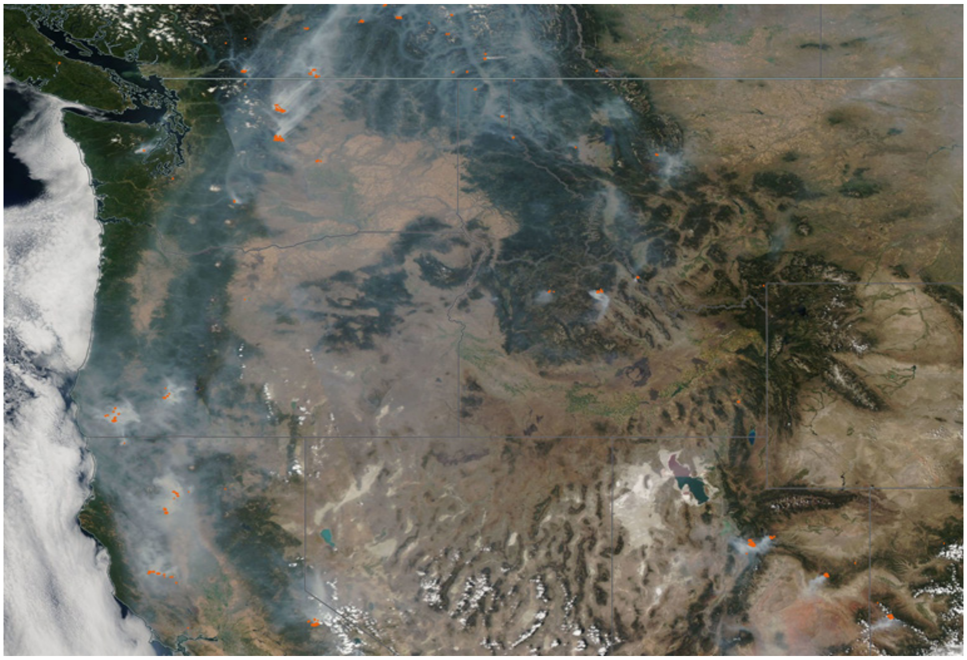

Figure 2A-9 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in Washington and Oregon on 08/09/2018

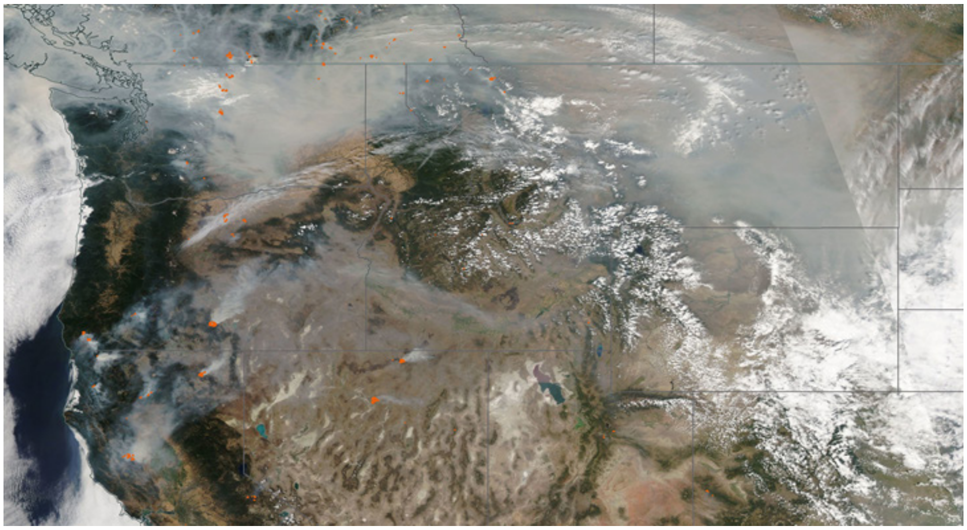

Figure 2A-10 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in Montana on 08/19/2018

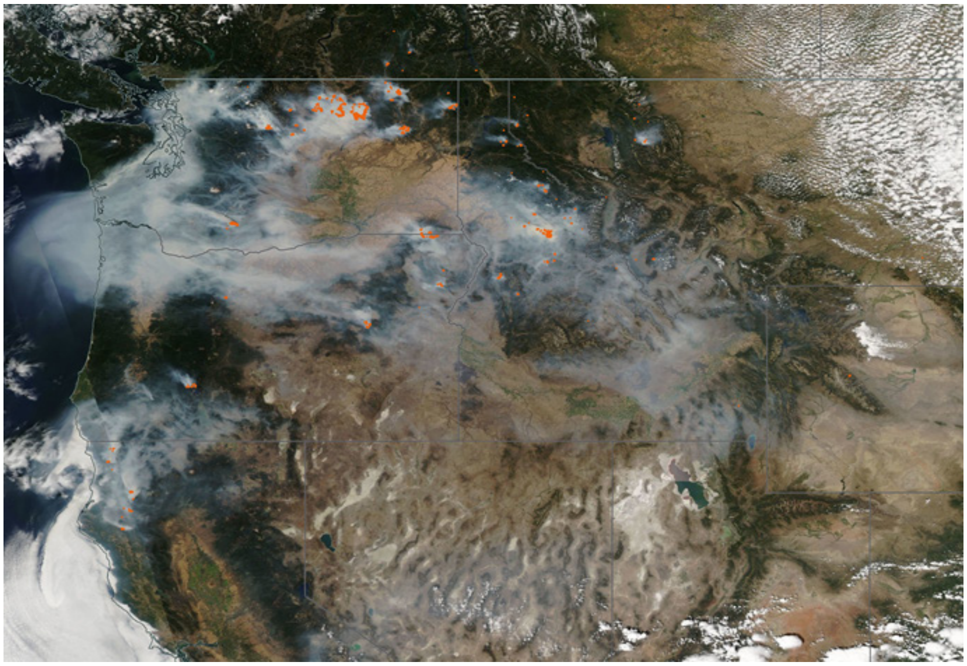

Figure 2A-11 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in Montana, Washington and Idaho on 08/22/2015

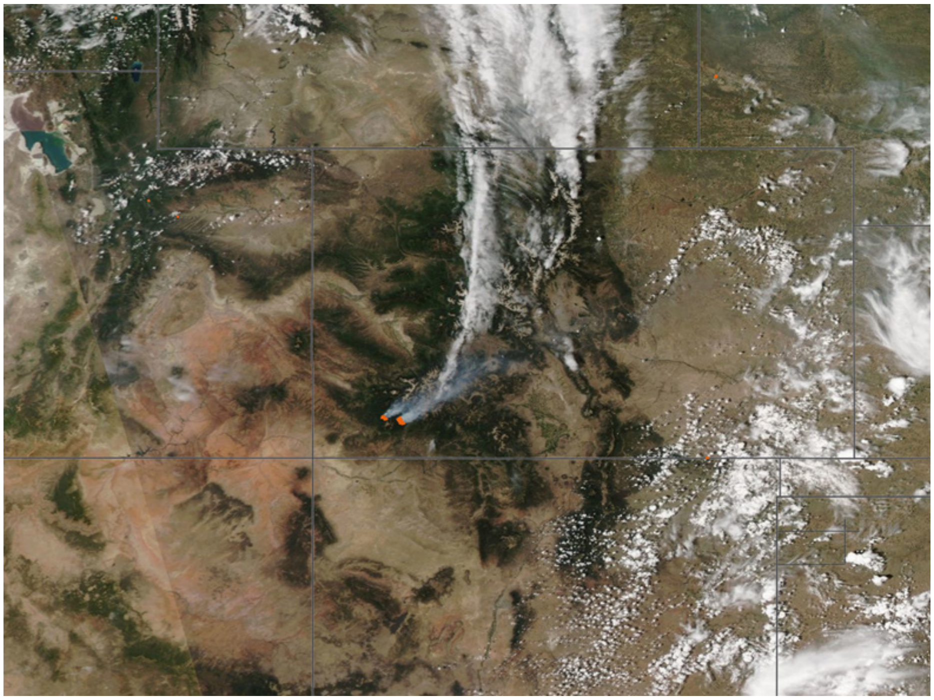

Figure 2A-12 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the 416/Burro Complex Fires on 06/10/2018

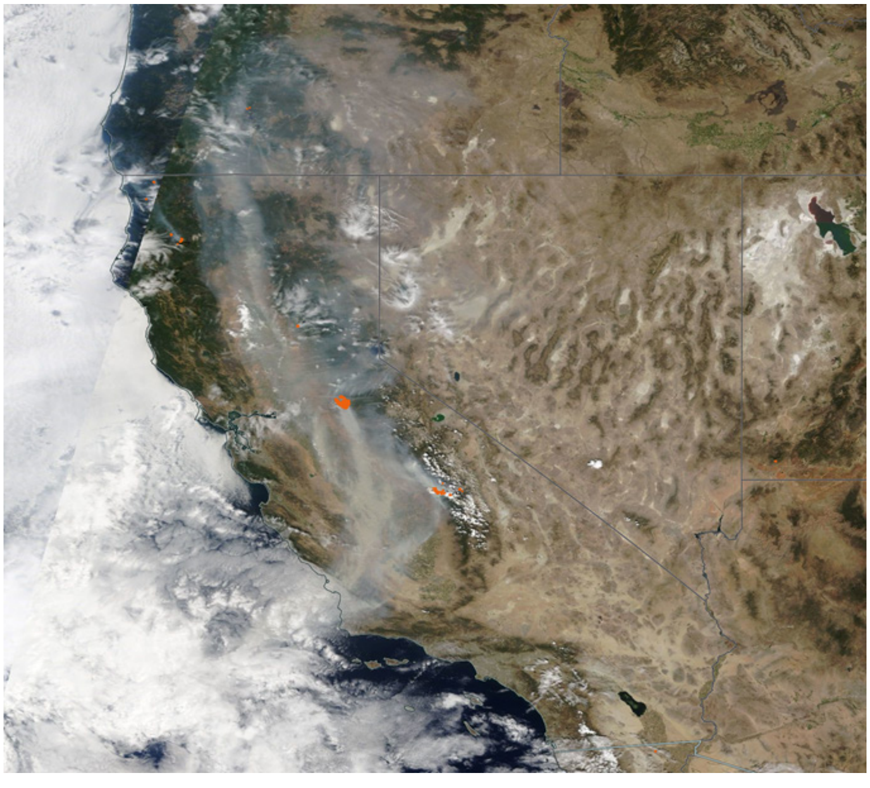

Figure 2A-13 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the Butte Fire on 09/11/2015

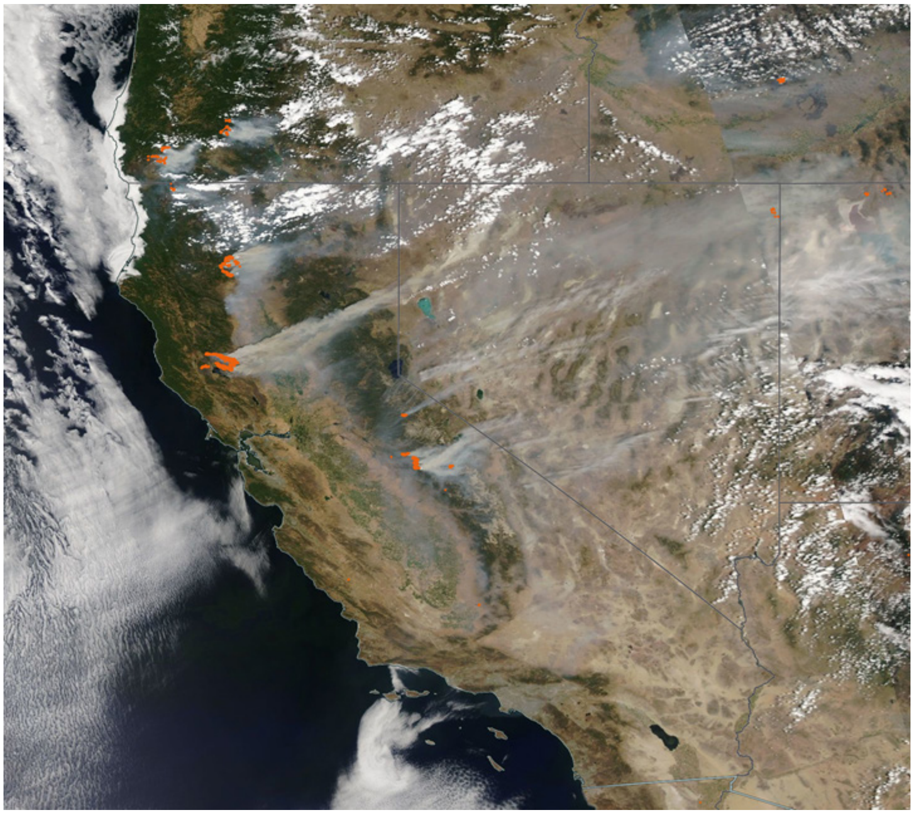

Figure 2A-14 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from the Carr/Mendocino/Ferguson Fires on 08/04/2018

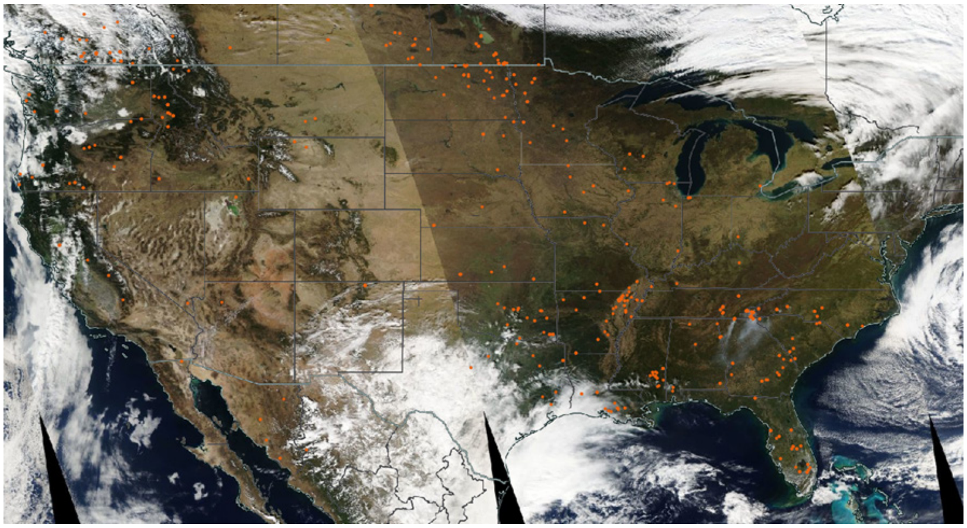

Figure 2A-15 Visible Satellite Imagery from NASA's Worldview Platform Showing Smoke from Fires in the Appalachians on 11/10/2016

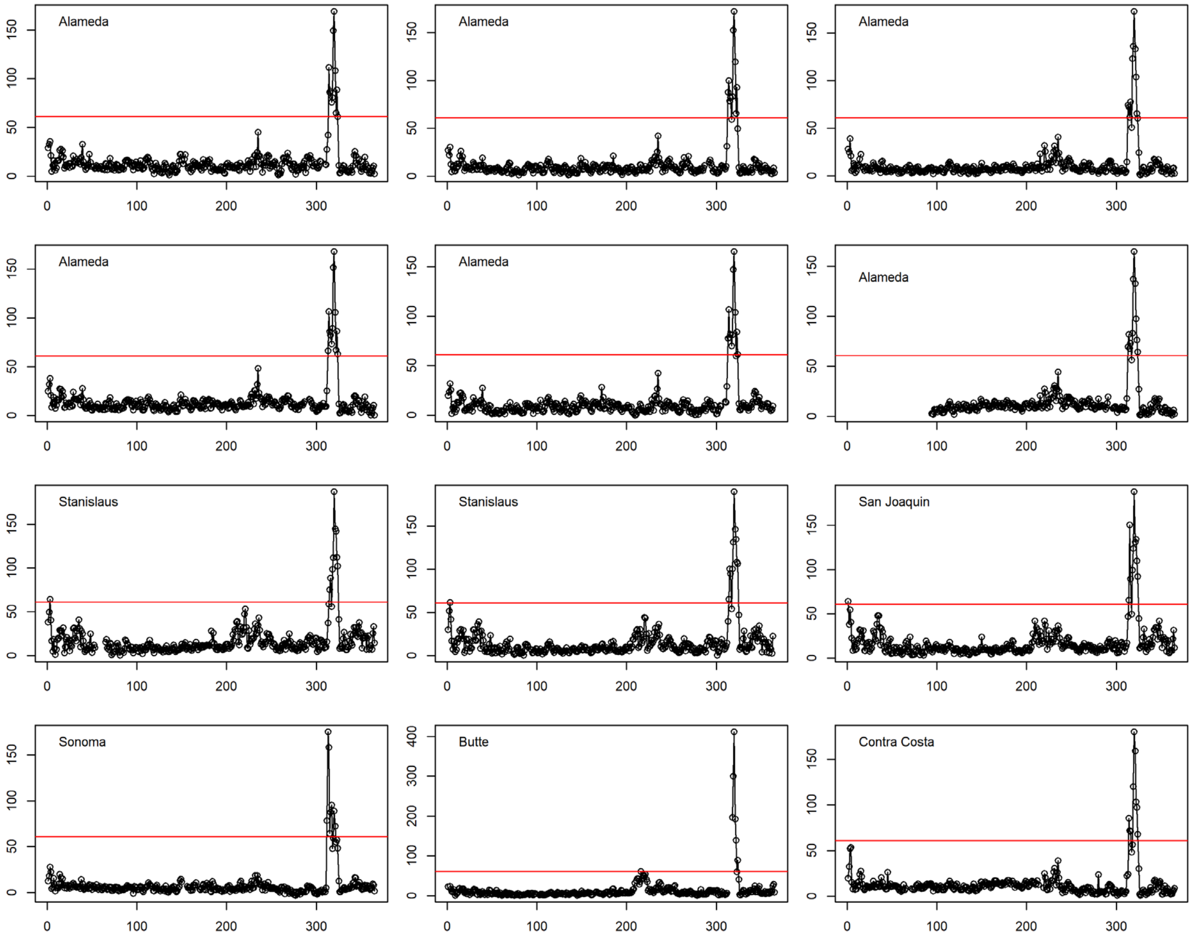

Figure 2A-16 Daily PM$_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by the Camp Fire in November 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 61 µg m^{-3} used for screening.

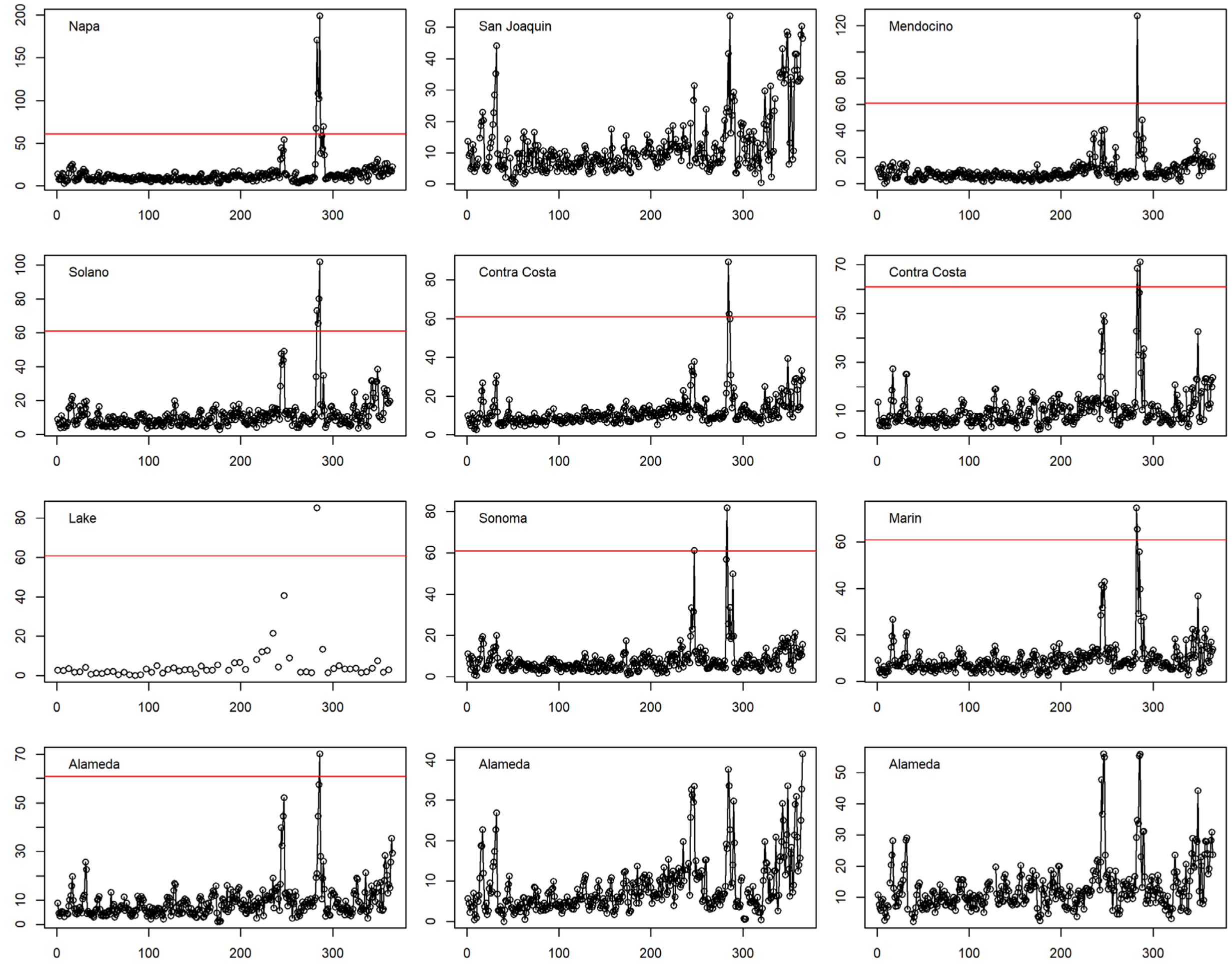

Figure 2A-17 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by the North Bay/Wine Country Fires in October 2017

Note: Bottom axis shows day in 2017. Red line indicates extreme value threshold of 61 µg m^{-3} used for screening.

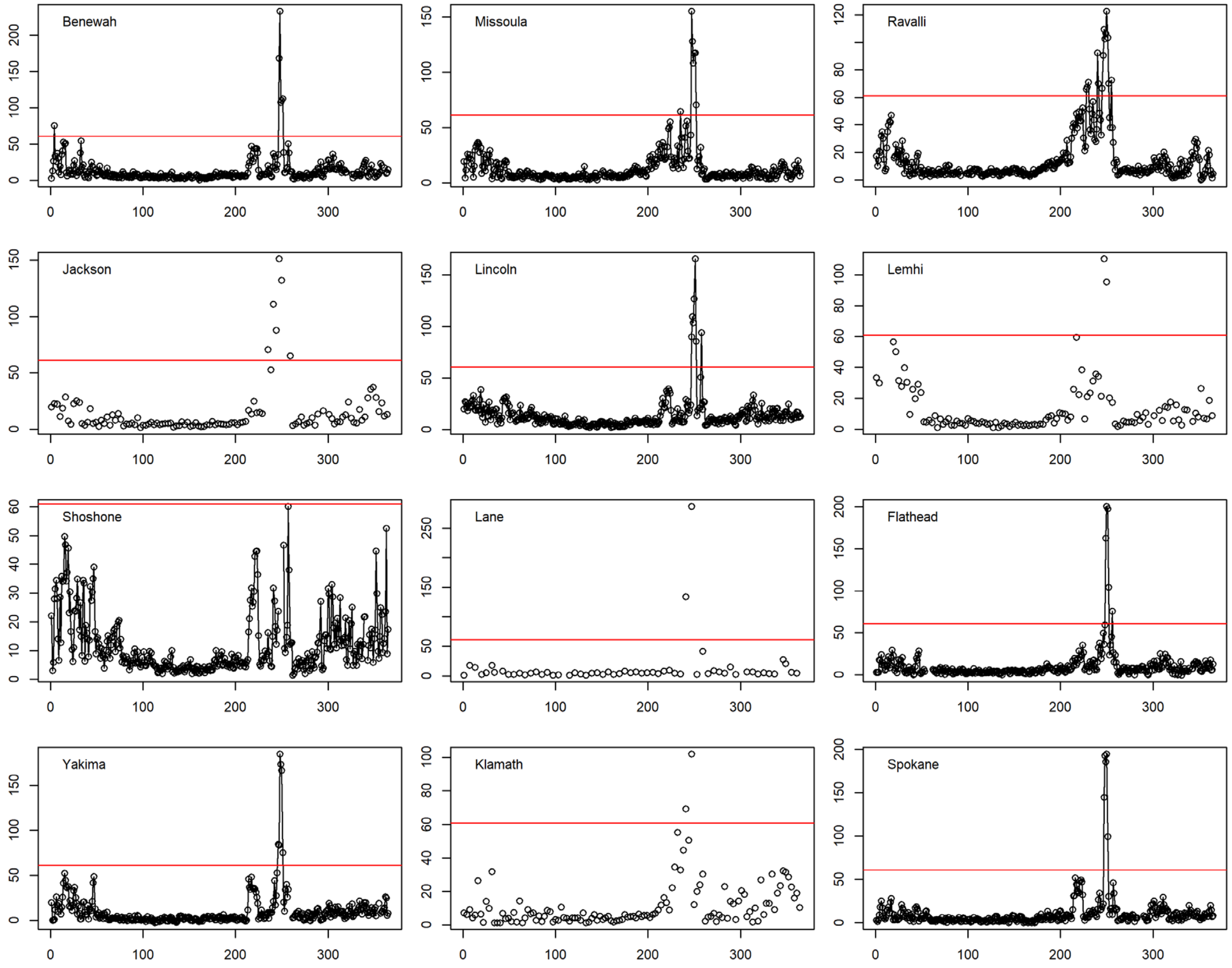

Figure 2A-18 Daily PM2.5 (in µg m-3) from a Subset of Monitors Impacted by Fires in the Pacific Northwest/Northern California in August-September 2017

Note: Bottom axis shows day in 2017. Red line indicates extreme value threshold of 61 µg m-3 used for screening.

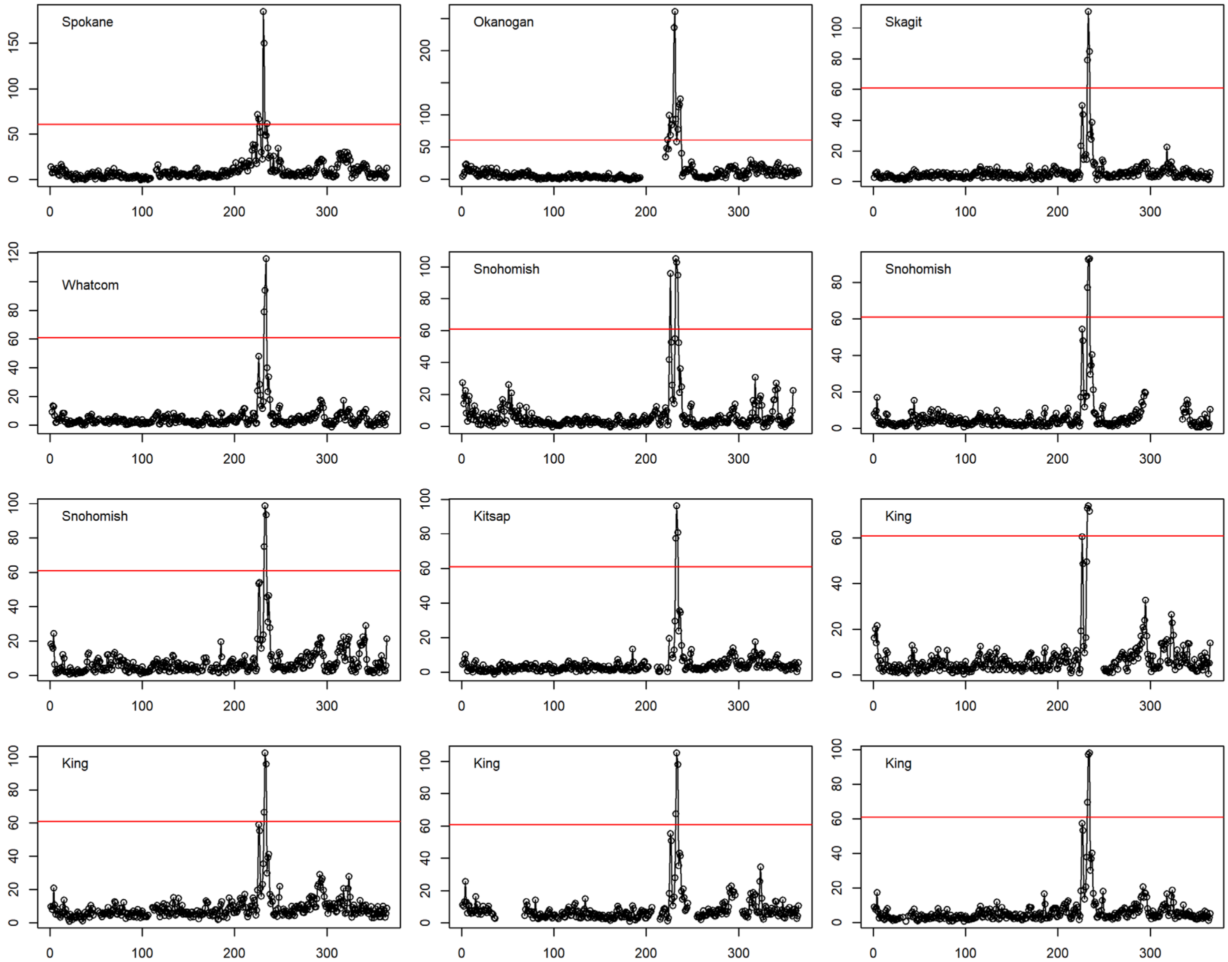

Figure 2A-19 Daily PM2.5 (in µg m-3) from a Subset of Monitors Impacted by Fires in Washington and Oregon in July-August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 61 µg m-3 used for screening.

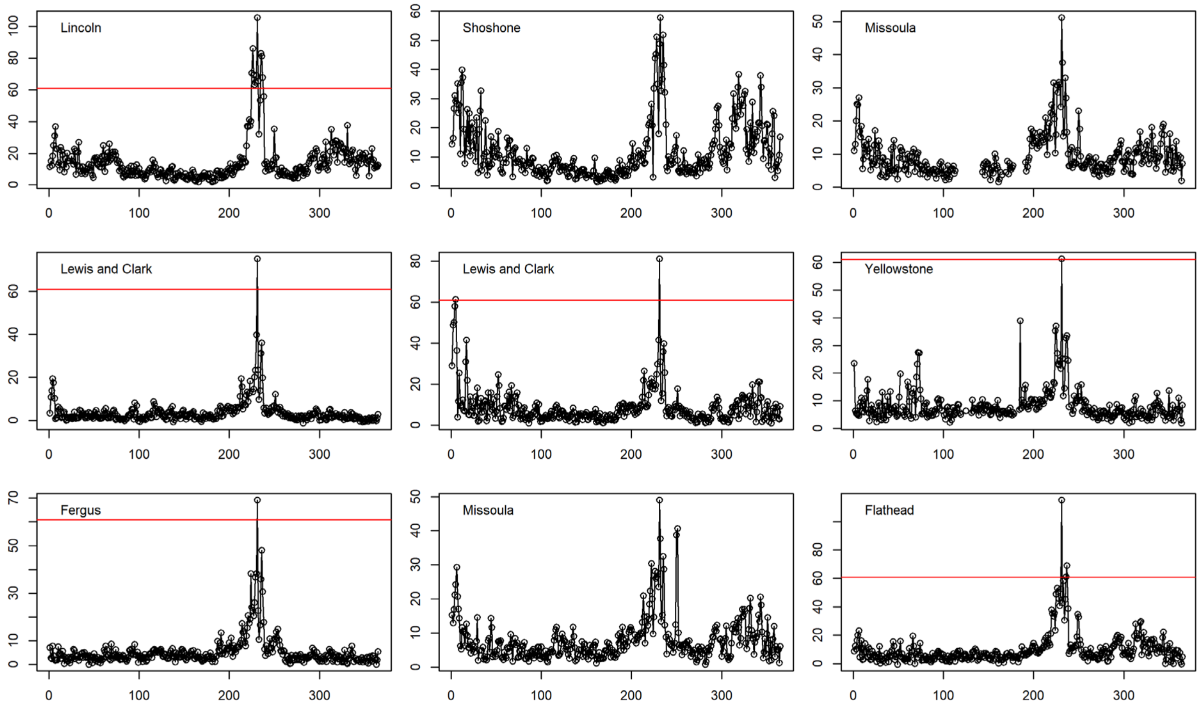

Figure 2A-20 Daily $PM_{2.5}$ (in µg m^{-3}) from the Monitors Impacted by Fires and Smoke in Montana in August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 61 µg m^{-3} used for screening.

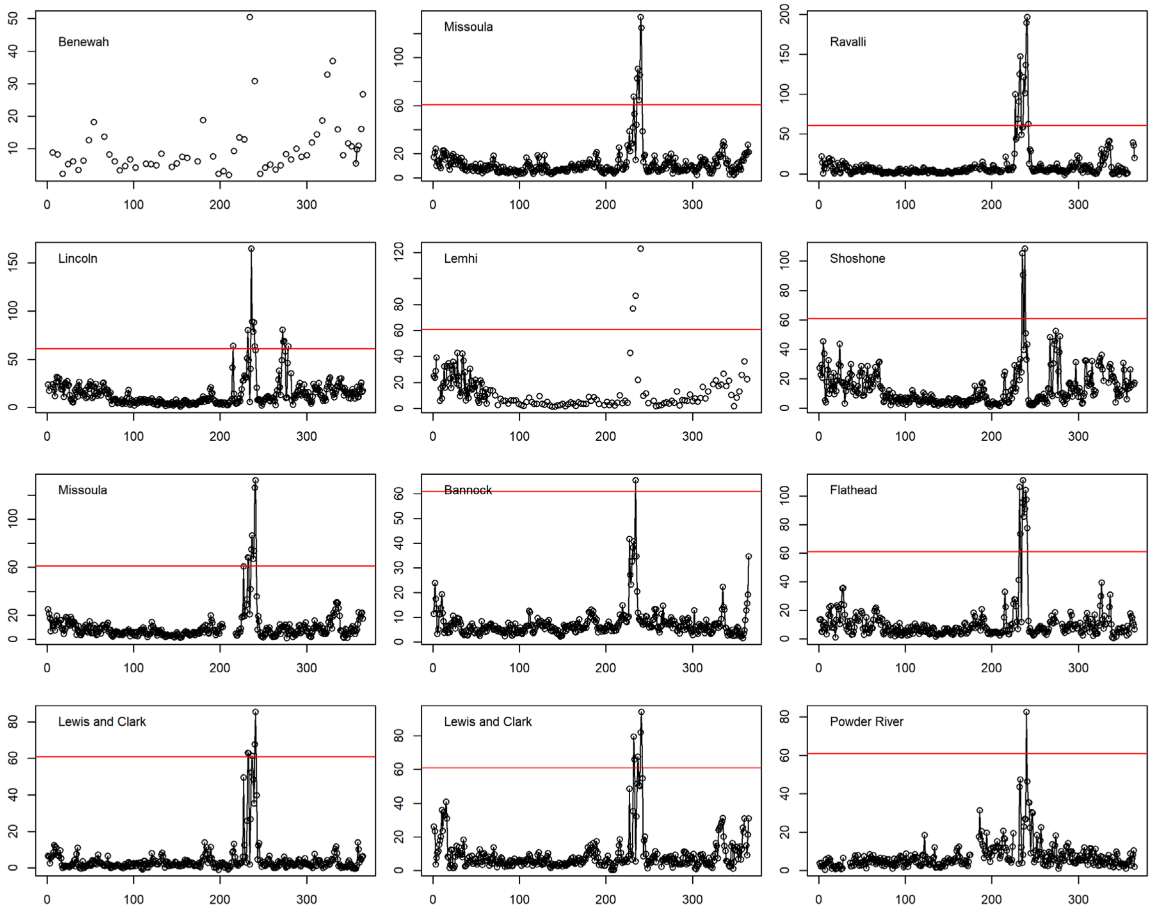

Figure 2A-21 Daily PM2.5 (in µg m-3) from a Subset of Monitors Impacted by Fires in Montana, Washington and Idaho in August 2015

Note: Bottom axis shows day in 2015. Red line indicates extreme value threshold of 61 µg m-3 used for screening.

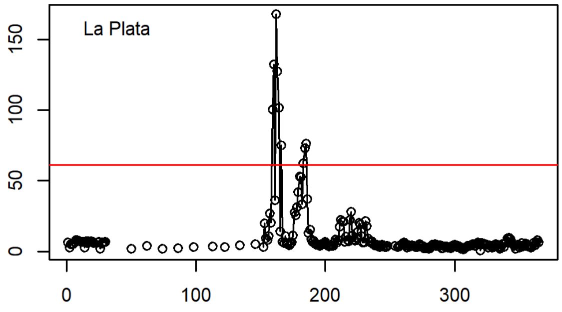

Figure 2A-22 Daily PM2.5 (in µg m-3) from the Monitor in Plata, CO Impacted by the 416/Burro Fire Complex in June 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 61 µg m-3 used for screening.

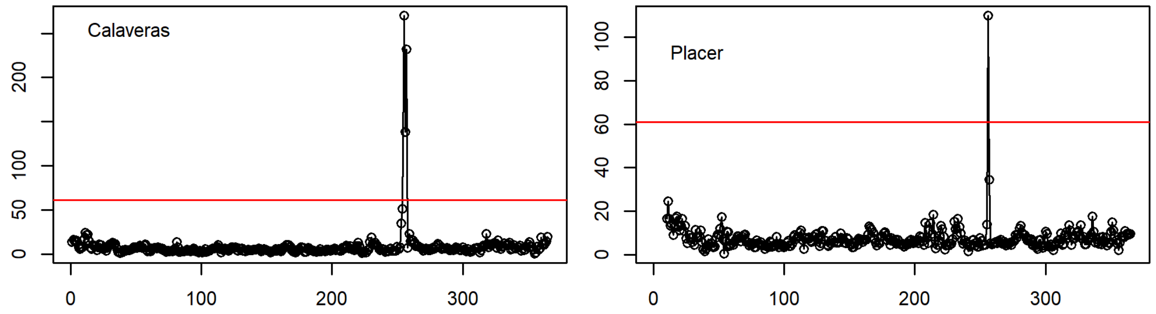

Figure 2A-23 Daily $PM_{2.5}$ (in µg m^{-3}) from the Two monitors Impacted by the Butte Fire in September 2015

Note: Bottom axis shows day in 2015. Red line indicates extreme value threshold of 61 µg m^{-3} used for screening.

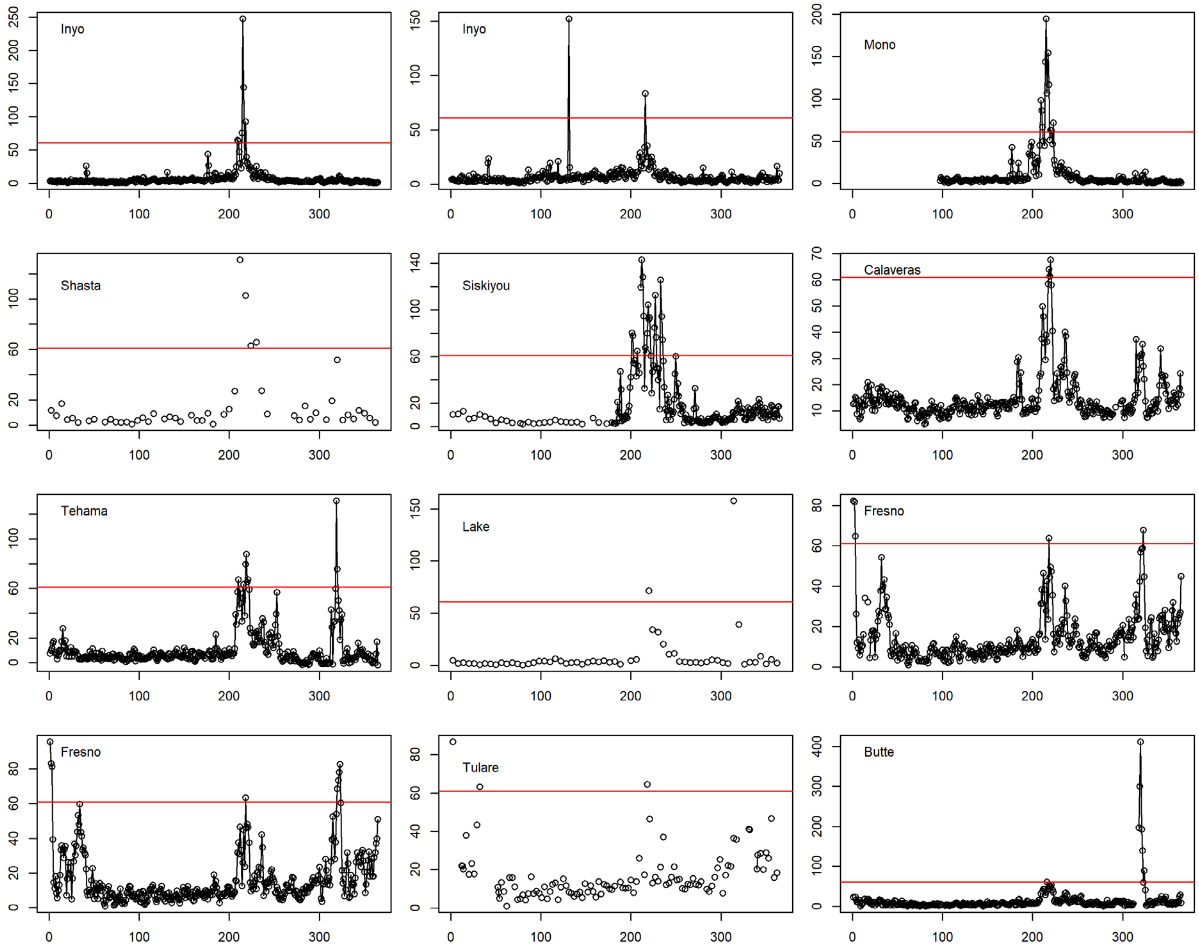

Figure 2A-24 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by the Carr/Mendocino/Ferguson Fires in August 2018

Note: Bottom axis shows day in 2018. Red line indicates extreme value threshold of 61 µg m^{-3} used for screening.

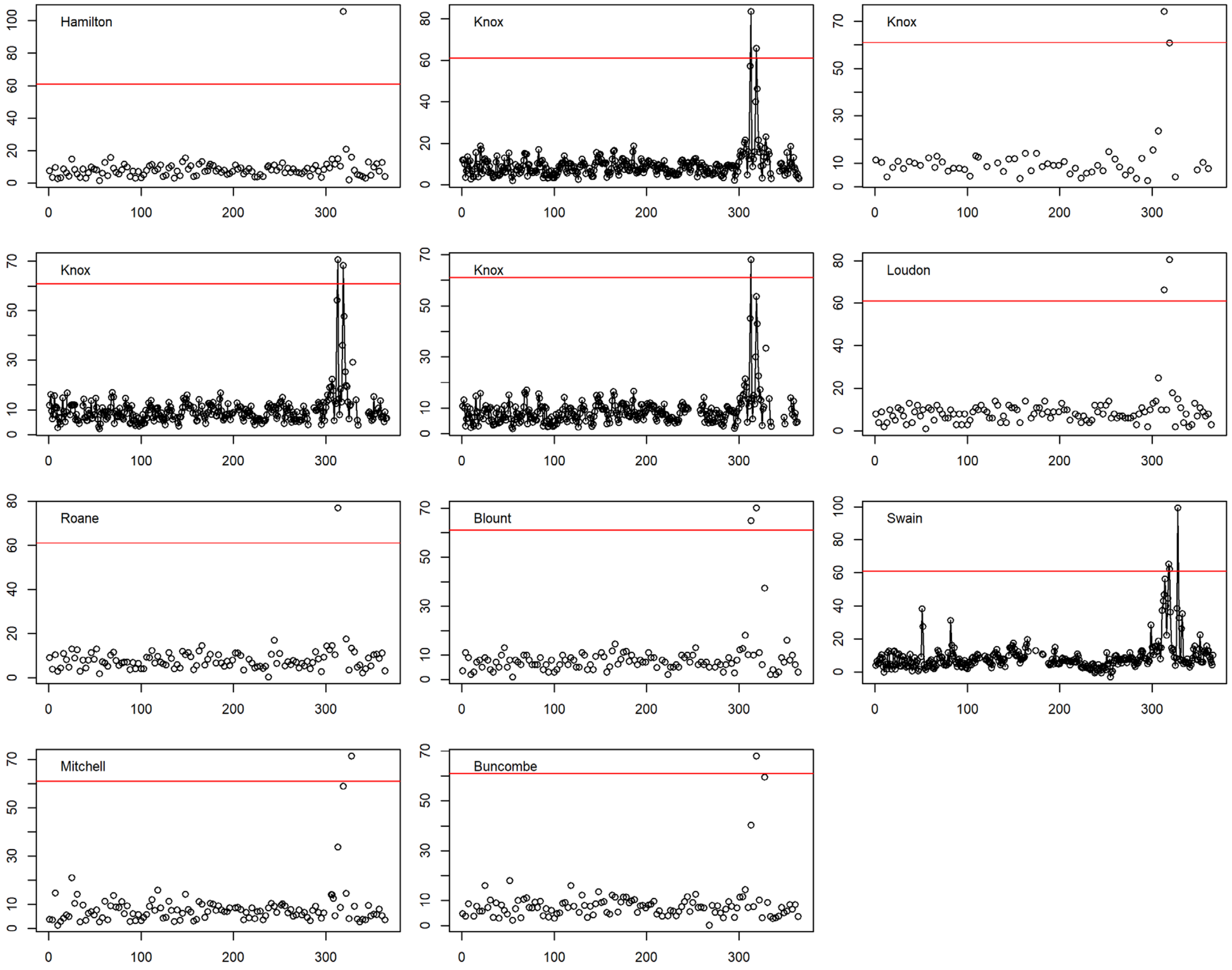

Figure 2A-25 Daily $PM_{2.5}$ (in µg m^{-3}) from a Subset of Monitors Impacted by Fires in the Appalachians in November 2016

Note: Bottom axis shows day in 2016. Red line indicates extreme value threshold of 61 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, Utah, 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 three counties (Los Angeles, San Bernardino, and Imperial) exceed only the annual standard. Los Angeles and San Bernardino are in the South Coast Air Basin along with Riverside County, which exceeds both the annual and 24-hour standard.

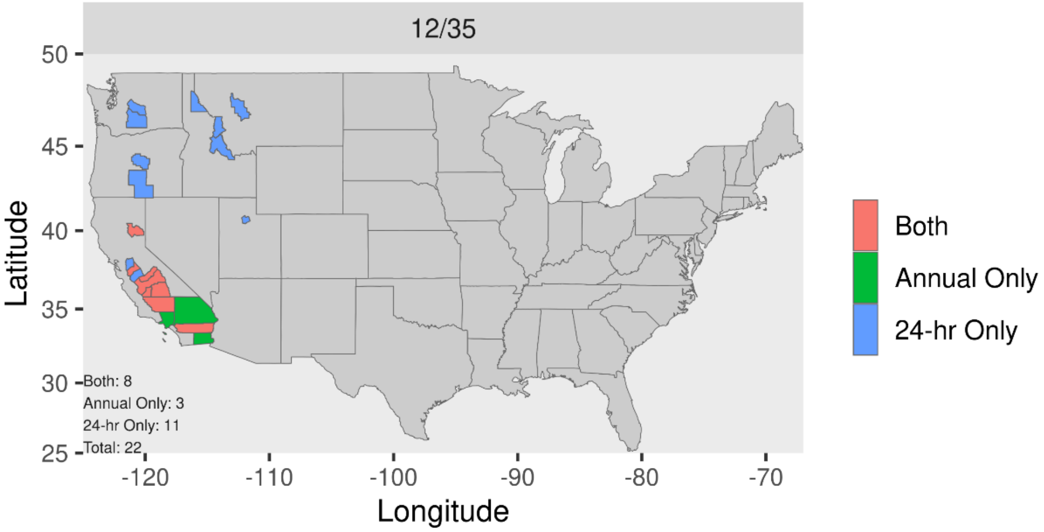

Figure 2A-26 **Counties with Projected 2032 $PM_{2.5}$ DVs that Exceed the 24-Hour (24-hr Only), Annual (Annual Only) or Both the 24-Hour and Annual (Both) Standards for the Combination of Existing Standards (12/35)**

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 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 $\mu g\ m^{-3}$ 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, six counties in the east, three in the NW, and fifteen in California have annual $PM_{2.5}$ DVs greater than 10 $\mu g\ m^{-3}$ in the 12/35 analytical baseline. For the 10/30 case, twenty-three counties have 24-hr DVs greater than 30 $\mu g\ m^{-3}$ and annual DVs less than 10 $\mu g\ m^{-3}$, and eleven counties exceed both the 24-hr and annual standards. For the 9/35 case, twenty-two counties exceed the annual standard in the eastern US, compared with six for the 10/35 and 10/30 cases. The total number of counties exceeding the standards increases from 51 to 141 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}.

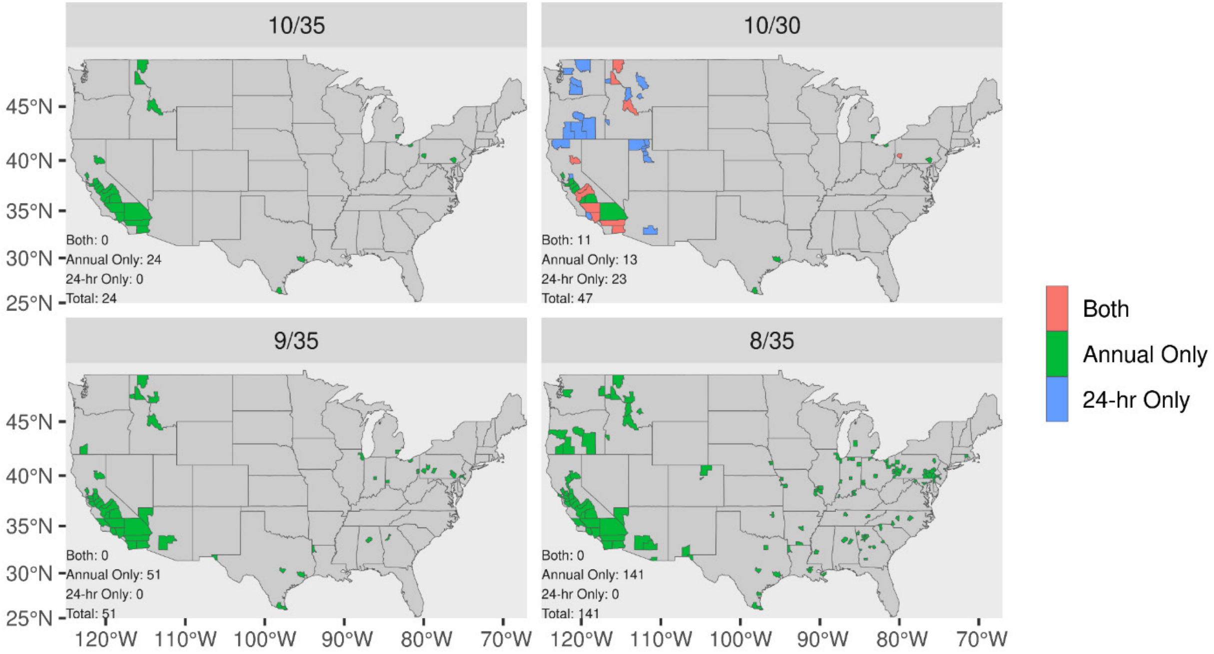

Figure 2A-27 **Counties with $PM_{2.5}$ DVs in the 12/35 Analytical Baseline that Exceed the 24-Hour (24-hr Only), Annual (Annual Only) or Both the 24-Hour and Annual (Both) Standards for the Combination of Existing Standards**

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	9.86	20.1	9.86	20.1
AL	Talladega	8.20	16.3	8.20	16.3
AZ	Maricopa	9.47	26.7	9.47	26.7
AZ	Pinal[a]	8.16	34.2	8.16	34.2
AZ	Santa Cruz	8.99	26.5	8.99	26.5
AR	Pulaski	8.99	19.3	8.99	19.3
AR	Union	8.12	17.0	8.12	17.0
CA	Alameda	10.14	25.4	10.14	25.4
CA	Butte	8.28	27.2	8.28	27.2
CA	Contra Costa	9.16	25.1	9.16	25.1
CA	Fresno	13.34	50.8	11.43	35.4
CA	Imperial	12.45	32.4	12.04	31.5
CA	Kern	16.20	57.2	12.04	32.5
CA	Kings	15.27	48.2	12.04	28.4
CA	Los Angeles	12.73	34.9	12.04	31.1
CA	Madera	12.13	39.8	10.60	31.1
CA	Marin	8.18	23.4	8.18	23.4
CA	Merced	11.88	36.3	10.79	29.1
CA	Napa	10.09	25.7	10.09	25.7
CA	Orange	7.79	31.5	7.47	28.5
CA	Plumas	14.52	47.8	10.60	35.4
CA	Riverside	14.10	39.9	12.04	33.1
CA	Sacramento	9.29	31.0	9.29	31.0
CA	San Bernardino	14.96	35.0	12.04	26.3
CA	San Diego	9.16	22.3	9.16	22.3
CA	San Joaquin	12.01	35.7	10.08	29.1
CA	San Luis Obispo	9.63	25.1	9.63	25.1
CA	Santa Clara	9.56	26.0	9.56	26.0
CA	Siskiyou	7.77	34.8	7.77	34.8
CA	Solano	9.04	24.7	9.04	24.7
CA	Stanislaus	12.43	38.7	11.08	29.8
CA	Sutter	8.82	27.6	8.82	27.6
CA	Tulare	14.66	46.5	12.04	25.3
CA	Ventura	9.23	33.5	9.23	33.5
CO	Denver	9.04	24.1	9.04	24.1
CO	Weld	8.14	24.9	8.14	24.9
DE	New Castle	8.14	21.4	8.14	21.4
DC	District of Columbia	8.21	19.8	8.21	19.8
GA	Bibb	8.80	18.3	8.80	18.3

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})
GA	Clayton	8.57	17.2	8.57	17.2
GA	Cobb	8.09	16.6	8.09	16.6
GA	DeKalb	8.08	18.2	8.08	18.2
GA	Dougherty	8.38	21.3	8.38	21.3
GA	Floyd	8.72	17.3	8.72	17.3
GA	Fulton	9.46	20.4	9.46	20.4
GA	Gwinnett	8.06	18.7	8.06	18.7
GA	Muscogee	8.68	27.3	8.68	27.3
GA	Richmond	8.54	21.0	8.54	21.0
GA	Wilkinson	8.97	19.2	8.97	19.2
ID	Benewah	9.61	35.2	9.61	35.2
ID	Canyon	8.86	31.4	8.86	31.4
ID	Lemhi	11.03	39.4	10.05	35.4
ID	Shoshone	11.04	36.6	10.75	35.4
IL	Cook	9.43	20.7	9.43	20.7
IL	Madison	9.03	19.0	9.03	19.0
IL	Saint Clair	8.99	17.6	8.99	17.6
IN	Allen	8.10	19.6	8.10	19.6
IN	Clark	8.58	19.8	8.58	19.8
IN	Elkhart	8.37	23.5	8.37	23.5
IN	Floyd	8.08	18.0	8.08	18.0
IN	Lake	8.92	22.2	8.92	22.2
IN	Marion	9.61	22.0	9.61	22.0
IN	St. Joseph	8.72	20.4	8.72	20.4
IN	Vanderburgh	8.40	17.5	8.40	17.5
IN	Vigo	8.47	19.2	8.47	19.2
KS	Wyandotte	8.15	19.9	8.15	19.9
KY	Jefferson	8.85	19.5	8.85	19.5
LA	Caddo	9.44	19.6	9.44	19.6
LA	East Baton Rouge	8.69	20.7	8.69	20.7
LA	Iberville	8.06	18.6	8.06	18.6
LA	St. Bernard	8.11	17.4	8.11	17.4
LA	West Baton Rouge	8.67	18.7	8.67	18.7
MD	Howard	8.21	18.6	8.21	18.6
MD	Baltimore (City)	8.17	21.5	8.17	21.5
MI	Kent	8.49	22.5	8.49	22.5
MI	Wayne	10.06	24.1	10.06	24.1
MS	Hinds	8.08	18.1	8.08	18.1
MO	Buchanan	8.15	17.1	8.15	17.1
MO	Jackson	8.09	18.1	8.09	18.1
MO	Jefferson	8.51	18.4	8.51	18.4
MO	Saint Louis	8.82	19.1	8.82	19.1

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 ($\mu g\ m^{-3}$)
MO	St. Louis City	8.36	19.8	8.36	19.8
MT	Lewis and Clark	8.57	37.6	8.03	35.4
MT	Lincoln	11.08	33.2	11.08	33.2
MT	Missoula	9.53	29.6	9.53	29.6
MT	Ravalli	8.75	38.0	8.11	35.4
MT	Silver Bow	8.64	30.6	8.64	30.6
NE	Douglas	8.08	17.8	8.08	17.8
NE	Sarpy	8.10	17.5	8.10	17.5
NV	Clark	9.24	23.0	9.24	23.0
NJ	Camden	9.21	22.3	9.21	22.3
NJ	Union	8.62	21.3	8.62	21.3
NM	Dona Ana	8.57	27.6	8.57	27.6
NY	New York	8.95	22.1	8.95	22.1
NC	Davidson	8.29	18.1	8.29	18.1
NC	Mecklenburg	8.15	17.5	8.15	17.5
NC	Wake	8.12	16.7	8.12	16.7
OH	Butler	9.82	20.7	9.82	20.7
OH	Cuyahoga	10.23	21.8	10.23	21.8
OH	Franklin	8.17	17.9	8.17	17.9
OH	Hamilton	8.91	20.1	8.91	20.1
OH	Jefferson	9.26	22.3	9.26	22.3
OH	Lucas	8.70	19.4	8.70	19.4
OH	Mahoning	8.20	19.0	8.20	19.0
OH	Stark	8.92	19.9	8.92	19.9
OH	Summit	8.72	19.9	8.72	19.9
OK	Tulsa	8.13	19.5	8.13	19.5
OR	Crook	8.29	35.5	8.27	35.4
OR	Harney	8.61	30.8	8.61	30.8
OR	Jackson	9.18	17.3	9.18	17.3
OR	Klamath	8.64	31.2	8.64	31.2
OR	Lake	7.89	37.3	7.42	35.4
OR	Lane	8.12	29.0	8.12	29.0
PA	Allegheny	11.19	34.7	11.19	34.7
PA	Armstrong	9.28	19.3	9.28	19.3
PA	Beaver	8.44	19.1	8.44	19.1
PA	Berks	8.18	23.9	8.18	23.9
PA	Cambria	9.08	22.8	9.08	22.8
PA	Chester	8.97	22.1	8.97	22.1
PA	Dauphin	8.37	24.5	8.37	24.5
PA	Delaware	9.96	23.6	9.96	23.6
PA	Lackawanna	8.07	18.6	8.07	18.6
PA	Lancaster	10.14	26.8	10.14	26.8

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 ($\mu g\ m^{-3}$)
PA	Lebanon	9.10	27.1	9.10	27.1
PA	Lehigh	8.17	21.0	8.17	21.0
PA	Mercer	8.42	19.6	8.42	19.6
PA	Philadelphia	9.75	22.7	9.75	22.7
PA	Washington	8.37	19.0	8.37	19.0
PA	York	8.56	21.4	8.56	21.4
RI	Providence	8.27	17.9	8.27	17.9
SC	Greenville	8.16	18.6	8.16	18.6
TN	Davidson	8.17	16.9	8.17	16.9
TN	Knox	8.60	19.3	8.60	19.3
TX	Cameron	9.75	24.5	9.75	24.5
TX	Dallas	8.08	17.1	8.08	17.1
TX	El Paso	9.08	23.8	9.08	23.8
TX	Harris	10.37	22.0	10.37	22.0
TX	Hidalgo	10.29	25.8	10.29	25.8
TX	Nueces	9.03	23.9	9.03	23.9
TX	Travis	9.07	18.8	9.07	18.8
UT	Box Elder	6.51	31.7	6.51	31.7
UT	Cache	7.07	32.7	7.07	32.7
UT	Davis	7.27	31.1	7.27	31.1
UT	Salt Lake	8.20	37.4	7.71	35.4
UT	Utah	7.63	31.5	7.63	31.5
UT	Weber	7.99	30.8	7.99	30.8
WA	King	8.31	26.5	8.31	26.5
WA	Kittitas	7.37	38.0	6.73	35.4
WA	Okanogan	-	31.8	-	31.8
WA	Snohomish	7.07	31.3	7.07	31.3
WA	Spokane	8.18	27.2	8.18	27.2
WA	Yakima	8.18	38.8	7.34	35.4
WV	Berkeley	8.21	22.1	8.21	22.1
WV	Brooke	8.41	19.8	8.41	19.8
WV	Marshall	8.46	19.7	8.46	19.7

[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, USEPA, 2012b), air quality ratios are used here to estimate the emission reductions beyond the 2032 modeling case that are needed to meet the existing 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 μg 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 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 μg 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:

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

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).

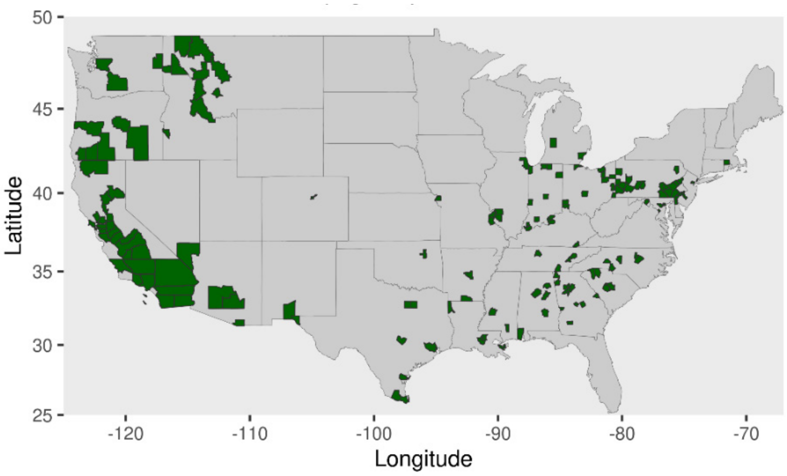

Figure 2A-28 Counties with 50% Reduction in Anthropogenic Primary $PM_{2.5}$ Emissions in 2028 Sensitivity Modeling

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.

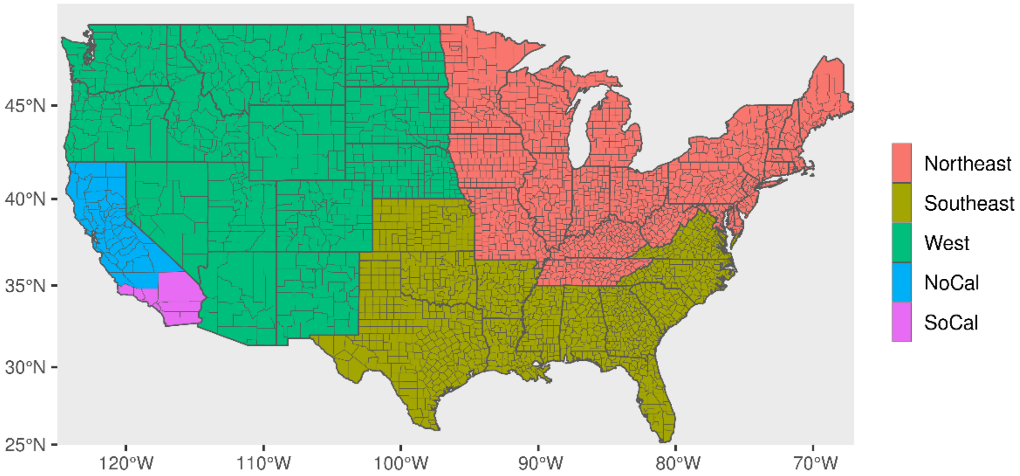

Figure 2A-29 Regional Groupings for Calculating Air Quality Ratios

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

Region	Annual Air Quality Ratio (μg m^{-3} per kton)	24-hour Air Quality Ratio (μg 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.

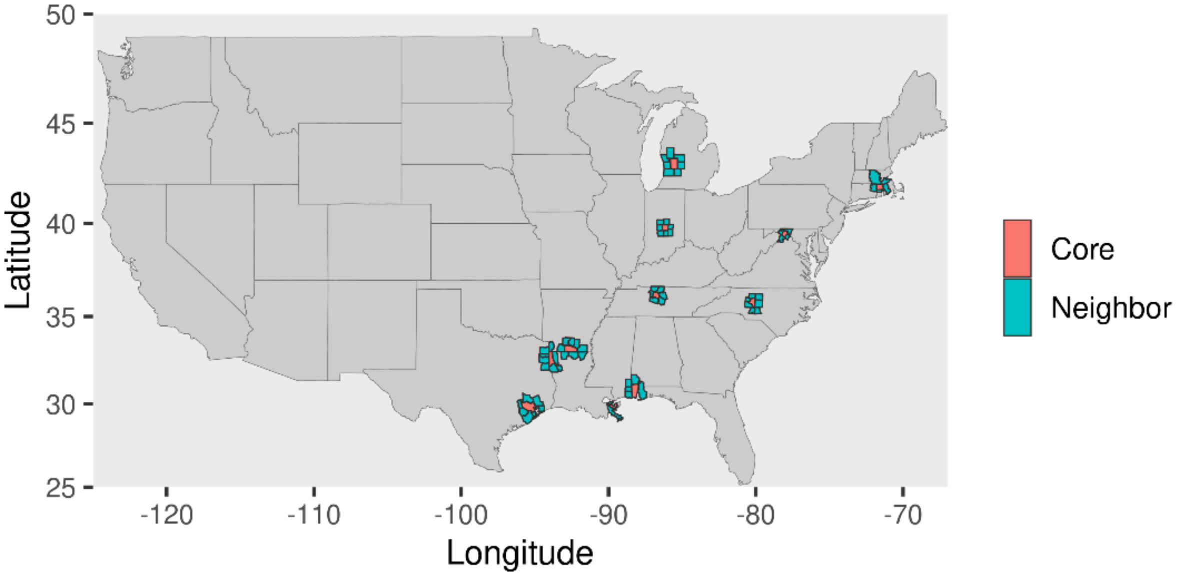

Figure 2A-30 Counties Used in Estimating the Relative Impact of Emissions in Core and Neighboring Counties

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:

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

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).

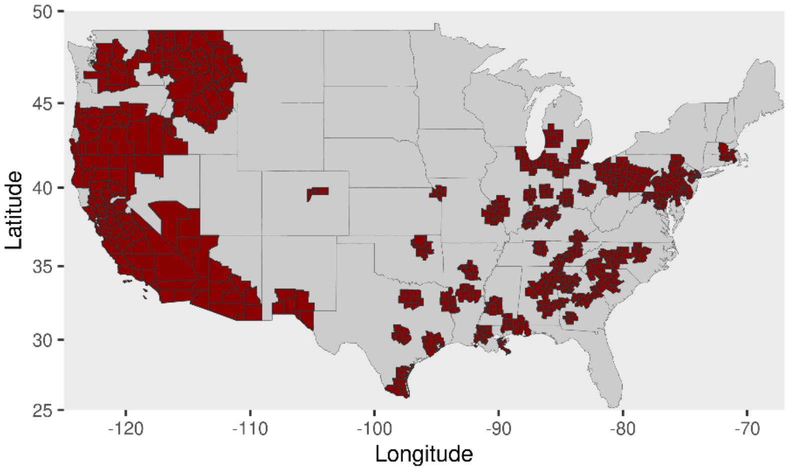

Figure 2A-31 **Counties with 50% Reduction in Anthropogenic NOx Emissions in 2028 Sensitivity Modeling**

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 78,700 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 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	12.38	34.9	12.06	31.9
060374008	Los Angeles	0.004	0.038	12.73	31.0	12.41	28.0
060592022	Orange	0.004	0.038	7.79	14.6	7.47	11.6
060590007	Orange	0.004	0.038	-	31.5	-	28.5
060658005	Riverside	0.004	0.038	14.10	39.9	13.78	36.9
060710027	San Bernardino	0.004	0.038	14.96	35.0	14.64	32.0

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 here, air quality ratios were calculated at monitors in SJV from the following equation:

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

The parenthesis labeled *CARB* indicates values from the SJV Plan, and the parenthesis labeled *2032* indicates values from the 2032 CMAQ modeling described above. $\%Chg.DV_i$ 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 (i.e., 53,500 ton) in the 2032 CMAQ modeling developed here. 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 Tranquility monitor. The Tranquility 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 40,200 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 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 ($\mu g\ m^{-3}$)
060190011	Fresno	0.033	0.337	13.25	50.8	11.94	37.3
060195025	Fresno	0.033	0.337	13.34	48.3	12.03	34.8
060290010	Kern	0.041	0.418	14.40	57.2	12.74	40.4
060290016	Kern	0.041	0.418	16.20	56.3	14.54	39.5
060311004	Kings	0.072	0.467	15.27	48.2	12.37	29.5
060392010	Madera	0.038	0.216	12.13	39.8	10.60	31.1
060470003	Merced	0.027	0.178	11.88	36.3	10.79	29.1
060771002	San Joaquin	0.048	0.164	12.01	35.7	10.08	29.1
060990006	Stanislaus	0.034	0.222	12.43	38.7	11.08	29.8
061072002	Tulare	0.047	0.472	14.66	46.5	12.76	27.6

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 14.54 $\mu g\ m^{-3}$ 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 794 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (14.54-12.04)/3.15 x 1000). The highest 2032 24-hour $PM_{2.5}$ DV in Kern County is 40.4 $\mu g\ m^{-3}$ at site 06-029-0010 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 $\mu g\ m^{-3}$, a total of 502 tons of primary $PM_{2.5}$ emissions would be needed (i.e., (40.4-35.4)/9.97 x 1000). To determine the emission reductions needed to meet an annual and 24-hour standard combination, the maximum needed emissions across standards is calculated as follows:

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

For the Kern County example, a total 794 tons of primary $PM_{2.5}$ emission reductions are needed to meet the 12/35 standard combination (i.e., max(794,502)).

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:

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

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

In the Kern County example, the adjusted annual DV for the 12/35 case is 12.04 $\mu g\ m^{-3}$ (14.54-794*3.15/1000) and the adjusted 24-hour DV is 32.5 $\mu g\ m^{-3}$ (40.4-794*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 $\mu g\ m^{-3}$ or 24-hour DVs greater than 30 $\mu g\ m^{-3}$ (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	9.86	20.1	9.86	20.1
AL	Talladega	0	1.22	3.51	8.20	16.3	8.20	16.3
AZ	Maricopa	0	2.14	8.70	9.47	26.7	9.47	26.7
AZ	Pinal	0	2.14	8.70	8.16	34.2	8.16	34.2
AZ	Santa Cruz	0	2.14	8.70	8.99	26.5	8.99	26.5
AR	Pulaski	0	1.22	3.51	8.99	19.3	8.99	19.3
AR	Union	0	1.22	3.51	8.12	17.0	8.12	17.0
CA	Alameda	0	3.15	9.97	10.14	25.4	10.14	25.4
CA	Butte	0	3.15	9.97	8.28	27.2	8.28	27.2
CA	Contra Costa	0	3.15	9.97	9.16	25.1	9.16	25.1
CA	Fresno	189	3.15	9.97	12.03	37.3	11.43	35.4
CA	Imperial	349	1.18	2.56	12.45	32.4	12.04	31.5
CA	Kern	791	3.15	9.97	14.54	40.4	12.04	32.5
CA	Kings	104	3.15	9.97	12.37	29.5	12.04	28.4
CA	Los Angeles	313	1.18	2.56	12.41	31.9	12.04	31.1
CA	Madera	0	3.15	9.97	10.60	31.1	10.60	31.1
CA	Marin	0	3.15	9.97	8.18	23.4	8.18	23.4
CA	Merced	0	3.15	9.97	10.79	29.1	10.79	29.1
CA	Napa	0	3.15	9.97	10.09	25.7	10.09	25.7
CA	Orange	0	1.18	2.56	7.47	28.5	7.47	28.5
CA	Plumas	1,244	3.15	9.97	14.52	47.8	10.60	35.4
CA	Riverside	1,478	1.18	2.56	13.78	36.9	12.04	33.1
CA	Sacramento	0	3.15	9.97	9.29	31.0	9.29	31.0
CA	San Bernardino	2,209	1.18	2.56	14.64	32.0	12.04	26.3
CA	San Diego	0	1.18	2.56	9.16	22.3	9.16	22.3
CA	San Joaquin	0	3.15	9.97	10.08	29.1	10.08	29.1
CA	San Luis Obispo	0	3.15	9.97	9.63	25.1	9.63	25.1
CA	Santa Clara	0	3.15	9.97	9.56	26.0	9.56	26.0
CA	Siskiyou	0	3.15	9.97	7.77	34.8	7.77	34.8
CA	Solano	0	3.15	9.97	9.04	24.7	9.04	24.7
CA	Stanislaus	0	3.15	9.97	11.08	29.8	11.08	29.8
CA	Sutter	0	3.15	9.97	8.82	27.6	8.82	27.6
CA	Tulare	230	3.15	9.97	12.76	27.6	12.04	25.3
CA	Ventura	0	1.18	2.56	9.23	33.5	9.23	33.5
CO	Denver	0	2.14	8.70	9.04	24.1	9.04	24.1
CO	Weld	0	2.14	8.70	8.14	24.9	8.14	24.9
DE	New Castle	0	1.37	4.33	8.14	21.4	8.14	21.4
DC	District of Columbia	0	1.22	3.51	8.21	19.8	8.21	19.8

State	County	∆Emission 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})
GA	Bibb	0	1.22	3.51	8.80	18.3	8.80	18.3
GA	Clayton	0	1.22	3.51	8.57	17.2	8.57	17.2
GA	Cobb	0	1.22	3.51	8.09	16.6	8.09	16.6
GA	DeKalb	0	1.22	3.51	8.08	18.2	8.08	18.2
GA	Dougherty	0	1.22	3.51	8.38	21.3	8.38	21.3
GA	Floyd	0	1.22	3.51	8.72	17.3	8.72	17.3
GA	Fulton	0	1.22	3.51	9.46	20.4	9.46	20.4
GA	Gwinnett	0	1.22	3.51	8.06	18.7	8.06	18.7
GA	Muscogee	0	1.22	3.51	8.68	27.3	8.68	27.3
GA	Richmond	0	1.22	3.51	8.54	21.0	8.54	21.0
GA	Wilkinson	0	1.22	3.51	8.97	19.2	8.97	19.2
ID	Benewah	0	2.14	8.70	9.61	35.2	9.61	35.2
ID	Canyon	0	2.14	8.70	8.86	31.4	8.86	31.4
ID	Lemhi	460	2.14	8.70	11.03	39.4	10.05	35.4
ID	Shoshone	138	2.14	8.70	11.04	36.6	10.75	35.4
IL	Cook	0	1.37	4.33	9.43	20.7	9.43	20.7
IL	Madison	0	1.37	4.33	9.03	19.0	9.03	19.0
IL	Saint Clair	0	1.37	4.33	8.99	17.6	8.99	17.6
IN	Allen	0	1.37	4.33	8.10	19.6	8.10	19.6
IN	Clark	0	1.37	4.33	8.58	19.8	8.58	19.8
IN	Elkhart	0	1.37	4.33	8.37	23.5	8.37	23.5
IN	Floyd	0	1.37	4.33	8.08	18.0	8.08	18.0
IN	Lake	0	1.37	4.33	8.92	22.2	8.92	22.2
IN	Marion	0	1.37	4.33	9.61	22.0	9.61	22.0
IN	St. Joseph	0	1.37	4.33	8.72	20.4	8.72	20.4
IN	Vanderburgh	0	1.37	4.33	8.40	17.5	8.40	17.5
IN	Vigo	0	1.37	4.33	8.47	19.2	8.47	19.2
KS	Wyandotte	0	1.22	3.51	8.15	19.9	8.15	19.9
KY	Jefferson	0	1.37	4.33	8.85	19.5	8.85	19.5
LA	Caddo	0	1.22	3.51	9.44	19.6	9.44	19.6
LA	East Baton Rouge	0	1.22	3.51	8.69	20.7	8.69	20.7
LA	Iberville	0	1.22	3.51	8.06	18.6	8.06	18.6
LA	St. Bernard	0	1.22	3.51	8.11	17.4	8.11	17.4
LA	West Baton Rouge	0	1.22	3.51	8.67	18.7	8.67	18.7
MD	Howard	0	1.37	4.33	8.21	18.6	8.21	18.6
MD	Baltimore (City)	0	1.37	4.33	8.17	21.5	8.17	21.5
MI	Kent	0	1.37	4.33	8.49	22.5	8.49	22.5
MI	Wayne	0	1.37	4.33	10.06	24.1	10.06	24.1
MS	Hinds	0	1.22	3.51	8.08	18.1	8.08	18.1
MO	Buchanan	0	1.37	4.33	8.15	17.1	8.15	17.1
MO	Jackson	0	1.37	4.33	8.09	18.1	8.09	18.1
MO	Jefferson	0	1.37	4.33	8.51	18.4	8.51	18.4

State	County	ΔEmission 2032 to 12/35 (ton)	AQ Ratio Annual ($\mu g\ m^{-3}$ per kton)	AQ Ratio 24-hour ($\mu g\ m^{-3}$ per kton)	2032[a] DV Annual ($\mu g\ m^{-3}$)	2032[a] DV 24-hour ($\mu g\ m^{-3}$)	12/35 DV Annual ($\mu g\ m^{-3}$)	12/35 DV 24-hour ($\mu g\ m^{-3}$)
MO	Saint Louis	0	1.37	4.33	8.82	19.1	8.82	19.1
MO	St. Louis City	0	1.37	4.33	8.36	19.8	8.36	19.8
MT	Lewis and Clark	253	2.14	8.70	8.57	37.6	8.03	35.4
MT	Lincoln	0	2.14	8.70	11.08	33.2	11.08	33.2
MT	Missoula	0	2.14	8.70	9.53	29.6	9.53	29.6
MT	Ravalli	299	2.14	8.70	8.75	38.0	8.11	35.4
MT	Silver Bow	0	2.14	8.70	8.64	30.6	8.64	30.6
NE	Douglas	0	2.14	8.70	8.08	17.8	8.08	17.8
NE	Sarpy	0	2.14	8.70	8.10	17.5	8.10	17.5
NV	Clark	0	2.14	8.70	9.24	23.0	9.24	23.0
NJ	Camden	0	1.37	4.33	9.21	22.3	9.21	22.3
NJ	Union	0	1.37	4.33	8.62	21.3	8.62	21.3
NM	Dona Ana	0	2.14	8.70	8.57	27.6	8.57	27.6
NY	New York	0	1.37	4.33	8.95	22.1	8.95	22.1
NC	Davidson	0	1.22	3.51	8.29	18.1	8.29	18.1
NC	Mecklenburg	0	1.22	3.51	8.15	17.5	8.15	17.5
NC	Wake	0	1.22	3.51	8.12	16.7	8.12	16.7
OH	Butler	0	1.37	4.33	9.82	20.7	9.82	20.7
OH	Cuyahoga	0	1.37	4.33	10.23	21.8	10.23	21.8
OH	Franklin	0	1.37	4.33	8.17	17.9	8.17	17.9
OH	Hamilton	0	1.37	4.33	8.91	20.1	8.91	20.1
OH	Jefferson	0	1.37	4.33	9.26	22.3	9.26	22.3
OH	Lucas	0	1.37	4.33	8.70	19.4	8.70	19.4
OH	Mahoning	0	1.37	4.33	8.20	19.0	8.20	19.0
OH	Stark	0	1.37	4.33	8.92	19.9	8.92	19.9
OH	Summit	0	1.37	4.33	8.72	19.9	8.72	19.9
OK	Tulsa	0	1.22	3.51	8.13	19.5	8.13	19.5
OR	Crook	11	2.14	8.70	8.29	35.5	8.27	35.4
OR	Harney	0	2.14	8.70	8.61	30.8	8.61	30.8
OR	Jackson	0	2.14	8.70	9.18	17.3	9.18	17.3
OR	Klamath	0	2.14	8.70	8.64	31.2	8.64	31.2
OR	Lake	218	2.14	8.70	7.89	37.3	7.42	35.4
OR	Lane	0	2.14	8.70	8.12	29.0	8.12	29.0
PA	Allegheny	0	1.37	4.33	11.19	34.7	11.19	34.7
PA	Armstrong	0	1.37	4.33	9.28	19.3	9.28	19.3
PA	Beaver	0	1.37	4.33	8.44	19.1	8.44	19.1
PA	Berks	0	1.37	4.33	8.18	23.9	8.18	23.9
PA	Cambria	0	1.37	4.33	9.08	22.8	9.08	22.8
PA	Chester	0	1.37	4.33	8.97	22.1	8.97	22.1
PA	Dauphin	0	1.37	4.33	8.37	24.5	8.37	24.5
PA	Delaware	0	1.37	4.33	9.96	23.6	9.96	23.6
PA	Lackawanna	0	1.37	4.33	8.07	18.6	8.07	18.6

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})
PA	Lancaster	0	1.37	4.33	10.14	26.8	10.14	26.8
PA	Lebanon	0	1.37	4.33	9.10	27.1	9.10	27.1
PA	Lehigh	0	1.37	4.33	8.17	21.0	8.17	21.0
PA	Mercer	0	1.37	4.33	8.42	19.6	8.42	19.6
PA	Philadelphia	0	1.37	4.33	9.75	22.7	9.75	22.7
PA	Washington	0	1.37	4.33	8.37	19.0	8.37	19.0
PA	York	0	1.37	4.33	8.56	21.4	8.56	21.4
RI	Providence	0	1.37	4.33	8.27	17.9	8.27	17.9
SC	Greenville	0	1.22	3.51	8.16	18.6	8.16	18.6
TN	Davidson	0	1.37	4.33	8.17	16.9	8.17	16.9
TN	Knox	0	1.37	4.33	8.60	19.3	8.60	19.3
TX	Cameron	0	1.22	3.51	9.75	24.5	9.75	24.5
TX	Dallas	0	1.22	3.51	8.08	17.1	8.08	17.1
TX	El Paso	0	1.22	3.51	9.08	23.8	9.08	23.8
TX	Harris	0	1.22	3.51	10.37	22.0	10.37	22.0
TX	Hidalgo	0	1.22	3.51	10.29	25.8	10.29	25.8
TX	Nueces	0	1.22	3.51	9.03	23.9	9.03	23.9
TX	Travis	0	1.22	3.51	9.07	18.8	9.07	18.8
UT	Box Elder	0	2.14	8.70	6.51	31.7	6.51	31.7
UT	Cache	0	2.14	8.70	7.07	32.7	7.07	32.7
UT	Davis	0	2.14	8.70	7.27	31.1	7.27	31.1
UT	Salt Lake	230	2.14	8.70	8.20	37.4	7.71	35.4
UT	Utah	0	2.14	8.70	7.63	31.5	7.63	31.5
UT	Weber	0	2.14	8.70	7.99	30.8	7.99	30.8
WA	King	0	2.14	8.70	8.31	26.5	8.31	26.5
WA	Kittitas	299	2.14	8.70	7.37	38.0	6.73	35.4
WA	Okanogan	0	2.14	8.70	-	31.8	-	31.8
WA	Snohomish	0	2.14	8.70	7.07	31.3	7.07	31.3
WA	Spokane	0	2.14	8.70	8.18	27.2	8.18	27.2
WA	Yakima	391	2.14	8.70	8.18	38.8	7.34	35.4
WV	Berkeley	0	1.37	4.33	8.21	22.1	8.21	22.1
WV	Brooke	0	1.37	4.33	8.41	19.8	8.41	19.8
WV	Marshall	0	1.37	4.33	8.46	19.7	8.46	19.7

[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 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.

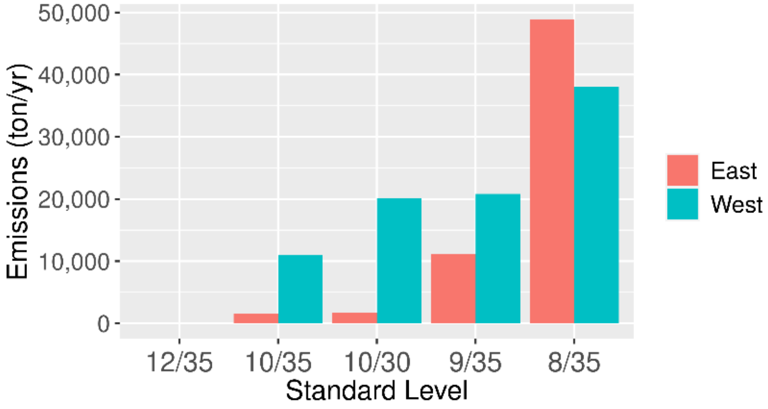

Figure 2A-32 **Total Primary $PM_{2.5}$ Emission Reductions Needed to Meet the Alternative Standard Levels of 10/35, 10/30, 9/35, and 8/35 Relative to the 12/35 Analytical Baseline in the East and West**

Table 2A-14 **Primary $PM_{2.5}$ Emission Reductions Needed to Meet the 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	670	1,488	0
Alabama	Talladega	0	0	131	0
Arizona	Maricopa	0	201	669	0
Arizona	Pinal	0	0	56	437
Arizona	Santa Cruz	0	0	444	0
Arkansas	Pulaski	0	0	777	0
Arkansas	Union	0	0	65	0
California	Alameda	32	349	666	32
California	Butte	0	0	76	0
California	Contra Costa	0	38	355	0
California	Fresno	440	757	1,074	502
California	Imperial	1,701	2,551	3,402	1,701
California	Kern	634	951	1,268	634
California	Kings	634	951	1,268	634
California	Los Angeles	1,701	2,551	3,402	1,701
California	Madera	179	496	813	179

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
California	Marin	0	0	44	0
California	Merced	237	554	871	237
California	Napa	16	333	650	16
California	Orange	0	0	0	0
California	Plumas	176	493	810	502
California	Riverside	1,701	2,551	3,402	1,701
California	Sacramento	0	79	396	60
California	San Bernardino	1,701	2,551	3,402	1,701
California	San Diego	0	102	953	0
California	San Joaquin	12	329	646	12
California	San Luis Obispo	0	187	504	0
California	Santa Clara	0	165	482	0
California	Siskiyou	0	0	0	441
California	Solano	0	0	317	0
California	Stanislaus	331	648	965	331
California	Sutter	0	0	247	0
California	Tulare	634	951	1,268	634
California	Ventura	0	162	1,012	1,213
Colorado	Denver	0	0	468	0
Colorado	Weld	0	0	47	0
Delaware	New Castle	0	0	73	0
District Of Columbia	District of Columbia	0	0	139	0
Georgia	Bibb	0	0	621	0
Georgia	Clayton	0	0	433	0
Georgia	Cobb	0	0	41	0
Georgia	DeKalb	0	0	33	0
Georgia	Dougherty	0	0	278	0
Georgia	Floyd	0	0	556	0
Georgia	Fulton	0	343	1,161	0
Georgia	Gwinnett	0	0	16	0
Georgia	Muscogee	0	0	523	0
Georgia	Richmond	0	0	409	0
Georgia	Wilkinson	0	0	760	0
Idaho	Benewah	0	267	734	552
Idaho	Canyon	0	0	383	115
Idaho	Lemhi	3	471	939	574
Idaho	Shoshone	330	797	1,265	574
Illinois	Cook	0	285	1,017	0
Illinois	Madison	0	0	724	0
Illinois	Saint Clair	0	0	695	0
Indiana	Allen	0	0	44	0
Indiana	Clark	0	0	395	0

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
Indiana	Elkhart	0	0	241	0
Indiana	Floyd	0	0	29	0
Indiana	Lake	0	0	644	0
Indiana	Marion	0	417	1,149	0
Indiana	St. Joseph	0	0	498	0
Indiana	Vanderburgh	0	0	263	0
Indiana	Vigo	0	0	315	0
Kansas	Wyandotte	0	0	90	0
Kentucky	Jefferson	0	0	593	0
Louisiana	Caddo	0	327	1,145	0
Louisiana	East Baton Rouge	0	0	531	0
Louisiana	Iberville	0	0	16	0
Louisiana	St. Bernard	0	0	57	0
Louisiana	West Baton Rouge	0	0	515	0
Maryland	Howard	0	0	124	0
Maryland	Baltimore (City)	0	0	95	0
Michigan	Kent	0	0	329	0
Michigan	Wayne	15	746	1,478	15
Mississippi	Hinds	0	0	33	0
Missouri	Buchanan	0	0	80	0
Missouri	Jackson	0	0	37	0
Missouri	Jefferson	0	0	344	0
Missouri	Saint Louis	0	0	571	0
Missouri	St. Louis City	0	0	234	0
Montana	Lewis and Clark	0	0	0	574
Montana	Lincoln	486	954	1,422	486
Montana	Missoula	0	229	697	0
Montana	Ravalli	0	0	33	574
Montana	Silver Bow	0	0	281	23
Nebraska	Douglas	0	0	19	0
Nebraska	Sarpy	0	0	28	0
Nevada	Clark	0	94	561	0
New Jersey	Camden	0	124	856	0
New Jersey	Union	0	0	424	0
New Mexico	Dona Ana	0	0	248	0
New York	New York	0	0	666	0
North Carolina	Davidson	0	0	204	0
North Carolina	Mecklenburg	0	0	90	0
North Carolina	Wake	0	0	65	0
Ohio	Butler	0	571	1,303	0
Ohio	Cuyahoga	139	871	1,603	139
Ohio	Franklin	0	0	95	0

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
Ohio	Hamilton	0	0	637	0
Ohio	Jefferson	0	161	893	0
Ohio	Lucas	0	0	483	0
Ohio	Mahoning	0	0	117	0
Ohio	Stark	0	0	644	0
Ohio	Summit	0	0	498	0
Oklahoma	Tulsa	0	0	74	0
Oregon	Crook	0	0	105	574
Oregon	Harney	0	0	267	46
Oregon	Jackson	0	65	533	0
Oregon	Klamath	0	0	281	92
Oregon	Lake	0	0	0	574
Oregon	Lane	0	0	37	0
Pennsylvania	Allegheny	842	1,573	2,305	994
Pennsylvania	Armstrong	0	176	907	0
Pennsylvania	Beaver	0	0	293	0
Pennsylvania	Berks	0	0	102	0
Pennsylvania	Cambria	0	29	761	0
Pennsylvania	Chester	0	0	681	0
Pennsylvania	Dauphin	0	0	241	0
Pennsylvania	Delaware	0	673	1,405	0
Pennsylvania	Lackawanna	0	0	22	0
Pennsylvania	Lancaster	73	805	1,537	73
Pennsylvania	Lebanon	0	44	776	0
Pennsylvania	Lehigh	0	0	95	0
Pennsylvania	Mercer	0	0	278	0
Pennsylvania	Philadelphia	0	520	1,251	0
Pennsylvania	Washington	0	0	241	0
Pennsylvania	York	0	0	381	0
Rhode Island	Providence	0	0	168	0
South Carolina	Greenville	0	0	98	0
Tennessee	Davidson	0	0	95	0
Tennessee	Knox	0	0	410	0
Texas	Cameron	0	581	1,398	0
Texas	Dallas	0	0	33	0
Texas	El Paso	0	33	850	0
Texas	Harris	270	1,087	1,905	270
Texas	Hidalgo	204	1,022	1,840	204
Texas	Nueces	0	0	809	0
Texas	Travis	0	25	842	0
Utah	Box Elder	0	0	0	149
Utah	Cache	0	0	0	264

State	County	Emission 10/35 (ton)	Emission 9/35 (ton)	Emission 8/35 (ton)	Emission 10/30 (ton)
Utah	Davis	0	0	0	80
Utah	Salt Lake	0	0	0	574
Utah	Utah	0	0	0	126
Utah	Weber	0	0	0	46
Washington	King	0	0	126	0
Washington	Kittitas	0	0	0	574
Washington	Okanogan	0	0	0	161
Washington	Snohomish	0	0	0	103
Washington	Spokane	0	0	65	0
Washington	Yakima	0	0	0	574
West Virginia	Berkeley	0	0	124	0
West Virginia	Brooke	0	0	271	0
West Virginia	Marshall	0	0	307	0

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

National $PM_{2.5}$ concentration fields corresponding to meeting the existing 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, version 1.8, 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 2015-2017 period were interpolated to the spatial grid using inverse distance-squared-weighting of monitored concentrations that were further weighted by the ratio of the 2016 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:

$$eVNA_{s,q,2016} = \sum Weight_x Monitor_{x,s,q} \frac{Model_{s,q,2016}}{Model_{s,q,2016}} \qquad (2A\text{-}10)$$

where $eVNA_{s,q,2016}$ 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 2015-2017; $Model_{s,q,2016}$ is the quarterly-average 2016 CMAQ concentration of species, s, during quarter, q, in the prediction grid cell; and $Model_{x,s,q,2016}$ is the quarterly-average 2016 CMAQ concentration of species, s, during quarter, q, in the grid cell of monitor, x.

The 2016 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 2016 eVNA component concentration in each grid cell is multiplied by the corresponding ratio of the quarterly-average CMAQ concentration predictions in 2032 and 2016:

$$eVNA_{s,q,2032} = eVNA_{s,q,2016} \frac{Model_{s,q,2032}}{Model_{s,q,2016}} \qquad (2A\text{-}11)$$

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.

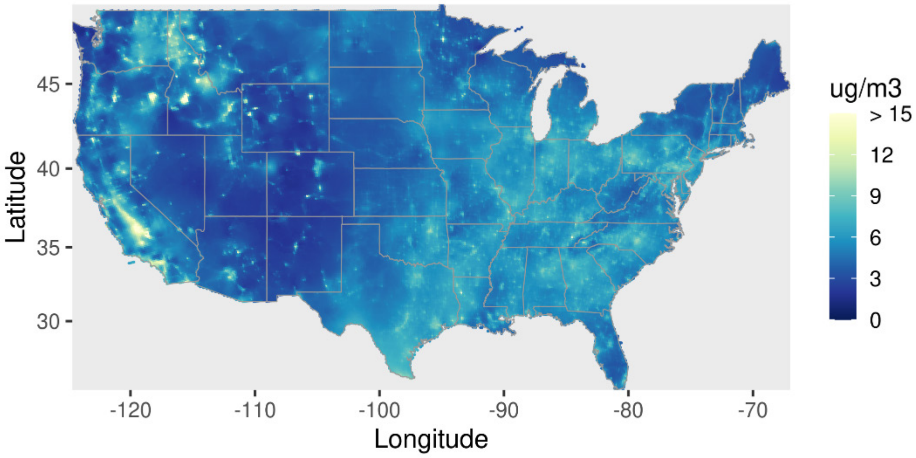

Figure 2A-33 PM2.5 Concentration for 2032 based on eVNA Method

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 the county non-highest monitors, the difference in $PM_{2.5}$ DVs was estimated by proportionally adjusting 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 seven 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 (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), 49-035-1001 (Salt Lake, UT), 49-035-3013 (Salt Lake, UT). 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.

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). An example of a spatial field for the incremental change in $PM_{2.5}$ concentration between the 2032 case and the case of meeting the existing standard combination, 12/35, is shown in Figure 2A-34.

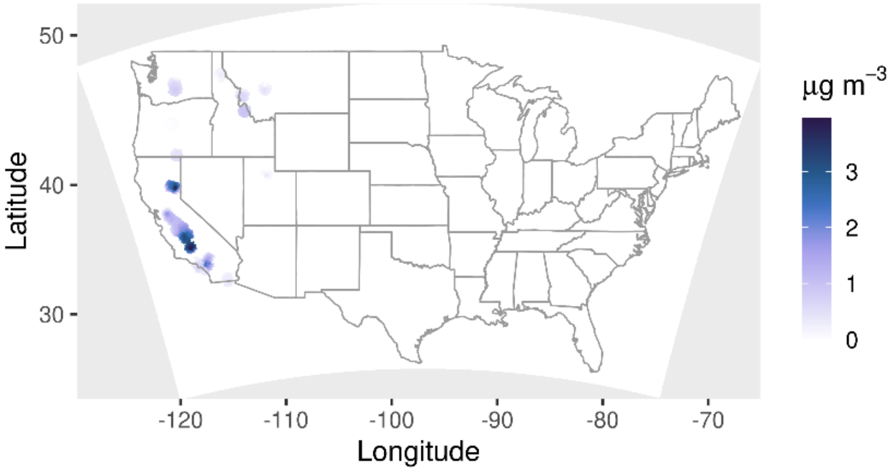

Figure 2A-34 **$PM_{2.5}$ Concentration Improvement Associated with Meeting 12/35 Relative to the 2032 Case**

National $PM_{2.5}$ concentration fields were 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 (two 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 μg 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.

2A.5 Calculating DV Impacts for Further EGU Emission Reductions

Additional EGU emissions reductions are expected to occur between 2016 and 2030 beyond those included in the 2032 CMAQ simulation. These additional emission reductions are mainly due to planned EGU retirements that were not known at the time of development of the emission projections. In this section, we consider the potential influence of these emission reductions on $PM_{2.5}$ DVs. First, the influence of further primary $PM_{2.5}$ emission reductions from EGUs on DVs is estimated for counties with 2032 $PM_{2.5}$ DVs that exceed the alternative standard levels. Next, the regional impact on annual $PM_{2.5}$ DVs of the estimated total SO_2 and NOx emission reductions from EGUs in the eastern US is estimated. Finally, the influence of these SO_2 and NOx emission reductions on annual $PM_{2.5}$ DVs in nearby county groups is estimated for two areas with the largest SO_2 reductions expected near monitors with 2032 $PM_{2.5}$ that exceed alternative standard levels.

2A.5.1 Estimating the Influence of Additional Primary $PM_{2.5}$ EGU Reductions

For ten of the counties with 2032 DVs that exceed the alternative annual standard level of 8 μg m^{-3} or the 24-hour standard level of 30 μg m^{-3}, additional reductions in primary $PM_{2.5}$ emissions from EGUs beyond the 2032 modeling case are expected. These counties are shown in Table 2A-15 with the expected emission reductions and the estimated influence on the annual and 24-hour DV. For reference, the 2032 DVs, corresponding to projections based on the CMAQ simulation of the 2032 emissions case (Section 2.2), are also shown in the Table. The DV impacts were calculated by applying the air quality ratios for these counties (Table 2A-9) to the emission estimates. The largest influence of the further EGU emission reductions is in Hamilton, OH (0.85 μg m^{-3}), Jefferson, MO (0.31 μg m^{-3}), and Allegheny, PA (0.18 μg m^{-3}). The significance of these DV reductions in the context of meeting alternative standard levels is discussed in section 3.2.4.

Table 2A-15 Primary $PM_{2.5}$ Emission Reductions from EGUs Expected beyond 2032 Modeling Case and Estimated Impact on DVs for Counties Exceeding Alternative Standards in the 2032 Case

State	County	$PM_{2.5}$ Emissions Reduction (ton)	2032 Annual DV[a] (μg m^{-3})	2032 24-hour DV[a] (μg m^{-3})	ΔDV Annual (μg m^{-3})	ΔDV 24-hour (μg m^{-3})
Arizona	Maricopa	6.0	9.47	26.7	0.01	0.1
California	Los Angeles	5.9	12.73	34.9	0.01	0.0
Colorado	Weld	0.1	8.14	24.9	0.00	0.0
Missouri	Jefferson	229.0	8.51	18.4	0.31	1.0
Nevada	Clark	19.4	9.24	23.0	0.04	0.2
Ohio	Hamilton	619.0	8.91	20.1	0.85	2.7
Pennsylvania	Allegheny	133.8	11.19	34.7	0.18	0.6
Texas	Dallas	11.7	8.08	17.1	0.01	0.0
Texas	El Paso	4.5	9.08	23.8	0.01	0.0
Texas	Travis	2.9	9.07	18.8	0.00	0.0

[a] The 2032 DVs correspond to projections based on the CMAQ simulation of the 2032 emissions case (Section 2.2) without any additional DV adjustments.

2A.5.2 Estimating the Regional Influence of Additional SO_2 and NOx EGU Emission Reductions

For states in the eastern US, a combined total of 170,411 tons of SO_2 and 52,718 tons of NOx emission reductions are expected to occur from EGUs beyond the 2032 modeling case. The emission tons are listed by state and county in Table 2A-16. Sensitivity model simulations with 50% SO_2 and NOx emission reductions relative to the 2028 case described above were used to estimate the regional influence of these emission reductions on annual DVs in the eastern US.

The counties with 50% reductions of SO_2 and NOx emissions in the 2028 CMAQ sensitivity simulations are shown in Figure 2A-35. The eastern states considered in this analysis are shaded in red in the figure. The total change in emissions in these states in the 50% NOx emission reduction simulation was 1,566,554 tons, and the total emission reduction was 479,342 tons in the 50% SO_2 emission reduction simulation. To estimate the regional influence of the additional EGU emission reductions, the change in DVs for the sensitivity simulations was calculated at monitors in the eastern states and scaled by the ratio of the EGU emission reductions to the sensitivity simulation emission reductions (i.e., 52,718 tons / 1,566,554 tons for NOx, and 170,411 tons / 479,342 tons for SO_2). Across monitors in the eastern states, the median total $PM_{2.5}$ DV change estimated this way is 0.06 $\mu g\ m^{-3}$ (25th/75th percentile: 0.05 $\mu g\ m^{-3}$/0.08 $\mu g\ m^{-3}$). The full distribution of the estimated changes in annual $PM_{2.5}$ DVs is shown in Figure 2A-36. Due to differences in the spatial distribution and magnitude of the emission changes in the sensitivity simulations and the EGU reductions, the $PM_{2.5}$ DV impacts are rough approximations, and photochemical modeling of the EGU reductions would be needed to provide better estimates.

Table 2A-16 SO_2 and NOx Emission Reductions from EGUs Expected Beyond 2032 Modeling Case by County

State	County	SO_2 (ton)	NOx (ton)
Connecticut	Hartford	385	1,101
Florida	Alachua	0	2
Florida	Hillsborough	1,328	414
Illinois	Christian	1,942	1,133
Illinois	Jasper	4,770	1,934
Illinois	Lake	1,024	933
Illinois	Massac	18,793	4,237
Illinois	Randolph	4,206	5,100
Illinois	Will	826	983
Indiana	LaPorte	1,289	1,441
Indiana	Spencer	35	19
Indiana	Warrick	766	442
Iowa	Des Moines	0	5
Iowa	Muscatine	1,039	1,308
Iowa	Winnebago	0	9
Louisiana	Ascension	0	147
Louisiana	Calcasieu	0	656
Louisiana	Pointe Coupee	4,225	1,149
Louisiana	Rapides	14,360	1,278
Maryland	Montgomery	0	14
Massachusetts	Middlesex	0	77
Michigan	Eaton	3,018	892
Michigan	Ottawa	6,799	3,343
Minnesota	Blue Earth	102	602
Minnesota	Cook	877	477
Minnesota	Goodhue	100	543
Missouri	Franklin	35,424	-
Missouri	Jasper	0	76
Missouri	Jefferson	37,421	3,286
New Jersey	Essex	0	11

State	County	SO_2 (ton)	NOx (ton)
New Jersey	Salem	0	8
New Mexico	Lea	0	3
New York	Queens	0	7
North Carolina	Cleveland	1,140	2,082
Ohio	Clermont	17,532	5,849
Ohio	Hamilton	3,663	6,127
Ohio	Lorain	3,799	1,437
Oklahoma	Osage	0	13
Pennsylvania	Allegheny	628	1,254
Pennsylvania	Bucks	0	39
Pennsylvania	Northampton	0	25
Pennsylvania	Somerset	0	16
South Dakota	Minnehaha	0	1
Tennessee	Stewart	720	527
Texas	Bexar	3,726	751
Texas	Dallas	0	59
Texas	El Paso	0	328
Texas	Orange	0	1,246
Texas	Pecos	0	4
Texas	Travis	0	15
Virginia	Dinwiddie	0	30
Wisconsin	Marathon	0	77
Wisconsin	Milwaukee	473	1,206

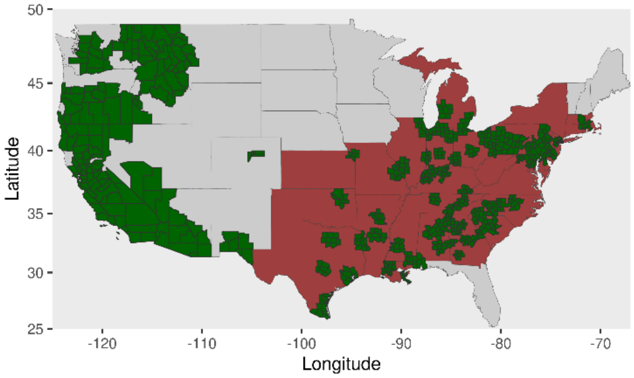

Figure 2A-35 $PM_{2.5}$ Counties with 50% Reductions of SO_2 Emissions in the 2028 CMAQ Sensitivity Simulations (Green) and Eastern States Considered in the EGU Sensitivity Analysis (Red)

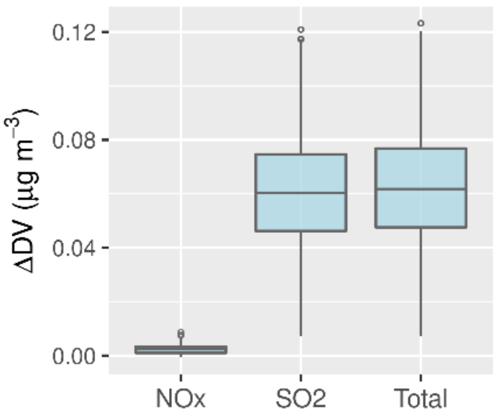

Figure 2A-36 Distributions of the Estimated Changes in Annual $PM_{2.5}$ DVs in the Eastern U.S. Associated with NOx and SO_2 EGU Emission Reductions in the Eastern US Beyond the 2032 Modeling Case

2A.5.3 Estimating the Local Influence of Additional SO_2 and NOx EGU Emission Reductions

In addition to estimating potential regional impacts of the additional SO_2 and NOx emissions reductions from EGUs, we considered the relatively local impacts of the reductions on DVs in nearby counties for two cases with large SO_2 reductions. In one case, the EGU emission reductions in Franklin and Jefferson, MO, and Randolph, IL were grouped to give a total of 77,100 tons of SO_2 and 8,390 tons of NOx emissions. To estimate the impact of these emission reductions, SO_2 and NOx air quality ratios for nearby counties were developed using the 2028 sensitivity modeling. The change in annual DV at sites within the relevant cluster of counties with emission reductions in the 2028 sensitivity modeling (Figure 2A-37) was calculated and divided by the change in emissions in that county group in the sensitivity modeling. This yielded an average annual air quality ratio for NOx of 0.002 $\mu g\ m^{-3}$ and for SO_2 of 0.006 $\mu g\ m^{-3}$ for estimating the impact of SO_2 and NOx emission reductions in the county group on the DVs in that group. Applying these ratios to the combined emission reductions in Franklin, Jefferson, and Randolph counties, yields an increment in the annual $PM_{2.5}$ DV of about 0.5 $\mu g\ m^{-3}$. The additional EGU emission reductions may have a DV impact of approximately this amount at the sites listed in Table 2A-17, although a better estimate could be provided through explicit photochemical modeling of the sources. The significance of these DV reductions in the context of meeting alternative standard levels is discussed in section 3.2.4.

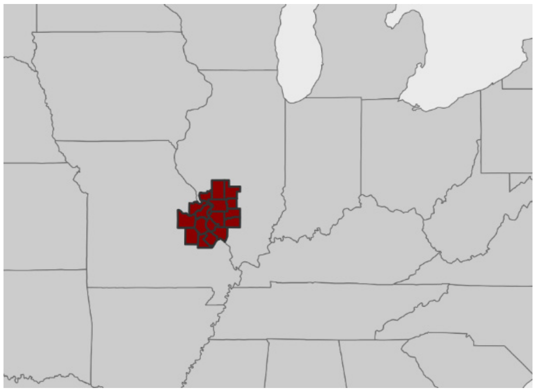

Figure 2A-37 **County Group in 2028 Sensitivity Modeling Used in Estimating the Response of DVs to EGU Emission Changes in Franklin and Jefferson, MO, and Randolph, IL**

Table 2A-17 **2032 $PM_{2.5}$ DVs and Estimated Influence of Emission Reductions from EGUs in Franklin and Jefferson, MO, and Randolph, IL on DVs in Nearby Counties**

Site ID	State	County	2032 Annual DV[a] ($\mu g\ m^{-3}$)	ΔDV Annual ($\mu g\ m^{-3}$)
171191007	Illinois	Madison	9.03	0.5
171630010	Illinois	Saint Clair	8.99	0.5
290990019	Missouri	Jefferson	8.51	0.5
291893001	Missouri	Saint Louis	8.82	0.5
295100085	Missouri	St. Louis City	8.36	0.5

[a] The 2032 DVs correspond to projections based on the CMAQ simulation of the 2032 emissions case (Section 2.2) without any additional DV adjustments.

In a second case, emission reductions in Clermont and Hamilton, OH were grouped to give a total of 21,190 tons of SO_2 and 11,980 tons of NOx. To estimate the impact of these reductions on DVs in nearby counties, the change in annual DV at sites within the relevant cluster of counties with emission reductions in the 2028 sensitivity modeling (Figure 2A-38) was calculated and divided by the change in emissions in that county group in the sensitivity modeling. This yielded an average annual air quality ratio for NOx of 0.003 μg m^{-3} and for SO_2 of 0.014 μg m^{-3} for estimating the impact of SO_2 and NOx emission reductions in the county group on the DVs in that group. Applying these ratios to the combined emission reductions in Clermont and Hamilton counties, yields an increment in the annual $PM_{2.5}$ DV of about 0.3 μg m^{-3}. The additional EGU emission reductions may have a DV impact of approximately this amount at the sites listed in Table 2A-18, although a better estimate could be provided through explicit photochemical modeling of the sources.

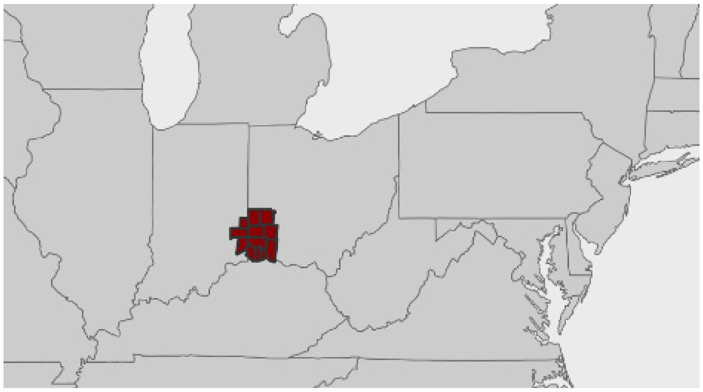

Figure 2A-38 County Group in 2028 Sensitivity Modeling Used in Estimating the Response of DVs to EGU Emission Changes in Clermont and Hamilton, OH

Table 2A-18 2032 $PM_{2.5}$ DVs and Estimated Influence of Emission Reductions from EGUs in Clermont and Hamilton, OH on DVs in Nearby Counties

Site ID	State	County	2032 Annual DV[a] (μg m^{-3})	ΔDV Annual (μg m^{-3})
390170022	Ohio	Butler	9.82	0.3
390610014	Ohio	Hamilton	8.91	0.3

[a] The 2032 DVs correspond to projections based on the CMAQ simulation of the 2032 emissions case (Section 2.2) without any additional DV adjustments.

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

Overview

The current annual primary $PM_{2.5}$ standard is 12 μg/m^3, and the current 24-hour standard is 35 μg/m^3. The Agency is proposing to revise the current annual $PM_{2.5}$ standard to a level within the range of 9-10 μg/m^3 and is soliciting comment on an alternative annual standard level down to 8 μg/m^3 and a level up to 11 μg/m^3. The Agency is also proposing to retain the current 24-hour standard of 35 μg/m^3 and is soliciting comment on an alternative 24-hour standard level of 25 μg/m^3. In this Regulatory Impact Analysis (RIA), we are analyzing the proposed annual and current 24-hour alternative standard levels of 10/35 μg/m^3 and 9/35 μg/m^3, as well as the following two more stringent alternative standard levels: (1) an 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) an alternative 24-hour standard level of 30 μg/m^3 in combination with the proposed annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). Because the EPA is proposing that the current secondary PM standards be retained, 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]

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 proposed 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 proposed and more stringent annual and 24-hour $PM_{2.5}$ alternative standard levels.[2] Because $PM_{2.5}$ concentrations are most responsive to direct 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 and the terrain is more complex, we only identified potential $PM_{2.5}$ emissions reductions within each county.

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[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 control measures. In this analysis, we developed a control strategy for each alternative standard level analyzed.

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 control measures to nonpoint (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 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 2016 and 2032, noting that over the period (1) NO_X emissions are projected to decrease by 3.8 million tons (40 percent), with the greatest reductions from mobile source and EGU emissions inventory sectors, and (2) SO_2 emissions are projected to decrease by 1 million tons (38 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. Further, Appendix 2A, Section 2A.5 includes a discussion of EGU NO_X, SO_2, and $PM_{2.5}$ emissions reductions that are expected to occur from *firm* retirements between 2016 and 2030; these reductions are beyond those included in the air quality modeling for this analysis. Lastly, Section 2A.5 includes a discussion of the potential influence of the reductions from these *firm* EGU retirements on future $PM_{2.5}$ design values (DVs) regionally in the east, as well as locally.

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, these counties would need additional $PM_{2.5}$ emissions reductions to meet 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 alternative 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 proposed 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. 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 $\mu g/m^3$ analytical baseline used in estimating the incremental costs and benefits associated with control strategies for the proposed 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 μg/m^3 (tons/year)

Area	12/35
Northeast	0
Southeast	0
West	2,298
CA	6,907
Total	9,205

Eighteen counties need $PM_{2.5}$ emissions reductions to meet the current standards in 2032 – 9 counties in California and 9 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 in Northern 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 proposed 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 alternative 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 alternative standard levels, we estimate $PM_{2.5}$ emissions reductions needed by county and then identify control technologies and measures 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 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

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[3] The 18 counties require primary PM emissions reductions to meet the current standards of 12/35 μg/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.

applying controls by area for the alternative standard levels analyzed. In Section 3.2.4, we discuss EGU emissions reductions from planned retirements and their potential influence in some areas. In Sections 3.2.5 and 3.2.6, we discuss areas with other types of influences affecting $PM_{2.5}$ 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. Sections 3.2.5 presents the emissions reductions still needed, and for each area Section 3.2.6 includes a qualitative discussion of the remaining area-specific air quality challenges. Appendix 3A, Tables 3A.2 through 3A.7 summarize estimated $PM_{2.5}$ emissions reductions by county for the 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 Alternative Standard Levels Analyzed

We apply regional $PM_{2.5}$ air quality ratios to estimate $PM_{2.5}$ DVs at air quality monitor locations and then again to estimate the emissions reductions needed to reach the proposed 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.

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[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.

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 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 alternative standard levels analyzed are listed in Table 2-1 in Chapter 2.) We estimated the emissions reductions needed to just meet the 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 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 each alternative standard level, Table 3-2 also includes an area's percent of the total estimated emissions reductions needed nationwide to reach that alternative standard level in all locations. For example, for the proposed standard level of 10/35 $\mu g/m^3$, California's 10,128 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 alternative standard levels analyzed.) Figure 3-2 shows the counties projected to exceed the annual and 24-hour 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

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

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 3-2 By Area, Summary of $PM_{2.5}$ Emissions Reductions Needed, in Tons/Year and as Percent of Total Reductions Needed Nationwide, for 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 $\mu g/m^3$ in 2032

Area	10/35	10/30	9/35	8/35
Northeast	1,068	1,221	6,996	30,843
Southeast	474	474	4,088	18,028
West	820	7,852	3,078	9,708
CA	10,128	12,230	17,750	28,293
Total	12,490	21,776	31,912	86,872

Area	10/35	10/30	9/35	8/35
Northeast	9%	6%	22%	36%
Southeast	4%	2%	13%	21%
West	7%	36%	10%	11%
CA	81%	56%	56%	33%

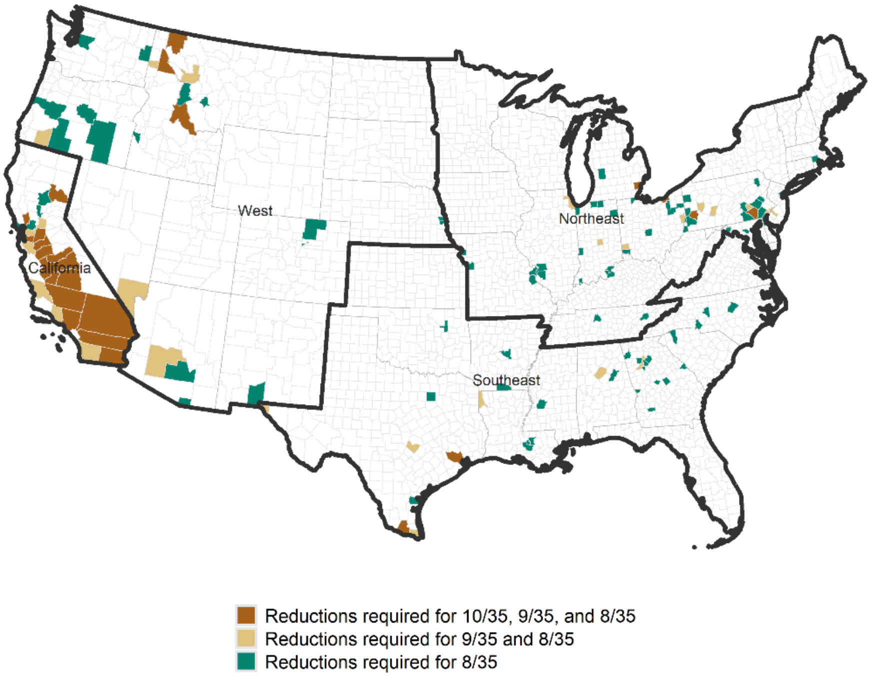

Figure 3-2 Counties Projected to Exceed in Analytical Baseline for Alternative Standard Levels of 10/35 $\mu g/m^3$, 9/35 $\mu g/m^3$, and 8/35 $\mu g/m^3$

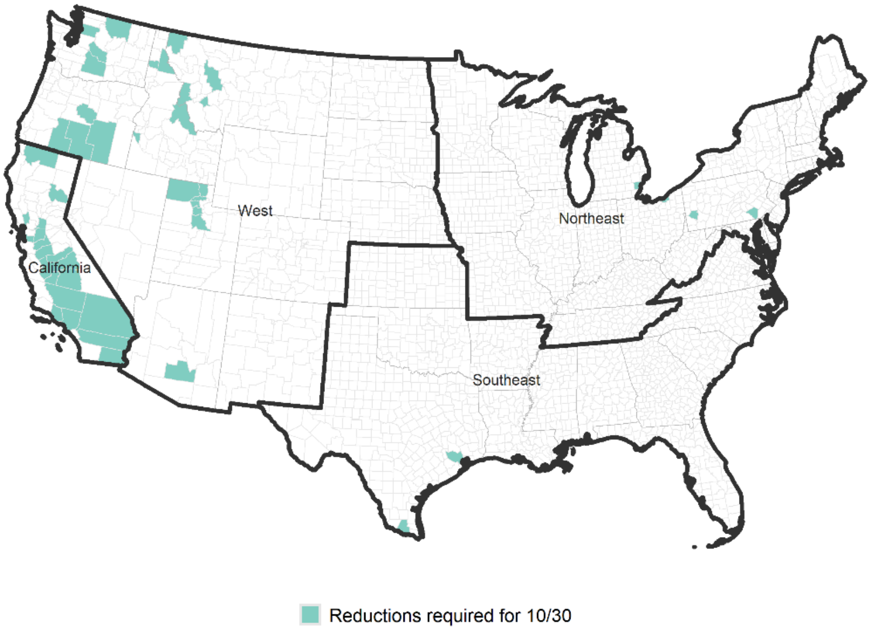

Figure 3-3 **Counties Projected to Exceed in Analytical Baseline for Alternative Standard Levels of 10/30 µg/m^3**

As presented previously, for each alternative standard level, 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 alternative standard level, in each geographic area that need $PM_{2.5}$ emissions reductions from the analytical baseline.

- 10/35 µg/m^3-- *24 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 2 counties in the southeast, 3 counties in the west, and 15 counties in California.
- 10/30 µg/m^3-- *47 counties* need $PM_{2.5}$ emissions reductions. This includes 4 counties in the northeast, 2 counties in the southeast, 23 counties in the west, and 18 counties in California.

- 9/35 μg/m^3 -- *51 counties* need $PM_{2.5}$ emissions reductions. This includes 14 counties in the northeast, 8 counties in the southeast, 8 counties in the west, and 21 counties in California.
- 8/35 μg/m^3 -- *141 counties* need $PM_{2.5}$ emissions reductions. This includes 57 counties in the northeast, 35 counties in the southeast, 24 counties in the west, and 25 counties in California.

3.2.2 Applying Control Technologies and Measures

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 154 counties in the analyses. The total number of counties below (154 counties) does not directly match the number of counties that would need emissions reductions for the more stringent alternative standard level of 8/35 μg/m^3 (141 counties) in Section 3.2.1 above. This difference is because there are thirteen counties that *do not* need $PM_{2.5}$ emissions reductions to meet alternative standard levels of 9/35 μg/m^3 and 8/35 μg/m^3 but *do* need $PM_{2.5}$ emissions reductions to meet an alternative standard level of 10/30 μg/m^3.

1. Northeast (57 counties) and Southeast (35 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. 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 μg/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 (36 counties) and California (26 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 control measures 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 control technologies or measures 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 control measures 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 measure 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

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[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 available upon request.

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

In some cases, more emissions reductions are selected by CoST than may be needed for some areas to meet the 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.

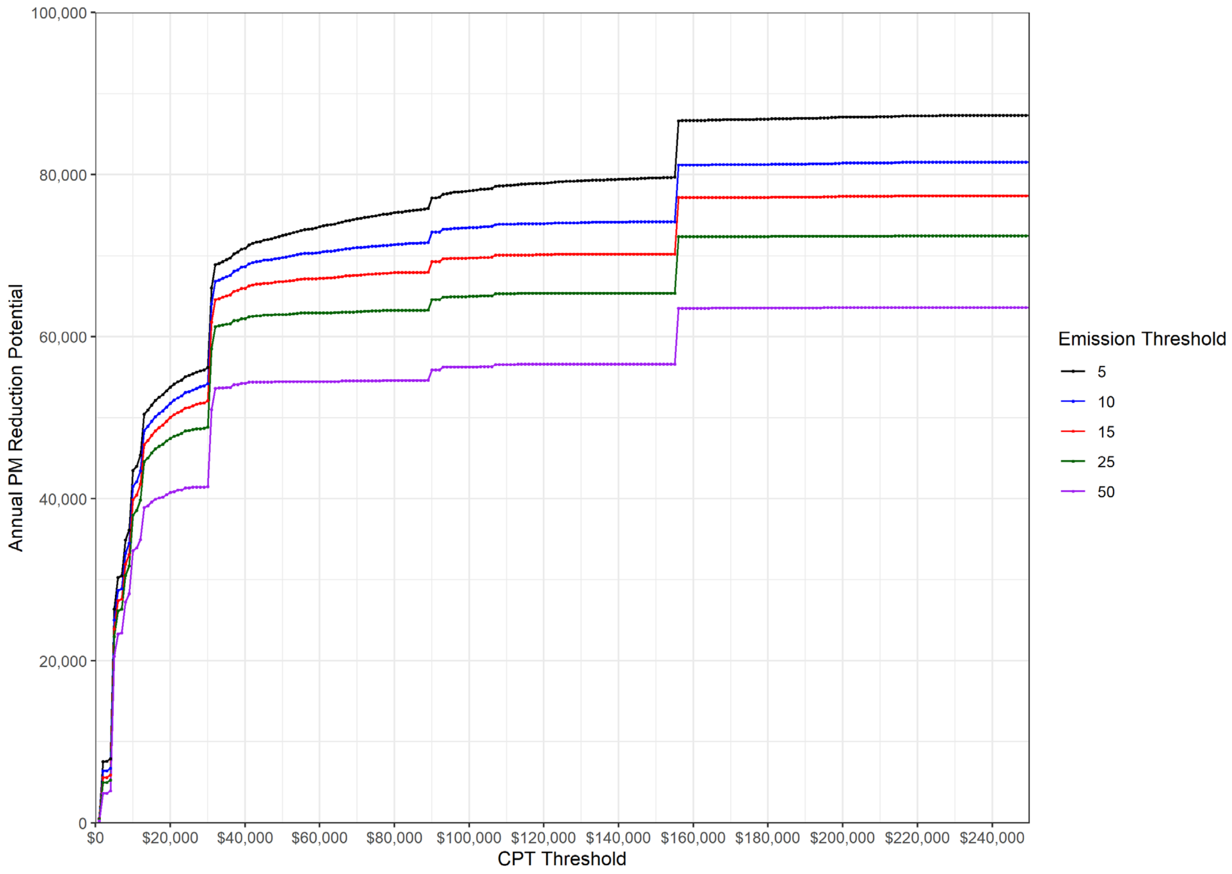

Figure 3-4 PM$_{2.5}$ Emissions Reductions and Costs Per Ton (CPT) in 2032 (tons, 2017$)

We identified control technologies and measures 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/m^3 and the 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 3-3 by emissions inventory sector, with an "X" indicating which control technologies were applied in analyzing each standard level. See Appendix 3A, Table 3A.1 for a more detailed presentation of control technologies applied for the alternative standard levels both by geographic area and by emissions inventory sector, as well as a discussion of some of the control measures.

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. Control measures 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 and road dust. (Also, see Appendix 2A, Section 2A.5 for a discussion of electric generating unit NO$_X$, SO$_2$, and PM$_{2.5}$ emissions reductions that are expected to occur between 2016 and 2030 beyond those included in the 2032 air quality modeling simulation for this analysis. These additional emissions reductions will result from planned EGU retirements that were not known when we developed the 2032 emissions projections.)

Table 3-3 By Inventory Sector, Control Measures Applied in Analyses of the Current Standards and the 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	x
	Fabric Filter-All Types	x	x	x	x	x
	Install new drift eliminator at 10% RP	x			x	x
	Install new drift eliminator at 25% RP	x	x	x	x	x
	Venturi Scrubber	x	x	x	x	x
Oil & Gas Point	Fabric Filter-All Types	x				x
	Install new drift eliminator at 25% RP					x
Non-Point (Area)	Add-on Scrubber at 25% RP		x	x		
	Annual tune-up at 10% RP			x	x	x
	Annual tune-up at 25% RP	x	x	x	x	x
	Biennial tune-up at 10% RP	x	x	x	x	x
	Biennial tune-up at 25% RP	x	x	x	x	x
	Catalytic oxidizers at 25% RP	x	x	x	x	x
	Electrostatic Precipitator at 10% RP				x	x
	Electrostatic Precipitator at 25% RP	x	x	x	x	x
	Fabric Filter-All Types				x	x
	HEPA filters at 10% RP		x	x	x	x
	HEPA filters at 25% RP		x		x	x
	Smokeless Broiler at 10% RP	x	x	x	x	x
	Smokeless Broiler at 25% RP				x	x
	Substitute chipping for burning	x	x	x	x	x
Residential Wood Combustion	Convert to Gas Logs at 25% RP	x	x	x	x	x
	EPA-certified wood stove at 10% RP					x
	EPA Phase 2 Qualified Units at 10% RP				x	x
	EPA Phase 2 Qualified Units at 25% RP		x	x		x
	Install Cleaner Hydronic Heaters at 10% RP			x		

Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
	Install Cleaner Hydronic Heaters at 25% RP	x	x	x	x	x
	Install Retrofit Devices at 10% RP	x			x	x
	Install Retrofit Devices at 25% RP		x	x		x
	New gas stove or gas logs at 10% RP	x	x	x	x	x
	New gas stove or gas logs at 25% RP	x	x	x	x	x
Area Source Fugitive Dust	Chemical Stabilizer at 10% RP		x	x	x	x
	Chemical Stabilizer at 25% RP	x			x	x
	Dust Suppressants at 10% RP					x
	Dust Suppressants at 25% RP					x
	Pave existing shoulders at 10% RP					x
	Pave existing shoulders at 25% RP	x	x	x	x	x
	Pave Unpaved Roads at 25% RP	x	x	x	x	x

Note: The 10% RP and 25% RP indicate the rule penetration (RP) percent, or the percent of the non-point (area), residential wood combustion, or area fugitive dust inventory emissions that the control measure is applied to at a specified percent control efficiency.

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

By area, Table 3-4 includes a summary of the estimated emissions reductions from control applications for the 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 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	1,070	1,222	6,334	19,142
Northeast (Adjacent Counties)	0	0	1,737	15,440
Southeast	475	475	3,040	12,212
Southeast (Adjacent Counties)	0	0	194	4,892
West	224	2,206	947	4,711
CA	1,792	2,481	2,958	4,925
Total	3,561	6,384	15,210	61,321

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 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 alternative standard levels analyzed, overall total emissions reductions are approximately 30 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 alternative standard levels analyzed, while additional reductions may be possible in some areas and different inventory sectors are selected for control in different 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 65 and 92 percent of total $PM_{2.5}$ emissions from the sources selected for control, with that percent increasing 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 15 and 19 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 21 and 23 percent across the alternative standard levels analyzed. It is worth noting that the control efficiencies associated with control measures for the non-point (area), area fugitive dust, and residential wood combustion sectors are generally lower than control efficiencies associated with control measures 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. As noted in Table 3-3, controls for emissions from these inventory sectors are applied to a percent of the relevant inventory (rule penetration) at a specified percent control efficiency. For the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 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 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 (tons/year)

Emissions Inventory Sector	10/35	10/30	9/35	8/35
Non-EGU Point				
PM2.5 Emissions	1,384	1,823	6,824	19,832
PM2.5 Emissions Reductions	901	1,326	6,035	18,289
Oil & Gas Point				
PM2.5 Emissions	0	0	0	83
PM2.5 Emissions Reductions	0	0	0	60
Non-Point (Area)				
PM2.5 Emissions	6,994	9,987	23,770	80,265
PM2.5 Emissions Reductions	1,771	2,572	6,269	27,352
Residential Wood Combustion				
PM2.5 Emissions	1,262	2,635	5,808	17,963
PM2.5 Emissions Reductions	296	556	1,276	4,193
Area Source Fugitive Dust				
PM2.5 Emissions	3,175	10,198	9,127	74,034
PM2.5 Emissions Reductions	593	1,930	1,630	11,427
Total				
PM2.5 Emissions	12,816	24,643	45,529	192,176
PM2.5 Emissions Reductions	3,561	6,384	15,210	61,321

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 alternative standard levels analyzed. Across alternative 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 21 and 40 percent of estimated reductions; (ii) non-point (area) inventory sector account for between 41 and 50 percent of estimated reductions; (iii) residential wood combustion inventory sector account for between 7 and 9 percent; and (iv) area fugitive dust inventory sector account for between 11 and 30 percent.

Also, across alternative standard levels analyzed, six control technologies and measures comprise between approximately 81 and 87 percent of the estimated emissions reductions. Those control technologies and measures 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 at 25% RP (non-point (area) inventory sector) – the control measure is applied to area source commercial cooking emissions.[8]
- Substitute Chipping for Burning (non-point (area) inventory sector) – the control measure is applied to area source waste disposal emissions.
- Convert to Gas Logs at 25% RP (residential wood combustion inventory sector) – the control measure is applied to area source residential wood combustion emissions.
- Pave Existing Shoulders at 25% RP (area fugitive dust inventory sector) – the control measure is applied to road dust emissions.
- Pave Unpaved Roads at 25% RP (area fugitive dust inventory sector) – the control measure is applied to road dust emissions.

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[8] RP indicates the rule penetration (RP) percent, or the percent of the non-point (area), residential wood combustion, or area fugitive dust inventory emissions that the control measure is applied to at a specified percent control efficiency.

The three control measures that result in the most emissions reductions for alternative standard levels of 10/35 µg/m^3, 9/35 µg/m^3, and 8/35 µg/m^3 are Fabric Filter- All Types, Electrostatic Precipitator at 25% RP, and Substitute Chipping for Burning. The three control measures that result in the most emissions reductions for alternative standard levels of 10/30 µg/m^3 are Fabric Filter- All Types, Substitute Chipping for Burning, and Pave Unpaved Roads at 25% RP. The 10% RP and 25% RP indicate the rule penetration (RP) percent, or the percent of the area source inventory emissions that the control measure is applied to at a specified percent control efficiency.

Table 3-6 Summary of Estimated Emissions Reductions from CoST by Inventory Sector and Control Technology for 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 (tons/year)

Inventory Sector	Control Technology	10/35	10/30	9/35	8/35
Non-EGU Point	Electrostatic Precipitator-All Types	16	0	27	20
	Fabric Filter-All Types	713	1,071	5,026	16,511
	Install new drift eliminator at 10% RP	0	0	5	2
	Install new drift eliminator at 25% RP	115	115	144	292
	Venturi Scrubber	56	139	833	1,464
Oil & Gas Point	Fabric Filter-All Types	0	0	0	55
	Install new drift eliminator at 25% RP	0	0	0	5
Non-Point (Area)	Add-on Scrubber at 25% RP	5	5	0	0
	Annual tune-up at 10% RP	0	1	1	1
	Annual tune-up at 25% RP	83	96	450	1,589
	Biennial tune-up at 10% RP	1	1	0	44
	Biennial tune-up at 25% RP	24	58	53	347
	Catalytic oxidizers at 25% RP	42	53	151	183
	Electrostatic Precipitator at 10% RP	0	0	11	1
	Electrostatic Precipitator at 25% RP	849	1,038	1,615	6,395
	Fabric Filter-All Types	0	0	77	199
	HEPA filters at 10% RP	0	1	1	2
	HEPA filters at 25% RP	1	0	6	27
	Smokeless Broiler at 10% RP	53	79	142	39
	Smokeless Broiler at 25% RP	0	0	411	177
	Substitute chipping for burning	712	1,240	3,351	18,349
Residential Wood Combustion	Convert to Gas Logs at 25% RP	219	369	805	2,446
	EPA-certified wood stove at 10% RP	0	0	0	1
	EPA Phase 2 Qualified Units at 10% RP	0	0	16	3
	EPA Phase 2 Qualified Units at 25% RP	15	20	0	66
	Install Cleaner Hydronic Heaters at 10% RP	0	1	0	0
	Install Cleaner Hydronic Heaters at 25% RP	22	42	285	901
	Install Retrofit Devices at 10% RP	0	0	12	6

Inventory Sector	Control Technology	10/35	10/30	9/35	8/35
	Install Retrofit Devices at 25% RP	11	11	0	9
	New gas stove or gas logs at 10% RP	3	54	45	86
	New gas stove or gas logs at 25% RP	25	58	111	675
Area Source Fugitive Dust	Chemical Stabilizer at 10% RP	22	71	42	1,524
	Chemical Stabilizer at 25% RP	0	0	52	1,488
	Dust Suppressants at 10% RP	0	0	0	0
	Dust Suppressants at 25% RP	0	0	0	126
	Pave existing shoulders at 10% RP	0	0	0	49
	Pave existing shoulders at 25% RP	200	611	769	4,854
	Pave Unpaved Roads at 25% RP	371	1,248	767	3,384
Total		3,561	6,384	15,210	61,321

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 alternative standard levels analyzed. As seen in Table 3-6, across alternative 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 21 and 40 percent of estimated reductions; (ii) non-point (area) inventory sector account for between 41 and 50 percent of estimated reductions; (iii) residential wood combustion inventory sector account for between 7 and 9 percent; and (iv) area fugitive dust inventory sector account for between 11 and 30 percent.

Across alternative standard levels analyzed, estimated $PM_{2.5}$ emissions reductions from control applications in the *Industrial Processes – Ferrous Metals*, *Industrial Processes – Not Elsewhere Classified*, and *Industrial Processes – Petroleum Refineries* inventory SCC sectors account for between 62 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 78 percent and 88 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 *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 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 (tons/year)

Sector	SCC Sector	10/35	10/30	9/35	8/35
Non-EGU Point	Agriculture - Livestock Waste	0	6.2	6.8	6.8
	Fuel Combustion - Commercial/Institutional Boilers - Biomass	0	0	0	15.6
	Fuel Combustion - Commercial/Institutional Boilers - Coal	0	0	8.0	8.0
	Fuel Combustion - Commercial/Institutional Boilers - Natural Gas	0	0	0	85.9
	Fuel Combustion - Commercial/Institutional Boilers - Other	64.7	64.7	64.7	69.8
	Fuel Combustion - Industrial Boilers, ICEs - Biomass	0	76.0	5.2	402.2
	Fuel Combustion - Industrial Boilers, ICEs - Coal	0	0	16.4	211.2
	Fuel Combustion - Industrial Boilers, ICEs - Natural Gas	6.1	75.4	81.7	405.8
	Fuel Combustion - Industrial Boilers, ICEs - Oil	0	0	0	18.1
	Fuel Combustion - Industrial Boilers, ICEs - Other	110.9	140.7	689.5	1,023.9
	Industrial Processes - Cement Manufacturing	0	0	89.8	688.5
	Industrial Processes - Chemical Manufacturing	29.3	40.3	136.5	953.8
	Industrial Processes - Ferrous Metals	142.8	150.1	836.0	2,378.0
	Industrial Processes - Mining	0	7.4	239.4	326.9
	Industrial Processes - Non-ferrous Metals	55.9	55.9	502.1	918.0
	Industrial Processes - Not Elsewhere Classified	304.3	456.1	2,169.9	6,818.0
	Industrial Processes - Petroleum Refineries	178.5	216.6	875.8	2,204.2
	Industrial Processes - Pulp & Paper	0	18.3	119.5	848.1
	Industrial Processes - Storage and Transfer	8.9	18.0	186.7	887.4
	Waste Disposal - Excavation/Soils Handling	0	0	0	5.8
	Waste Disposal - General Processes	0	0	7.0	7.0
	Waste Disposal - Landfill Dump	0	0	0	5.5
Oil & Gas Point	Industrial Processes - Not Elsewhere Classified	0	0	0	3.6
	Industrial Processes - Oil & Gas Production	0	0	0	54.9
	Industrial Processes - Petroleum Refineries	0	0	0	1.8

Sector	SCC Sector	10/35	10/30	9/35	8/35
Non-Point (Area)	Commercial Cooking	950.2	1,176.5	2,336.9	6,823.5
	Fuel Combustion - Commercial/Institutional Boilers - Biomass	16.3	20.2	52.8	258.6
	Fuel Combustion - Commercial/Institutional Boilers - Coal	0	0	0	0.5
	Fuel Combustion - Commercial/Institutional Boilers - Natural Gas	18.9	22.2	49.8	95.5
	Fuel Combustion - Commercial/Institutional Boilers - Oil	0	0	3.0	14.4
	Fuel Combustion - Industrial Boilers, ICEs - Biomass	66.0	103.3	345.0	1,499.0
	Fuel Combustion - Industrial Boilers, ICEs - Coal	0	2.4	17.8	39.1
	Fuel Combustion - Industrial Boilers, ICEs - Natural Gas	4.0	4.0	32.7	65.5
	Fuel Combustion - Industrial Boilers, ICEs - Oil	1.0	1.0	1.0	5.4
	Fuel Combustion - Industrial Boilers, ICEs - Other	2.0	2.0	2.0	2.0
	Industrial Processes - Chemical Manufacturing	0	0	77.4	199.1
	Waste Disposal - All Categories	603.2	880.0	2,641.3	14,623.5
	Waste Disposal - Residential	109.2	360.5	709.2	3,725.4
Residential Wood Combustion	Fuel Combustion - Residential - Wood	296.2	555.6	1,275.9	4,193.4
Area Source Fugitive Dust	Dust - Paved Road Dust	199.9	611.0	768.9	4,903.3
	Dust - Unpaved Road Dust	392.7	1,319.3	861.3	6,523.6
Total		3,561.0	6,383.7	15,210.0	61,320.7

3.2.4 Potential Influence of EGU Emissions Reductions from Planned Retirements

As indicated in Appendix 2A and the Overview section above, we did not apply controls and estimate emissions reductions and costs for EGUs; however, Appendix 2A, Section 2A.5 includes a discussion of EGU NO_X, SO_2, and $PM_{2.5}$ emissions reductions from planned EGU retirements that are expected to occur between 2016 and 2030 beyond those included in the air quality modeling for this analysis. Section 2A.5 discusses the potential influence of these EGU emissions reductions on $PM_{2.5}$ DVs in three ways – (i) local impact of the direct $PM_{2.5}$ emissions reductions from EGUs on DVs for counties with 2032 $PM_{2.5}$ DVs that exceed the alternative standard levels, (ii) regional impact of the total EGU SO_2 and

NO_X emissions reductions in the eastern U.S. on 2032 $PM_{2.5}$ DVs, and (iii) relatively local impact of the EGU NO_X and SO_2 emissions reductions on 2032 $PM_{2.5}$ DVs in nearby counties for two cases with large SO_2 reductions. The emissions reductions from the planned EGU retirements are not expected to have large impacts on $PM_{2.5}$ DVs in the areas that need emissions reductions in this analysis. We include brief discussions below; for more detailed discussions see Appendix 2A, Section 2A.5.

In assessing the local impact of direct $PM_{2.5}$ emissions reductions on DVs for counties with 2032 $PM_{2.5}$ DVs that exceed the alternative standard levels, ten counties had $PM_{2.5}$ reductions from the planned EGU retirements (see Table 2A-15). The direct $PM_{2.5}$ EGU emissions reductions from just three counties (out of the ten counties) account for 95 percent of these EGU $PM_{2.5}$ reductions from these ten counties. In these three counties, either emissions reductions were not needed for, or the control strategy analysis identified sufficient non-EGU emissions reductions for, the alternative standard levels of 10/35 $\mu g/m^3$, 10/30 $\mu g/m^3$, and 9/35 $\mu g/m^3$; in all three counties the control strategy analysis did not identify sufficient non-EGU reductions for an alternative standard level of 8/35 $\mu g/m^3$. If the EGU $PM_{2.5}$ emissions reductions from the planned retirements were directly included in the control strategy analyses, these reductions may have offset the need for some of the controls applied for all of the alternative standard levels. In particular, we note that for Hamilton County, Ohio, Jefferson County, Missouri, and Allegheny County, Pennsylvania, the planned retirements could offset the need for some of the other non-EGU controls identified in this analysis.

In assessing the regional impact of the total EGU NO_X and SO_2 emissions reductions (see Table 2A-16) on annual 2032 $PM_{2.5}$ DVs, across monitors in the eastern states the estimated median annual 2032 $PM_{2.5}$ DV change is 0.06 $\mu g/m^3$. See Figure 2A-36 for the distributions of annual 2032 $PM_{2.5}$ DV changes from the NO_X and SO_2 emissions reductions. Therefore, these NO_X and SO_2 emissions reductions from planned retirements could have a small impact on $PM_{2.5}$ DVs regionally across the eastern U.S. but are unlikely to have a substantial impact on the need for the additional non-EGU controls identified in this analysis.

For the areas with the largest SO_2 reductions expected near monitors with 2032 $PM_{2.5}$ DVs that exceed alternative standard levels, we combined the NO_X and SO_2 EGU emissions reductions from the relevant counties and estimated their impact on the annual 2032 $PM_{2.5}$ DVs. For one area, the EGU emissions reductions are estimated to impact the 2032 annual $PM_{2.5}$ DV at each of the five monitoring sites listed in Table 2A-17 by approximately 0.5 $\mu g/m^3$. For the other area, the emissions reductions are estimated to impact the 2032 annual $PM_{2.5}$ DV at the two monitoring sites listed in Table 2A-18 by approximately 0.3 $\mu g/m^3$. For a few counties in these two areas, the NO_X and SO_2 reductions could offset the need for some of the controls applied in the analysis, particularly for a standard level of 8/35 $\mu g/m^3$.

3.2.5 Estimates of $PM_{2.5}$ Emissions Reductions Still Needed after Applying Control Technologies and Measures

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 alternative 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 proposed alternative standard level of 10/35 $\mu g/m^3$, the northeast and southeast have sufficient *estimated* emissions reductions. For the west, the *estimated* emissions reductions are approximately 27 percent of the total needed, and for California the *estimated* emissions reductions are approximately 18 percent of the total needed.
- For the proposed alternative standard level of 9/35 $\mu g/m^3$, for the northeast we were able to identify approximately 97 percent of the reductions needed. For the southeast we were able to identify approximately 76 percent of the reductions needed. For the west, we were able to identify approximately 31

> percent of the reductions needed, and for California the percentage is approximately 17 percent.

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

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 proposed 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 alternative standards 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 alternative standards 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 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, 1 (out of 14) county needs additional emissions reductions to reach attainment of the proposed alternative standard level of 9/35 $\mu g/m^3$, and 22 (out of 57) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 8/35 μg/m^3. For the southeast, 2 (out of 8) counties need additional emissions reductions to reach attainment of the proposed alternative standard level of 9/35 μg/m^3, and 10 (out of 35) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 8/35 μg/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 alternative standard levels. For the west, 3 (out of 3) counties need additional emissions reductions to reach attainment of the proposed alternative standard level of 10/35 μg/m^3, 16 (out of 23) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 10/30 μg/m^3, 4 (out of 8) counties need additional emissions reductions to reach attainment of the proposed alternative standard level of 9/35 μg/m^3, and 8 (out of 24) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 8/35 μg/m^3. For California, 12 (out of 15) counties need additional emissions reductions to reach attainment of the proposed alternative standard level of 10/35 μg/m^3, 14 (out of 18) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 10/30 μg/m^3, 15 (out of 21) counties need additional emissions reductions to reach attainment of the proposed alternative standard level of 9/35 μg/m^3, and 21 (out of 25) counties need additional emissions reductions to reach attainment of the more stringent alternative standard level of 8/35 μg/m^3.

Table 3-8 Summary of PM$_{2.5}$ Emissions Reductions Still Needed by Area for the 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 (tons/year)

Region	10/35	10/30	9/35	8/35
Northeast	0	0	238	6,741
Southeast	0	0	994	4,780
West	595	5,651	2,132	5,023
CA	8,336	9,749	14,793	23,368
Total	8,931	15,400	18,157	39,912

Table 3-9 Summary of $PM_{2.5}$ Emissions Reductions Still Needed by Area and by County for the 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	Saint Clair County, IL	0	0	0	13
	Marion County, IN	0	0	0	390
	St. Joseph County, IN	0	0	0	207
	Vigo County, IN	0	0	0	63
	Wayne County, MI	0	0	0	286
	St. Louis City County, MO	0	0	0	77
	Camden County, NJ	0	0	0	608
	Union County, NJ	0	0	0	76
	New York County, NY	0	0	0	266
	Butler County, OH	0	0	0	410
	Cuyahoga County, OH	0	0	0	436
	Hamilton County, OH	0	0	0	36
	Jefferson County, OH	0	0	0	680
	Allegheny County, PA	0	0	0	382
	Armstrong County, PA	0	0	0	294
	Cambria County, PA	0	0	0	129
	Delaware County, PA	0	0	238	970
	Lancaster County, PA	0	0	0	600
	Lebanon County, PA	0	0	0	523
	Philadelphia County, PA	0	0	0	51
	Brooke County, WV	0	0	0	119
	Marshall County, WV	0	0	0	124
Southeast	Bibb County, GA	0	0	0	154
	Clayton County, GA	0	0	0	304
	Floyd County, GA	0	0	0	15
	Fulton County, GA	0	0	0	396
	Muscogee County, GA	0	0	0	265
	Caddo Parish, LA	0	0	0	359
	West Baton Rouge Parish, LA	0	0	0	55
	Cameron County, TX	0	0	427	1,244
	El Paso County, TX	0	0	0	603
	Hidalgo County, TX	0	0	567	1,385
West	Pinal County, AZ	0	272	0	0
	Santa Cruz County, AZ	0	0	0	431
	Denver County, CO	0	0	0	323
	Benewah County, ID	0	419	134	601
	Lemhi County, ID	3	575	471	939
	Shoshone County, ID	330	575	797	1,265
	Lewis and Clark County, MT	0	487	0	0
	Lincoln County, MT	262	262	730	1,197
	Ravalli County, MT	0	514	0	0
	Silver Bow County, MT	0	0	0	148
	Crook County, OR	0	352	0	0
	Harney County, OR	0	0	0	119
	Lake County, OR	0	575	0	0

Area	Area Name	10/35	10/30	9/35	8/35
	Cache County, UT	0	29	0	0
	Davis County, UT	0	1	0	0
	Salt Lake County, UT	0	413	0	0
	Weber County, UT	0	7	0	0
	Kittitas County, WA	0	575	0	0
	Okanogan County, WA	0	22	0	0
	Yakima County, WA	0	575	0	0
CA	Alameda County, CA	0	0	0	175
	Fresno County, CA	192	253	509	826
	Imperial County, CA	1,701	1,701	2,551	3,402
	Kern County, CA	634	634	951	1,268
	Kings County, CA	634	634	951	1,268
	Los Angeles County, CA	542	542	1,393	2,243
	Madera County, CA	67	67	384	702
	Merced County, CA	136	136	453	770
	Napa County, CA	0	0	300	617
	Plumas County, CA	176	502	493	810
	Riverside County, CA	1,701	1,701	2,551	3,402
	Sacramento County, CA	0	0	0	168
	San Bernardino County, CA	1,701	1,701	2,551	3,402
	San Diego County, CA	0	0	0	337
	San Joaquin County, CA	0	0	161	478
	San Luis Obispo County, CA	0	0	59	376
	Siskiyou County, CA	0	43	0	0
	Solano County, CA	0	0	0	167
	Stanislaus County, CA	218	218	535	852
	Sutter County, CA	0	0	0	56
	Tulare County, CA	634	634	951	1,268
	Ventura County, CA	0	983	0	783
Total		8,931	15,400	18,157	39,912

Note: The table includes only those counties that still need reductions (e.g., in the Northeast there were 57 counties that needed emissions reductions, and only the 22 counties still need emissions reductions for an alternative standard level of 8/35 μg/m^3).

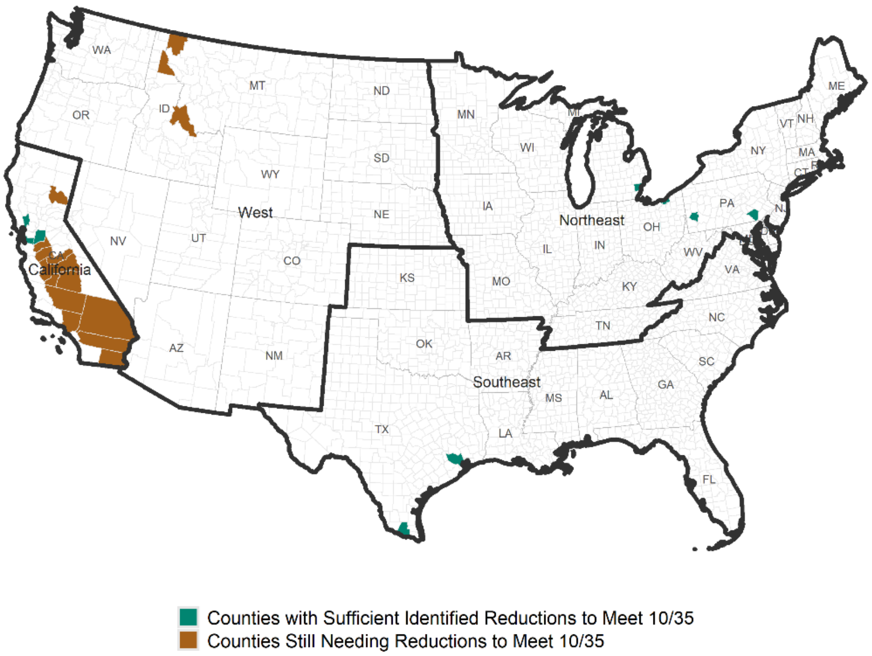

Figure 3-5 Counties that Still Need PM2.5 Emissions Reductions for Proposed Alternative Standard Level of 10/35 µg/m^3

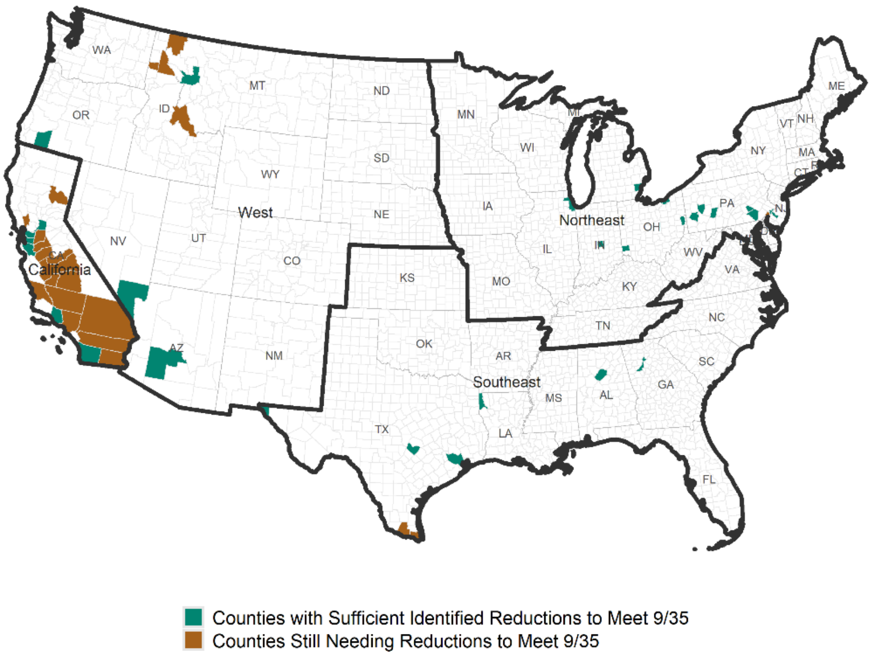

Figure 3-6 Counties that Still Need PM2.5 Emissions Reductions for Proposed Alternative Standard Level of 9/35 µg/m^3

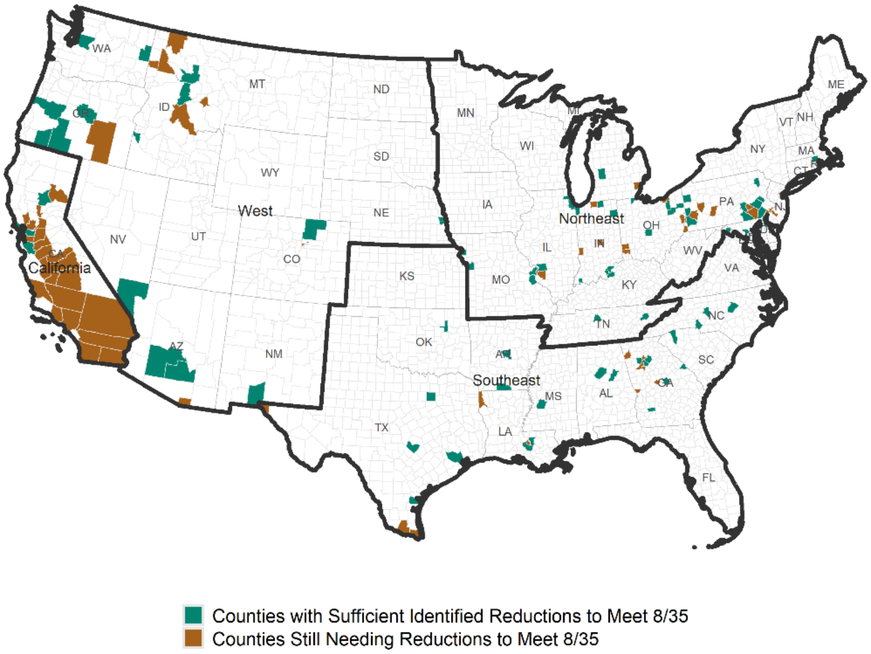

Figure 3-7 Counties that Still Need $PM_{2.5}$ Emissions Reductions for More Stringent Alternative Standard Level of 8/35 $\mu g/m^3$

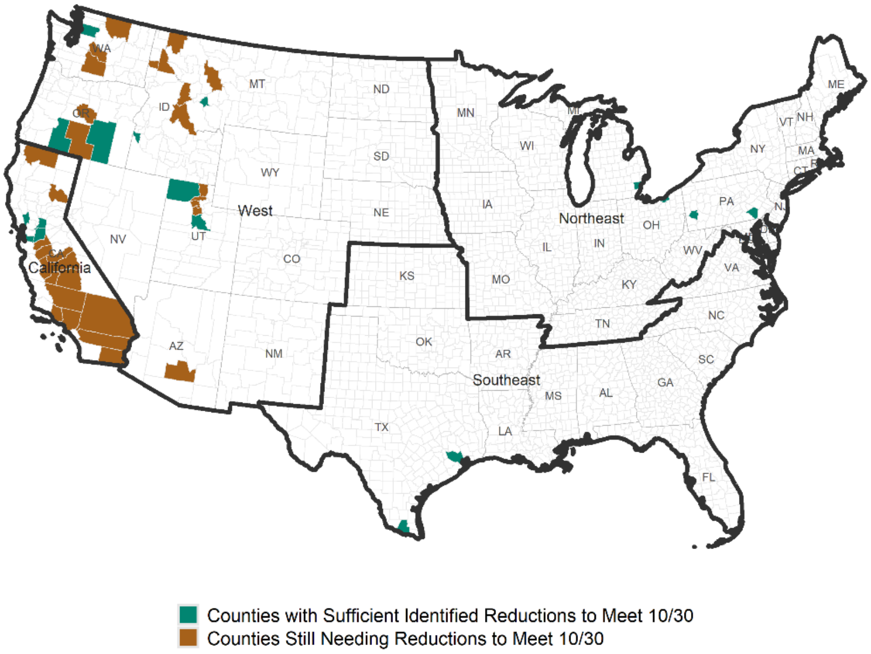

Figure 3-8 Counties that Still Need $PM_{2.5}$ Emissions Reductions for More Stringent Alternative Standard Level of 10/30 $\mu g/m^3$

3.2.6 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 proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$; the areas include a county in Pennsylvania potentially affected by local sources, 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 local source-to-monitor impacts, 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 proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$, we group counties into the following "bins": Delaware County, Pennsylvania, border areas, small mountain valleys, and California areas. By bin, Table 3-10 below summarizes the counties that need additional emissions reductions for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$.

Table 3-10 Summary of Counties by Bin that Still Need Emissions Reductions for Proposed Alternative Primary Standard Levels of 10/35 μg/m^3 and 9/35 μg/m^3

Bin	Area	Counties[a] for 10/35 mg/m^3	Additional Counties[a] for 9/35 mg/m^3
Delaware County, Pennsylvania	Northeast	--	Delaware County, PA
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	Benewah County, ID
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) Riverside County, CA (SCAQMD) San Bernardino County, CA (SCAQMD) Stanislaus County, CA (SJVAPCD) Tulare County, CA (SJVAPCD)	Napa County, CA (BAAQMD) San Joaquin County, CA (SJVAPCD) San Luis Obispo 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 have no identified PM$_{2.5}$ emissions reductions because available controls were applied for the current standard of 12/35 μg/m^3 and additional controls were not available: Imperial, Kern, Kings, Lemhi, Plumas, Riverside, San Bernardino, Shoshone, and Tulare.

3.2.6.1 Delaware County, Pennsylvania (Northeast)

As shown in Table 3-9 above, the analysis indicates that counties in the northeast do not need additional emissions reductions for the proposed alternative standard level of 10/35 μg/m^3; Delaware County, Pennsylvania county needs additional emissions reductions for the proposed alternative standard level of 9/35 μg/m^3.

In analyzing the proposed alternative standard level of 9/35 μg/m^3, we estimated Delaware County would need 673 tons of PM$_{2.5}$ emissions reductions.[9] The control strategy analysis identified 277 tons of reductions within Delaware County from the application of several controls, including a potential control at one of the facilities adjacent to a monitor.[10]

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

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

Some additional control applications within Delaware County included: Electrostatic Precipitator at 25% RP applied to commercial cooking emissions in the non-point (area) inventory sector; Pave Existing Shoulders at 25% RP 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 at 25% RP and New Gas Stove or Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector.

To analyze the 396 tons of $PM_{2.5}$ emissions reductions still needed, we identified 633 tons of $PM_{2.5}$ emissions reductions from adjacent counties[11], which is the equivalent of 158 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 238 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Delaware 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, Philadelphia County and Montgomery County, which are adjacent to Delaware County, have 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 discuss a monitor located on the property of Evonik Degussa Corporation in Delaware County, Pennsylvania. The state, in their *Commonwealth of Pennsylvania Department of Environmental Protection 2018 Annual Ambient Air Monitoring Network Plan,* concluded that local emissions sources are impacting this monitor (Chester monitor) based on comparisons of $PM_{2.5}$ concentrations from the Chester monitor and a monitor approximately 2.5 miles away (Marcus Hook monitor). The EPA's 2032 DV projections are consistent with a local source influence on the Chester monitor. It is possible that controls applied in the illustrative control strategy analysis at one of the facilities adjacent to the Chester monitor might result in sufficient emissions reductions for

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

the proposed alternative standard level of 9/35 μg/m^3 at that monitor because $PM_{2.5}$ concentrations are more responsive to primary $PM_{2.5}$ emission reductions located close to a monitor. However, specifically quantifying the impacts of the CoST-recommended control at one of the facilities adjacent to the Chester monitor would require a more detailed local analysis. In addition, the CoST-recommended control may not be applicable if the underlying emissions inventory did not accurately reflect existing controls at the facility adjacent to the Chester monitor.

3.2.6.2 Border Areas (Southeast, California)

As shown in Table 3-9 above, the analysis indicates that counties in the southeast do not need additional emissions reductions for the proposed alternative standard level of 10/35 μg/m^3; Cameron County and Hidalgo County, Texas need additional emissions reductions for the proposed alternative standard level of 9/35 μg/m^3.

We estimated Cameron County would need 581 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 148 tons of reductions within Cameron County from the application of several controls.[12] The control applications within Cameron County included: Electrostatic Precipitator at 25% RP applied to commercial cooking emissions in the non-point (area) inventory sector; Pave Existing Shoulders at 25% RP and Pave Unpaved Roads at 25% RP applied to road dust emissions in the area fugitive dust inventory sector; Convert to Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector.

To analyze the 433 tons of $PM_{2.5}$ emissions reductions still needed, we identified 22 tons of $PM_{2.5}$ emissions reductions from adjacent counties[13], which was the equivalent of 5.5 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 427 tons of $PM_{2.5}$

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

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

emissions reductions still needed. As shown in Table 3A-8, Cameron County has area fugitive dust *(afdust)*, point source agriculture fire (*ptagfire*), 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 1,022 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 406 tons of reductions within Hidalgo County from the application of several controls.[14] Some of the control applications within Hidalgo County included: Electrostatic Precipitator at 25% RP applied to commercial cooking 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 at 25% RP and Pave Unpaved Roads at 25% RP applied to road dust emissions in the area fugitive dust inventory sector; Convert to Gas Logs at 25% RP and New Gas Stove or Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector.

To analyze the 616 tons of $PM_{2.5}$ emissions reductions still needed, we identified 194 tons of $PM_{2.5}$ emissions reductions from adjacent counties[15], which was the equivalent of 48.5 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 567 tons of $PM_{2.5}$ emissions reductions still needed. As shown in Table 3A-8, Hidalgo County has area fugitive dust *(afdust)*, point source agriculture fire (*ptagfire*), non-point (area) (*nonpt*), non-point source oil and gas (*np_oilgas*), non-electric generating unit point source (*ptnonipm)*, point source oil and gas (*pt_oilgas*), and residential wood combustion (*rwc*) emissions remaining

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

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

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 proposed alternative standard level of 9/35 $\mu g/m^3$ 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 2016 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 2016 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 2016 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 are 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 did not identify any emissions reductions from the application of controls.[16] As shown in Table 3A-8, Imperial County has area fugitive dust *(afdust)*, non-point (area) (*nonpt*), non-electric generating unit point source (*ptnonipm)*, point source agriculture fire (*ptagfire*), 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

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[16] As shown in Table 3A-8, for Imperial, CA, CoST identified controls to apply toward the current standard of 12/35 $\mu g/m^3$. Additional controls were not available for the proposed or more stringent alternative standard levels.

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 (12.45 $\mu g/m^3$, 9.13 $\mu g/m^3$, and 8.02 $\mu g/m^3$, 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 proposed alternative 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 is needed.[17]

3.2.6.3 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 3-11 below summarizes the estimated $PM_{2.5}$ emissions reductions needed and emissions reductions identified by CoST for each of these counties for the proposed alternative standard level of 9/35 $\mu g/m^3$.

Table 3-11 Summary of Estimated $PM_{2.5}$ Emissions Reductions Needed and Emissions Reductions Identified by CoST for the West for the Proposed Primary Standard Level of 9/35 $\mu g/m^3$ in 2032 (tons/year)

County/State	$PM_{2.5}$ Emissions Reductions Needed	In-County $PM_{2.5}$ Emissions Reductions Identified by CoST
Plumas, CA	493.2	0
Benewah, ID	266.6	132.8
Lemhi, ID	471.0	0
Shoshone, ID	797.4	0
Lincoln, MT	954.0	224.2

Note: As shown in Table 3A-8, for Plumas, CA and Lemhi and Shoshone, ID, CoST identified controls to apply toward the current standard of 12/35 $\mu g/m^3$. Additional controls in those counties were not available for the proposed or more stringent alternative standard levels.

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[17] 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.

As shown in Table 3-11, the control strategy analysis identified emissions reductions for two of the counties. Some of the control applications in those counties included: Pave Existing Shoulders at 25% RP and Pave Unpaved Roads at 25% RP applied to road dust emissions in the area fugitive dust inventory sector; Install Cleaner Hydronic Heaters at 25% RP and New Gas Stove or Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) 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)*, 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 2-17). 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 2-18 and 2-19 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 control measure 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 proposed standard levels, more detailed analyses that include local $PM_{2.5}$ response factors, emissions estimates, and controls for each local area are 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.[18] We performed sensitivity projections to assess the potential for wildfire impacts. These projections suggest that Benewah County, Oregon may be largely affected by wildfires and that annual 2032 DVs in Lemhi County and Shoshone County, Oregon, and Lincoln County, Montana could be much lower if detailed analyses resulted in additional data exclusion. Detailed local analyses are 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.

3.2.6.4 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 all of the 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 proposed alternative standard level of 9/35 $\mu g/m^3$, the District needed 5,636 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis

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[18] 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 (Chapter 2, Section 2.2.2).

identified 741 tons of reductions from the application of several controls.[19] Some of the control applications included: Electrostatic Precipitator at 25% RP applied to commercial cooking 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 at 25% RP and Pave Unpaved Roads at 25% RP applied to road dust emissions in the area fugitive dust inventory sector; Convert to Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) 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 2-23); wildfire emissions also influence $PM_{2.5}$ concentrations.

Specific, local information on control measures to reduce emissions from agricultural dust and burning and prescribed burning is needed given the magnitude of emissions from these sources. In addition, more detailed analyses are 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.

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

In the SCAQMD, in analyzing the proposed alternative standard level of 9/35 μg/m^3, the District needed 7,654 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 1,159 tons of reductions from the application of several controls.[20] Some of the control applications included: Electrostatic Precipitator at 25% RP applied to commercial cooking 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; Convert to Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) 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 2-26).

Specific, local information on control measures to reduce emissions from many of the non-point (area) emissions sources (e.g., commercial and residential cooking) is needed given the magnitude of emissions from these sources. In addition, more detailed analyses are 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 proposed alternative standard level of 9/35 μg/m^3, the District needed 884 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis

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

identified 586 tons of reductions from the application of several controls.[21] Some of the control applications included: Smokeless Broiler at 25% RP, Catalytic Oxidizers at 25% RP, and Electrostatic Precipitator at 25% RP applied to commercial cooking emissions in the non-point (area) inventory sector; Fabric Filter – All Types and Venturi Scrubber applied to industrial, commercial, and institutional boilers and industrial processes in the non-EGU point inventory sector; Pave Existing Shoulders at 25% RP and Pave Unpaved Roads at 25% RP applied to road dust emissions in the area fugitive dust inventory sector; Convert to Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied to waste disposal emissions in the non-point (area) inventory sector. We did not attempt to identify additional $PM_{2.5}$ emissions reductions in adjacent counties or air districts.

As discussed in Chapter 2, Section 2.4.4, $PM_{2.5}$ concentrations in Napa County may have relatively large contributions from local emissions sources, as well as contributions from wildfires and sources in nearby regions including the BAAQMD and the SJVAPCD. In addition, previous research reported that modeled concentrations of carbonaceous $PM_{2.5}$ at the monitor in Napa County were underestimated. The research suggested that carbonaceous $PM_{2.5}$ emissions, possibly from wood burning, may have been strongly underrepresented in the Napa County emissions inventory. Additional work to develop local emissions inventories and identify appropriate controls is needed.

In San Luis Obispo County APCD, in analyzing the proposed alternative standard level of 9/35 $\mu g/m^3$, the District needed 187 tons of $PM_{2.5}$ emissions reductions. The control strategy analysis identified 128 tons of reductions from the application of several controls.[22] The control applications included: Electrostatic Precipitator at 25% RP applied to commercial cooking emissions in the non-point (area) inventory sector; Fabric Filter – All Types applied to industrial processes in the non-EGU point inventory sector; Convert to Gas Logs at 25% RP applied to area source residential wood combustion emissions in the residential wood combustion inventory sector; and Substitute Chipping for Burning applied

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

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

to waste disposal emissions in the non-point (area) inventory sector. We did not attempt to identify additional $PM_{2.5}$ emissions reductions in adjacent counties or air districts.

As discussed in Chapter 2, Section 2.4.4, in recent years the $PM_{2.5}$ DVs have decreased at the monitor in San Luis Obispo County APCD -- the annual $PM_{2.5}$ DVs for the 2018-2020 and 2019-2021 periods are 8.0 and 7.7 $\mu g/m^3$, respectively (Chapter 2, Figure 2-28). The projected 2032 annual DV (9.63 $\mu g/m^3$) at the monitor is based on data from the 2014-2018 period and does not capture these recent air quality improvements. Based on the data for these two most recent DV periods, the monitor may not need additional emissions reductions for the proposed alternative standard level of 9/35 $\mu g/m^3$.

3.3 Limitations and Uncertainties

The EPA's analysis is based on its best judgment for various input assumptions that are uncertain. As a general matter, the Agency selects the best available information from engineering studies of air pollution controls and has set up what it believes is the most 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. In the following, we summarize the limitations and uncertainties that are most significant.

- **Illustrative control strategy:** A control strategy is the set of control measures or actions that States may take to meet a standard, such as which industries should be required to install end-of-pipe controls or certain types of equipment and technology. The illustrative control strategy analyses in this RIA present only one potential pathway for controlling emissions. The control strategies are not recommendations for how a revised $PM_{2.5}$ NAAQS should be implemented, and States will make all final decisions regarding implementation strategies for a revised NAAQS. We do not presume that the controls presented in this RIA are an exhaustive list of possibilities for emissions reductions.

- **Emissions inventories and air quality modeling:** These serve as a foundation for the projected $PM_{2.5}$ DVs, control strategies, and estimated costs in this analysis and thus limitations and uncertainties for these inputs impact the results, especially for issues such as future year emissions projections and information on controls currently in place at many sources. Limitations and uncertainties for these inputs are discussed in previous chapters. In addition, there are factors that affect emissions, such as economic growth and the makeup of the economy that introduce additional uncertainty.

- **Projecting level and geographic scope of exceedances:** Estimates of the geographic areas that would exceed alternative standard levels in a future year, and the level to which those areas would exceed, are approximations based on several factors. The actual nonattainment determinations that would result from a revised NAAQS will likely depend on the consideration of local issues, changes in source operations between the time of this analysis and implementation of a new standard, and changes in control technologies over time.
- **Assumptions about the baseline:** There is significant uncertainty about the illustration of the impact of rules on the baseline. In addition, the February 2022 *Proposed Federal Implementation Plan Addressing Regional Ozone Transport for the 2015 Ozone National Ambient Air Quality Standard* and the *firm* EGU retirements are not included in the 2032 projections.
- **Applicability of control measures:** The applicability of a control measure 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. The applicability of control measures to area sources is also subject to the uncertainty of the area source emissions estimated.
- **Control measure advances over time:** The control measures applied do not reflect potential effects of technological change that may be available in future years. All estimates of impacts associated with control measures applied

reflect our current knowledge, and not projections, of the measures' effectiveness or costs.

- **Pollutants to be targeted:** Local knowledge of atmospheric chemistry in each geographic area may result in a different prioritization of pollutants for potential control.

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 proposed and more stringent alternative annual and 24-hour standard levels -- 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 additional information about the control technologies and measures that were applied, as well as additional details on the estimated $PM_{2.5}$ emissions reductions.

3A.1 Types of Control Measures

Several types of control measures were applied in the analyses for the analytical baseline and alternative standard levels. We identified control measures 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 control technologies and measures is below.

3A.1.1 PM Control Measures 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 $PM_{2.5}$ control technologies 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.

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[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 Control Measures 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. Control measures for non-point sources are applied to the county level emissions. Several control measures 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, and paving existing shoulders to suppress paved road dust.

3A.2 EGU Trends Reflected in EPA's Integrated Planning Model (IPM) v6 Platform, Summer 2021 Reference Case Projections

The EPA's Integrated Planning Model (IPM) v6 Platform Summer 2021 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 Summer 2021 Reference Case is below. This version features bottom-up comprehensive input data and assumption updates[3], including the following:

- Demand – Annual Energy Outlook (AEO) 2020
- Gas Market Assumptions – Updated as of September 2020
- Coal Market Assumptions – Updated as of September 2020
- Cost and Performance of Fossil Generation Technologies – AEO 2020
- Cost and Performance of Renewable Energy Generation Technologies – National Renewable Energy Lab Annual Technology Baseline 2020 mid-case
- Nuclear Unit Operational Costs – AEO 2020 with some adjustments
- Environmental Rules and Regulations (On-the-Books) -- Revised Cross-State Air Pollution Rule, Mercury and Air Toxics Standard, 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), State Rules
- Financial Assumptions – Based on 2016-2020 data, reflects tax credit extensions from Consolidated Appropriations Act of 2021

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[2] Documentation of the Summer 2021 Reference Case and the corresponding results are available at https://www.epa.gov/power-sector-modeling/epas-power-sector-modeling-platform-v6-using-ipm-summer-2021-reference-case.

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

- Transmission – Updated data with build options
- Retrofits – carbon capture and storage option for combined cycles
- 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 Summer 2021

The Summer 2021 Reference Case projections show a gradual 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 increase in actual projects reflected in NEEDS prior to the IPM projections; long-term increase is largely driven by improved renewable energy technology costs.

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.

3A.3 Applying Control Technologies and Measures

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

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

Table 3A-2 through Table 3A-7 include detailed summaries of $PM_{2.5}$ emissions reductions by county for the 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 (57 counties) and the adjacent counties (75 counties), for the alternative standard levels of 10/35 $\mu g/m^3$ and 10/30 $\mu g/m^3$, controls were applied in 4 counties and no additional emissions reductions were needed in adjacent counties. For the alternative standard level of 9/35 $\mu g/m^3$, we estimated a total of 8,701 tons of $PM_{2.5}$ emission reductions available from the application of controls – approximately 78 percent of that total is available from within a county and 22 percent is from an adjacent county. For the alternative standard level of 8/35 $\mu g/m^3$, we estimated a total of 34,582 tons of $PM_{2.5}$ emission reductions – approximately 55 percent of that total is available from within a county and 45 percent is from an adjacent county.

As shown in Table 3A-4 and Table 3A-5 for the southeast counties (35 counties) and the adjacent counties (32 counties), for the alternative standard levels of 10/35 $\mu g/m^3$ and 10/30 $\mu g/m^3$, controls were applied in two counties and no additional emissions reductions were needed in adjacent counties. For the alternative standard level of 9/35 $\mu g/m^3$, we estimated a total of 3,235 tons of $PM_{2.5}$ emission reductions – approximately 94 percent of that total is available from the application of controls from within a county and six percent is from an adjacent county. For the alternative standard level of 8/35 $\mu g/m^3$, we estimated a total of 17,104 tons of $PM_{2.5}$ emission reductions – approximately 71 percent of that total is available from within a county and 29 percent is from an adjacent county.

As shown in Table 3A-6 for the west (36 counties), for the alternative standard level of 10/35 $\mu g/m^3$ controls were applied in one county. For the alternative standard level of 10/30 $\mu g/m^3$ controls were applied in 18 counties; for the alternative standard level of 9/35 $\mu g/m^3$ controls were applied in six counties; and for the alternative standard level of 8/35 $\mu g/m^3$ controls were applied in 22 counties.

As shown in Table 3A-7 for California (26 counties) of the eight counties in the San Joaquin Valley Air Pollution Control District, we estimated that five need $PM_{2.5}$ emissions reductions. For four counties, we identified some emissions reductions available for an alternative standard level of 10/35 μg/m^3 and no additional emissions reductions for lower alternative standard levels. For one county, we identified some emissions reductions available for an alternative standard level of 10/35 μg/m^3 and additional reductions available for an alternative standard level of 9/35 μg/m^3. Of the four counties in the South Coast Air Quality Management District, we estimated that three need emissions reductions. For two counties we did not identify any emissions reductions from the application of controls for any of the alternative standard levels. For one county, we identified some emissions reductions available for an alternative standard level of 10/35 μg/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 alternative standard levels being 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., Pinal County, AZ).

The table is intended to present information about potential nearby emissions reductions that might be available to help counties attain an 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, Control Measures Applied in Analyses of the Current Standards 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		x	
		Fabric Filter-All Types		x	x	x	x
		Install new drift eliminator at 25% RP				x	x
		Venturi Scrubber		x	x	x	x
	Non-Point (Area)	Annual tune-up at 10% RP					x
		Annual tune-up at 25% RP		x	x	x	x
		Biennial tune-up at 10% RP		x	x		x
		Biennial tune-up at 25% RP		x	x	x	x
		Catalytic oxidizers at 25% RP		x	x	x	x
		Electrostatic Precipitator at 10% RP				x	
		Electrostatic Precipitator at 25% RP		x	x	x	x
		HEPA filters at 10% RP		x	x		x
		HEPA filters at 25% RP		x		x	x
		Smokeless Broiler at 10% RP					x
		Smokeless Broiler at 25% RP				x	x
		Substitute chipping for burning		x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs at 25% RP		x	x	x	x
		EPA-certified wood stove at 10% RP					x
		EPA Phase 2 Qualified Units at 10% RP				x	x
		EPA Phase 2 Qualified Units at 25% RP					x
		Install Cleaner Hydronic Heaters at 25% RP		x	x	x	x
		Install Retrofit Devices at 10% RP				x	x
		Install Retrofit Devices at 25% RP					x
		New gas stove or gas logs at 10% RP		x	x		x
		New gas stove or gas logs at 25% RP		x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer at 10% RP					x
		Chemical Stabilizer at 25% RP				x	x
		Dust Suppressants at 10% RP					x
		Pave existing shoulders at 10% RP					x
		Pave existing shoulders at 25% RP				x	x
		Pave Unpaved Roads at 25% RP				x	x
Northeast (Adjacent Counties)	Non-EGU Point	Fabric Filter-All Types				x	x
		Install new drift eliminator at 25% RP				x	x
		Venturi Scrubber				x	x
	Oil & Gas Point	Fabric Filter-All Types					x
	Non-Point (Area)	Annual tune-up at 25% RP				x	x
		Biennial tune-up at 10% RP				x	
		Biennial tune-up at 25% RP				x	x
		Catalytic oxidizers at 25% RP					x
		Electrostatic Precipitator at 25% RP				x	x
		Fabric Filter-All Types				x	x
		Smokeless Broiler at 10% RP					x
		Smokeless Broiler at 25% RP					x

Area	Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
		Substitute chipping for burning				x	x
	Residential Wood Combustion	Convert to Gas Logs at 25% RP				x	x
		Install Cleaner Hydronic Heaters at 25% RP				x	x
		New gas stove or gas logs at 25% RP				x	x
	Area Source Fugitive Dust	Chemical Stablizer at 10% RP				x	x
		Chemical Stablizer at 25% RP				x	
		Pave existing shoulders at 25% RP				x	x
		Pave Unpaved Roads at 25% RP					x
Southeast	Non-EGU Point	Electrostatic Precipitator-All Types					x
		Fabric Filter-All Types		x	x	x	x
		Install new drift eliminator at 10% RP				x	x
		Install new drift eliminator at 25% RP		x	x	x	x
		Venturi Scrubber				x	x
	Oil & Gas Point	Install new drift eliminator at 25% RP					x
	Non-Point (Area)	Annual tune-up at 25% RP				x	x
		Biennial tune-up at 10% RP					x
		Biennial tune-up at 25% RP		x	x		x
		Catalytic oxidizers at 25% RP		x	x	x	x
		Electrostatic Precipitator at 10% RP				x	x
		Electrostatic Precipitator at 25% RP		x	x	x	x
		HEPA filters at 10% RP					x
		HEPA filters at 25% RP					x
		Smokeless Broiler at 10% RP		x	x	x	x
		Smokeless Broiler at 25% RP				x	x
		Substitute chipping for burning		x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs at 25% RP		x	x	x	x
		EPA Phase 2 Qualified Units at 25% RP		x	x		x
		Install Cleaner Hydronic Heaters at 25% RP				x	x
		Install Retrofit Devices at 10% RP					x
		New gas stove or gas logs at 10% RP					x
		New gas stove or gas logs at 25% RP		x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer at 10% RP		x	x	x	
		Chemical Stabilizer at 25% RP					x
		Pave existing shoulders at 10% RP					x
		Pave existing shoulders at 25% RP				x	x
		Pave Unpaved Roads at 25% RP				x	x
Southeast (Adjacent Counties)	Non-EGU Point	Fabric Filter-All Types					x
		Install new drift eliminator at 25% RP					x
	Non-Point (Area)	Annual tune-up at 25% RP					x
		Electrostatic Precipitator at 25% RP				x	x
		Substitute chipping for burning				x	x
	Residential Wood Combustion	Convert to Gas Logs at 25% RP					x
		Install Cleaner Hydronic Heaters at 25% RP					x
		New gas stove or gas logs at 25% RP					x
	Area Source Fugitive Dust	Pave existing shoulders at 25% RP				x	x
		Pave Unpaved Roads at 25% RP				x	x

Area	**Inventory Sector**	**Control Technology**	**12/35**	**10/35**	**10/30**	**9/35**	**8/35**
West	Non-EGU Point	Fabric Filter-All Types	x		x	x	x
		Install new drift eliminator at 10% RP					x
		Install new drift eliminator at 25% RP				x	x
		Venturi Scrubber			x	x	x
	Non-Point (Area)	Annual tune-up at 10% RP			x		
		Annual tune-up at 25% RP	x		x	x	x
		Biennial tune-up at 10% RP					x
		Biennial tune-up at 25% RP	x		x	x	x
		Catalytic oxidizers at 25% RP	x		x	x	x
		Electrostatic Precipitator at 25% RP	x		x		x
		HEPA filters at 25% RP					x
		Smokeless Broiler at 10% RP	x		x	x	x
		Smokeless Broiler at 25% RP				x	
		Substitute chipping for burning	x	x	x	x	x
	Residential Wood Combustion	Convert to Gas Logs at 25% RP	x		x		x
		EPA Phase 2 Qualified Units at 25% RP			x		x
		Install Cleaner Hydronic Heaters at 10% RP			x		
		Install Cleaner Hydronic Heaters at 25% RP	x	x	x	x	x
		Install Retrofit Devices at 10% RP	x				
		Install Retrofit Devices at 25% RP					x
		New gas stove or gas logs at 10% RP	x		x	x	x
		New gas stove or gas logs at 25% RP	x	x	x	x	x
	Area Source Fugitive Dust	Chemical Stabilizer at 10% RP			x		x
		Chemical Stabilizer at 25% RP	x				x
		Dust Suppressants at 25% RP					x
		Pave existing shoulders at 25% RP	x		x	x	x
		Pave Unpaved Roads at 25% RP	x	x	x	x	x
CA	Non-EGU Point	Electrostatic Precipitator-All Types					x
		Fabric Filter-All Types	x	x	x	x	x
		Install new drift eliminator at 10% RP	x				
		Install new drift eliminator at 25% RP	x				
		Venturi Scrubber	x	x	x	x	x
	Oil & Gas Point	Fabric Filter-All Types	x				
	Non-Point (Area)	Add-on Scrubber at 25% RP		x	x		
		Annual tune-up at 10% RP				x	
		Annual tune-up at 25% RP	x	x	x	x	x
		Biennial tune-up at 10% RP	x				
		Biennial tune-up at 25% RP	x			x	
		Catalytic oxidizers at 25% RP	x			x	
		Electrostatic Precipitator at 25% RP	x	x	x	x	x
		Fabric Filter-All Types					x
		HEPA filters at 10% RP				x	
		HEPA filters at 25% RP				x	
		Smokeless Broiler at 10% RP			x	x	
		Smokeless Broiler at 25% RP				x	x
		Substitute chipping for burning	x	x	x	x	x

Area	Inventory Sector	Control Technology	12/35	10/35	10/30	9/35	8/35
	Residential Wood Combustion	Convert to Gas Logs at 25% RP	x	x	x	x	x
		Install Retrofit Devices at 10% RP				x	
		Install Retrofit Devices at 25% RP		x	x		
	Area Source Fugitive Dust	Chemical Stabilizer at 10% RP				x	
		Chemical Stabilizer at 25% RP					x
		Pave existing shoulders at 25% RP	x	x	x	x	x
		Pave Unpaved Roads at 25% RP	x	x	x	x	x

Table 3A-2 Summary of PM$_{2.5}$ Estimated Emissions Reductions from CoST for the Northeast (57 counties) for 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 (tons/year)

County	10/35	10/30	9/35	8/35
New Castle County, DE	0	0	0	73
Cook County, IL	0	0	285	710
Madison County, IL	0	0	0	724
St. Clair County, IL	0	0	0	579
Allen County, IN	0	0	0	44
Clark County, IN	0	0	0	395
Elkhart County, IN	0	0	0	213
Floyd County, IN	0	0	0	40
Lake County, IN	0	0	0	644
Marion County, IN	0	0	405	405
St. Joseph County, IN	0	0	0	205
Vanderburgh County, IN	0	0	0	161
Vigo County, IN	0	0	0	206
Jefferson County, KY	0	0	0	552
Baltimore city, MD	0	0	0	95
Howard County, MD	0	0	0	124
Kent County, MI	0	0	0	330
Wayne County, MI	15	15	645	645
Buchanan County, MO	0	0	0	81
Jackson County, MO	0	0	0	37
Jefferson County, MO	0	0	0	346
St. Louis city, MO	0	0	0	157
St. Louis County, MO	0	0	0	571
Camden County, NJ	0	0	110	110
Union County, NJ	0	0	0	168
New York County, NY	0	0	0	268
Butler County, OH	0	0	571	704
Cuyahoga County, OH	139	139	825	825
Franklin County, OH	0	0	0	96
Hamilton County, OH	0	0	0	439
Jefferson County, OH	0	0	93	93
Lucas County, OH	0	0	0	483

County	**10/35**	**10/30**	**9/35**	**8/35**
Mahoning County, OH	0	0	0	117
Stark County, OH	0	0	0	644
Summit County, OH	0	0	0	310
Allegheny County, PA	842	994	1,573	1,613
Armstrong County, PA	0	0	142	142
Beaver County, PA	0	0	0	260
Berks County, PA	0	0	0	103
Cambria County, PA	0	0	34	191
Chester County, PA	0	0	0	598
Dauphin County, PA	0	0	0	242
Delaware County, PA	0	0	277	277
Lackawanna County, PA	0	0	0	66
Lancaster County, PA	73	73	805	937
Lebanon County, PA	0	0	44	181
Lehigh County, PA	0	0	0	95
Mercer County, PA	0	0	0	230
Philadelphia County, PA	0	0	524	896
Washington County, PA	0	0	0	242
York County, PA	0	0	0	381
Providence County, RI	0	0	0	195
Davidson County, TN	0	0	0	95
Knox County, TN	0	0	0	410
Berkeley County, WV	0	0	0	124
Brooke County, WV	0	0	0	120
Marshall County, WV	0	0	0	148
Total	1,070	1,222	6,334	19,142

Table 3A-3 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Adjacent Counties in the Northeast (75 counties) for 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
Clinton County, IL	Madison County, IL St. Clair County, IL	0	0	0	122
DuPage County, IL	Cook County, IL	0	0	0	124
Kane County, IL	Cook County, IL	0	0	0	98
Lake County, IL	Cook County, IL	0	0	0	434
McHenry County, IL	Cook County, IL	0	0	0	95
Monroe County, IL	St. Clair County, IL	0	0	0	110
Randolph County, IL	St. Clair County, IL	0	0	0	91
Washington County, IL	St. Clair County, IL	0	0	0	90
Will County, IL	Cook County, IL	0	0	0	476
Boone County, IN	Marion County, IN	0	0	3	75
Clay County, IN	Vigo County, IN	0	0	0	65
Gibson County, IN	Vanderburgh County, IN	0	0	0	29
Hamilton County, IN	Marion County, IN	0	0	8	281
Hancock County, IN	Marion County, IN	0	0	3	77
Hendricks County, IN	Marion County, IN	0	0	17	208
Johnson County, IN	Marion County, IN	0	0	4	168
LaPorte County, IN	St. Joseph County, IN	0	0	0	186
Marshall County, IN	Elkhart County, IN St. Joseph County, IN	0	0	0	121
Morgan County, IN	Marion County, IN	0	0	12	207
Parke County, IN	Vigo County, IN	0	0	0	30
Posey County, IN	Vanderburgh County, IN	0	0	0	199
Shelby County, IN	Marion County, IN	0	0	3	400
Starke County, IN	St. Joseph County, IN	0	0	0	34
Sullivan County, IN	Vigo County, IN	0	0	0	58
Vermillion County, IN	Vigo County, IN	0	0	0	31
Warrick County, IN	Vanderburgh County, IN	0	0	0	182
Bullitt County, KY	Jefferson County, KY	0	0	0	71
Hardin County, KY	Jefferson County, KY	0	0	0	38
Oldham County, KY	Jefferson County, KY	0	0	0	23
Shelby County, KY	Jefferson County, KY	0	0	0	17
Spencer County, KY	Jefferson County, KY	0	0	0	13
Montgomery County, MD	Howard County, MD	0	0	0	2
Macomb County, MI	Wayne County, MI	0	0	59	409
Monroe County, MI	Wayne County, MI	0	0	240	463
Oakland County, MI	Wayne County, MI	0	0	55	954
Washtenaw County, MI	Wayne County, MI	0	0	53	365
Atlantic County, NJ	Camden County, NJ	0	0	7	98
Burlington County, NJ	Camden County, NJ	0	0	26	183
Essex County, NJ	Union County, NJ	0	0	0	116
Gloucester County, NJ	Camden County, NJ	0	0	27	274
Hudson County, NJ	Union County, NJ	0	0	0	73
Middlesex County, NJ	Union County, NJ	0	0	0	299

County	Adjacent Counties	10/35	10/30	9/35	8/35
Morris County, NJ	Union County, NJ	0	0	0	164
Somerset County, NJ	Union County, NJ	0	0	0	69
Bronx County, NY	New York County, NY	0	0	0	91
Kings County, NY	New York County, NY	0	0	0	215
Queens County, NY	New York County, NY	0	0	0	223
Belmont County, OH	Jefferson County, OH	0	0	81	126
Carroll County, OH	Jefferson County, OH Stark County, OH	0	0	34	68
Clermont County, OH	Hamilton County, OH	0	0	0	279
Columbiana County, OH	Jefferson County, OH Mahoning County, OH Stark County, OH	0	0	144	172
Geauga County, OH	Cuyahoga County, OH Summit County, OH	0	0	9	256
Harrison County, OH	Jefferson County, OH	0	0	12	109
Lake County, OH	Cuyahoga County, OH	0	0	6	184
Lorain County, OH	Cuyahoga County, OH	0	0	145	301
Medina County, OH	Cuyahoga County, OH Summit County, OH	0	0	9	340
Montgomery County, OH	Butler County, OH	0	0	0	303
Portage County, OH	Cuyahoga County, OH Mahoning County, OH Stark County, OH Summit County, OH	0	0	15	287
Preble County, OH	Butler County, OH	0	0	0	82
Warren County, OH	Butler County, OH Hamilton County, OH	0	0	0	366
Bedford County, PA	Cambria County, PA	0	0	0	121
Blair County, PA	Cambria County, PA	0	0	0	365
Bucks County, PA	Lehigh County, PA Philadelphia County, PA	0	0	0	581
Butler County, PA	Allegheny County, PA Armstrong County, PA Beaver County, PA Mercer County, PA	0	0	34	631
Clarion County, PA	Armstrong County, PA	0	0	4	90
Clearfield County, PA	Cambria County, PA	0	0	0	171
Indiana County, PA	Armstrong County, PA Cambria County, PA	0	0	55	294
Jefferson County, PA	Armstrong County, PA	0	0	5	260
Montgomery County, PA	Berks County, PA Chester County, PA Delaware County, PA Lehigh County, PA Philadelphia County, PA	0	0	633	633
Schuylkill County, PA	Berks County, PA Dauphin County, PA Lebanon County, PA Lehigh County, PA	0	0	0	287

County	Adjacent Counties	10/35	10/30	9/35	8/35
Somerset County, PA	Cambria County, PA	0	0	0	204
Westmoreland County, PA	Allegheny County, PA Armstrong County, PA Cambria County, PA Washington County, PA	0	0	37	609
Hancock County, WV	Brooke County, WV	0	0	0	32
Ohio County, WV	Brooke County, WV Marshall County, WV	0	0	0	96
Wetzel County, WV	Marshall County, WV	0	0	0	45
Total		0	0	1,737	15,440

Table 3A-4 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Southeast (35 counties) for 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 (tons/year)

County	10/35	10/30	9/35	8/35
Jefferson County, AL	0	0	671	1,488
Talladega County, AL	0	0	0	131
Pulaski County, AR	0	0	0	777
Union County, AR	0	0	0	66
District of Columbia	0	0	0	140
Bibb County, GA	0	0	0	158
Clayton County, GA	0	0	0	58
Cobb County, GA	0	0	0	42
DeKalb County, GA	0	0	0	34
Dougherty County, GA	0	0	0	481
Floyd County, GA	0	0	0	400
Fulton County, GA	0	0	344	599
Gwinnett County, GA	0	0	0	17
Muscogee County, GA	0	0	0	176
Richmond County, GA	0	0	0	409
Wilkinson County, GA	0	0	0	761
Wyandotte County, KS	0	0	0	90
Caddo Parish, LA	0	0	327	436
East Baton Rouge Parish, LA	0	0	0	531
Iberville Parish, LA	0	0	0	17
St. Bernard Parish, LA	0	0	0	60
West Baton Rouge Parish, LA	0	0	0	393
Hinds County, MS	0	0	0	33
Davidson County, NC	0	0	0	204
Mecklenburg County, NC	0	0	0	91
Wake County, NC	0	0	0	66
Tulsa County, OK	0	0	0	74
Greenville County, SC	0	0	0	98
Cameron County, TX	0	0	148	148
Dallas County, TX	0	0	0	33
El Paso County, TX	0	0	33	240
Harris County, TX	270	270	1,087	1,905
Hidalgo County, TX	205	205	406	406
Nueces County, TX	0	0	0	810
Travis County, TX	0	0	25	842
Total	475	475	3,040	12,212

Table 3A-5 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the Adjacent Counties in the Southeast (32 counties) for 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 (tons/year)

County	Adjacent Counties	10/35	10/30	9/35	8/35
Bartow County, GA	Cobb County, GA Floyd County, GA	0	0	0	135
Carroll County, GA	Fulton County, GA	0	0	0	154
Chattahoochee County, GA	Muscogee County, GA	0	0	0	37
Chattooga County, GA	Floyd County, GA	0	0	0	116
Cherokee County, GA	Cobb County, GA Fulton County, GA	0	0	0	151
Coweta County, GA	Fulton County, GA	0	0	0	120
Crawford County, GA	Bibb County, GA	0	0	0	112
Douglas County, GA	Cobb County, GA Fulton County, GA	0	0	0	71
Fayette County, GA	Clayton County, GA Fulton County, GA	0	0	0	76
Forsyth County, GA	Fulton County, GA Gwinnett County, GA	0	0	0	89
Gordon County, GA	Floyd County, GA	0	0	0	123
Harris County, GA	Muscogee County, GA	0	0	0	204
Henry County, GA	Clayton County, GA DeKalb County, GA	0	0	0	88
Houston County, GA	Bibb County, GA	0	0	0	640
Jones County, GA	Bibb County, GA Wilkinson County, GA	0	0	0	145
Monroe County, GA	Bibb County, GA	0	0	0	161
Polk County, GA	Floyd County, GA	0	0	0	118
Spalding County, GA	Clayton County, GA	0	0	0	122
Talbot County, GA	Muscogee County, GA	0	0	0	87
Twiggs County, GA	Bibb County, GA Wilkinson County, GA	0	0	0	180
Walker County, GA	Floyd County, GA	0	0	0	71
Bossier Parish, LA	Caddo Parish, LA	0	0	0	237
De Soto Parish, LA	Caddo Parish, LA	0	0	0	160
East Feliciana Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	0	0	0	66
Pointe Coupee Parish, LA	Iberville Parish, LA West Baton Rouge Parish, LA	0	0	0	80
Red River Parish, LA	Caddo Parish, LA	0	0	0	1,001
West Feliciana Parish, LA	West Baton Rouge Parish, LA	0	0	0	121
Brooks County, TX	Hidalgo County, TX	0	0	66	66
Hudspeth County, TX	El Paso County, TX	0	0	0	31
Kenedy County, TX	Hidalgo County, TX	0	0	43	43
Starr County, TX	Hidalgo County, TX	0	0	62	62
Willacy County, TX	Cameron County, TX Hidalgo County, TX	0	0	22	22
Total		0	0	194	4,892

Table 3A-6 Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for the West (36 counties) for 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 $\mu g/m^3$ in 2032 (tons/year)

County	10/35	10/30	9/35	8/35
Maricopa County, AZ	0	0	201	669
Pinal County, AZ	0	164	0	61
Santa Cruz County, AZ	0	0	0	13
Denver County, CO	0	0	0	145
Weld County, CO	0	0	0	47
Benewah County, ID	0	133	133	133
Canyon County, ID	0	115	0	384
Lemhi County, ID	0	0	0	0
Shoshone County, ID	0	0	0	0
Lewis and Clark County, MT	0	87	0	0
Lincoln County, MT	224	224	224	224
Missoula County, MT	0	0	229	697
Ravalli County, MT	0	58	0	31
Silver Bow County, MT	0	25	0	133
Douglas County, NE	0	0	0	19
Sarpy County, NE	0	0	0	28
Dona Ana County, NM	0	0	0	248
Clark County, NV	0	0	94	561
Crook County, OR	0	222	0	126
Harney County, OR	0	49	0	148
Jackson County, OR	0	0	66	533
Klamath County, OR	0	94	0	281
Lake County, OR	0	0	0	0
Lane County, OR	0	0	0	37
Box Elder County, UT	0	149	0	0
Cache County, UT	0	236	0	0
Davis County, UT	0	79	0	0
Salt Lake County, UT	0	162	0	0
Utah County, UT	0	127	0	0
Weber County, UT	0	39	0	0
King County, WA	0	0	0	126
Kittitas County, WA	0	0	0	0
Okanogan County, WA	0	139	0	0
Snohomish County, WA	0	104	0	0
Spokane County, WA	0	0	0	66
Yakima County, WA	0	0	0	0
Total	224	2,206	947	4,711

Table 3A-7 **Summary of $PM_{2.5}$ Estimated Emissions Reductions from CoST for California (26 counties) for 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	32	32	349	491
Contra Costa County, CA	Bay Area AQMD	0	0	38	355
Marin County, CA	Bay Area AQMD	0	0	0	45
Napa County, CA	Bay Area AQMD	16	16	33	33
Santa Clara County, CA	Bay Area AQMD	0	0	166	482
Solano County, CA	Bay Area AQMD	0	0	0	150
Butte County, CA	Butte County AQMD	0	0	0	76
Sutter County, CA	Feather River AQMD	0	0	0	191
Imperial County, CA	Imperial County APCD	0	0	0	0
Plumas County, CA	Northern Sierra AQMD	0	0	0	0
Sacramento County, CA	Sacramento Metro AQMD	0	60	79	228
San Diego County, CA	San Diego County APCD	0	0	102	615
Fresno County, CA	San Joaquin Valley APCD	248	248	248	248
Kern County, CA	San Joaquin Valley APCD	0	0	0	0
Kings County, CA	San Joaquin Valley APCD	0	0	0	0
Madera County, CA	San Joaquin Valley APCD	111	111	111	111
Merced County, CA	San Joaquin Valley APCD	101	101	101	101
San Joaquin County, CA	San Joaquin Valley APCD	12	12	168	168
Stanislaus County, CA	San Joaquin Valley APCD	113	113	113	113
Tulare County, CA	San Joaquin Valley APCD	0	0	0	0
San Luis Obispo County, CA	San Luis Obispo County APCD	0	0	128	128
Siskiyou County, CA	Siskiyou County APCD	0	398	0	0
Los Angeles County, CA	South Coast AQMD	1,159	1,159	1,159	1,159
Riverside County, CA	South Coast AQMD	0	0	0	0
San Bernardino County, CA	South Coast AQMD	0	0	0	0
Ventura County, CA	Ventura County APCD	0	229	162	229
Total		1,792	2,481	2,958	4,925

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
Cochise County, AZ	Santa Cruz County, AZ	afdust	1,516	-	-	-	-	-	-
		nonpt	128	54	-	-	-	-	-
		ptnonipm	117	55	-	-	-	-	-
		rwc	38	3	-	-	-	-	-
Gila County, AZ	Pinal County, AZ	afdust	900	-	-	-	-	-	-
		nonpt	70	30	-	-	-	-	-
		ptnonipm	361	240	-	-	-	-	-
		rwc	22	-	-	-	-	-	-
Graham County, AZ	Pinal County, AZ	afdust	718	49	-	-	-	-	-
		nonpt	38	13	-	-	-	-	-
		rwc	9	-	-	-	-	-	-
Pima County, AZ	Pinal County, AZ	afdust	3,446	-	-	-	-	-	-
	Santa Cruz County, AZ	nonpt	739	269	-	-	-	-	-
		ptnonipm	79	11	-	-	-	-	-
		rwc	244	25	-	-	-	-	-
Pinal County, AZ	-	afdust	3,385	-	-	-	-	-	-
		nonpt	297	156	-	-	156	-	61
		ptagfire	19	-	-	-	-	-	-
		ptnonipm	94	-	-	-	-	-	-
		rwc	103	8	-	-	8	-	-
Santa Cruz County, AZ	-	afdust	167	-	-	-	-	-	-
		nonpt	47	13	-	-	-	-	13
		rwc	13	-	-	-	-	-	-
Alameda County, CA	Napa County, CA	afdust	543	60	-	-	-	-	60
	Solano County, CA	nonpt	885	134	-	-	-	86	134
		ptnonipm	450	208	-	32	32	173	208
		rwc	368	90	-	-	-	90	90
Contra Costa County, CA	Alameda County, CA	afdust	405	47	-	-	-	-	-
	Napa County, CA	nonpt	646	82	-	-	-	-	-
	Solano County, CA	pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	1,798	999	-	-	-	38	355
		rwc	812	169	-	-	-	-	-

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
Fresno County, CA	Kern County, CA	afdust	2,277	224	-	224	224	224	224
	Kings County, CA	nonpt	519	81	79	-	-	-	-
	Madera County, CA	pt_oilgas	36	-	-	-	-	-	-
	Merced County, CA	ptagfire	882	-	-	-	-	-	-
	San Joaquin County, CA	ptnonipm	275	108	82	24	24	24	24
	Stanislaus County, CA	rwc	289	29	29	-	-	-	-
	Tulare County, CA								
Imperial County, CA	-	afdust	3,596	-	-	-	-	-	-
		nonpt	221	9	9	-	-	-	-
		ptagfire	198	-	-	-	-	-	-
		ptnonipm	134	80	80	-	-	-	-
		rwc	18	3	3	-	-	-	-
Kern County, CA	Fresno County, CA	afdust	1,396	-	-	-	-	-	-
	Kings County, CA	nonpt	823	276	276	-	-	-	-
	Madera County, CA	pt_oilgas	331	51	51	-	-	-	-
	Merced County, CA	ptagfire	332	-	-	-	-	-	-
	San Joaquin County, CA	ptnonipm	517	209	209	-	-	-	-
	Stanislaus County, CA	rwc	224	27	27	-	-	-	-
	Tulare County, CA								
Kings County, CA	Fresno County, CA	afdust	849	30	30	-	-	-	-
	Kern County, CA	nonpt	57	9	9	-	-	-	-
	Madera County, CA	ptagfire	210	-	-	-	-	-	-
	Merced County, CA	ptnonipm	69	-	-	-	-	-	-
	San Joaquin County, CA	rwc	31	4	4	-	-	-	-
	Stanislaus County, CA								
	Tulare County, CA								
Los Angeles County, CA	Riverside County, CA	afdust	2,240	-	-	-	-	-	-
	San Bernardino County, CA	nonpt	5,052	723	0	722	722	722	722
		pt_oilgas	18	-	-	-	-	-	-
		ptnonipm	2,087	638	313	325	325	325	325
		rwc	947	112	-	112	112	112	112

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
Madera County, CA	Fresno County, CA	afdust	672	68	-	68	68	68	68
	Kern County, CA	nonpt	197	27	-	27	27	27	27
	Kings County, CA	ptagfire	415	-	-	-	-	-	-
	Merced County, CA	ptnonipm	52	12	-	12	12	12	12
	San Joaquin County, CA	rwc	52	4	-	4	4	4	4
	Stanislaus County, CA								
	Tulare County, CA								
Marin County, CA	Alameda County, CA	afdust	168	18	-	-	-	-	-
	Napa County, CA	nonpt	144	23	-	-	-	-	-
	Solano County, CA	ptnonipm	74	54	-	-	-	-	45
		rwc	220	10	-	-	-	-	-
Merced County, CA	Fresno County, CA	afdust	1,304	73	-	73	73	73	73
	Kern County, CA	nonpt	111	19	-	19	19	19	19
	Kings County, CA	ptagfire	152	-	-	-	-	-	-
	Madera County, CA	ptnonipm	67	-	-	-	-	-	-
	San Joaquin County, CA	rwc	114	10	-	10	10	10	10
	Stanislaus County, CA								
	Tulare County, CA								
Napa County, CA	Alameda County, CA	afdust	112	10	-	-	-	10	10
	Solano County, CA	nonpt	63	7	-	5	5	7	7
		ptagfire	7	-	-	-	-	-	-
		ptnonipm	37	-	-	-	-	-	-
		rwc	123	16	-	11	11	16	16
Nevada County, CA	Plumas County, CA	afdust	343	44	-	-	-	-	-
		nonpt	72	6	-	-	-	-	-
		ptnonipm	6	-	-	-	-	-	-
		rwc	279	18	-	-	-	-	-
Orange County, CA	Los Angeles County, CA	afdust	672	-	-	-	-	-	-
	Riverside County, CA	nonpt	1,862	288	-	-	-	-	-
	San Bernardino County, CA	ptnonipm	200	20	-	-	-	-	-
		rwc	305	54	-	-	-	-	-

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
Plumas County, CA	-	afdust	483	99	99	-	-	-	-
		nonpt	43	-	-	-	-	-	-
		ptnonipm	7	-	-	-	-	-	-
		rwc	326	9	9	-	-	-	-
Riverside County, CA	Los Angeles County, CA San Bernardino County, CA	afdust	2,589	-	-	-	-	-	-
		nonpt	973	137	137	-	-	-	-
		ptagfire	34	-	-	-	-	-	-
		ptnonipm	128	21	21	-	-	-	-
		rwc	468	34	34	-	-	-	-
Sacramento County, CA	-	afdust	1,023	-	-	-	-	-	-
		nonpt	713	109	-	-	32	50	109
		ptagfire	46	-	-	-	-	-	-
		ptnonipm	92	29	-	-	29	29	29
		rwc	1,790	90	-	-	-	-	90
San Bernardino County, CA	Los Angeles County, CA Riverside County, CA	afdust	2,424	-	-	-	-	-	-
		nonpt	1,094	144	144	-	-	-	-
		pt_oilgas	56	-	-	-	-	-	-
		ptagfire	7	-	-	-	-	-	-
		ptnonipm	2,642	1,965	1,965	-	-	-	-
		rwc	470	31	31	-	-	-	-
San Diego County, CA	-	afdust	2,485	194	-	-	-	-	194
		nonpt	1,949	371	-	-	-	81	371
		ptnonipm	489	12	-	-	-	11	12
		rwc	678	39	-	-	-	11	39
San Francisco County, CA	Alameda County, CA Napa County, CA Solano County, CA	afdust	108	13	-	-	-	-	-
		nonpt	588	107	-	-	-	-	-
		ptnonipm	45	7	-	-	-	-	-
		rwc	49	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
San Joaquin County, CA	Fresno County, CA Kern County, CA Kings County, CA Madera County, CA Merced County, CA Stanislaus County, CA Tulare County, CA	afdust	1,110	80	-	-	-	80	80
		nonpt	290	40	-	4	4	40	40
		ptagfire	126	-	-	-	-	-	-
		ptnonipm	167	19	-	8	8	19	19
		rwc	217	28	-	-	-	28	28
San Luis Obispo County, CA	-	afdust	133	-	-	-	-	-	-
		nonpt	226	57	-	-	-	57	57
		ptagfire	13	-	-	-	-	-	-
		ptnonipm	42	6	-	-	-	6	6
		rwc	475	65	-	-	-	65	65
San Mateo County, CA	Alameda County, CA Napa County, CA Solano County, CA	afdust	249	26	-	-	-	-	-
		nonpt	419	61	-	-	-	-	-
		ptnonipm	131	42	-	-	-	-	-
		rwc	167	26	-	-	-	-	-
Santa Clara County, CA	Alameda County, CA Napa County, CA Solano County, CA	afdust	717	85	-	-	-	-	83
		nonpt	945	173	-	-	-	93	173
		ptnonipm	244	111	-	-	-	72	103
		rwc	614	122	-	-	-	-	122
Sierra County, CA	Plumas County, CA	afdust	240	48	-	-	-	-	-
		nonpt	35	-	-	-	-	-	-
		rwc	11	-	-	-	-	-	-
Siskiyou County, CA	-	afdust	901	166	-	-	166	-	-
		nonpt	480	217	-	-	217	-	-
		ptagfire	38	-	-	-	-	-	-
		rwc	217	15	-	-	15	-	-
Solano County, CA	Alameda County, CA Napa County, CA	afdust	414	34	-	-	-	-	34
		nonpt	251	40	-	-	-	-	40
		ptagfire	23	-	-	-	-	-	-
		ptnonipm	185	35	-	-	-	-	35
		rwc	328	42	-	-	-	-	42

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
Sonoma County, CA	Alameda County, CA	afdust	420	34	-	-	-	-	-
	Napa County, CA	nonpt	355	54	-	-	-	-	-
	Solano County, CA	ptnonipm	103	20	-	-	-	-	-
		rwc	572	66	-	-	-	-	-
Stanislaus County, CA	Fresno County, CA	afdust	1,139	-	-	-	-	-	-
	Kern County, CA	nonpt	236	31	-	31	31	31	31
	Kings County, CA	ptagfire	150	-	-	-	-	-	-
	Madera County, CA	ptnonipm	146	60	-	60	60	60	60
	Merced County, CA	rwc	188	22	-	22	22	22	22
	San Joaquin County, CA								
	Tulare County, CA								
Sutter County, CA	-	afdust	280	25	-	-	-	-	25
		nonpt	386	149	-	-	-	-	149
		ptagfire	195	-	-	-	-	-	-
		ptnonipm	33	5	-	-	-	-	5
		rwc	199	11	-	-	-	-	11
Tulare County, CA	Fresno County, CA	afdust	2,106	137	137	-	-	-	-
	Kern County, CA	nonpt	222	28	28	-	-	-	-
	Kings County, CA	ptagfire	560	-	-	-	-	-	-
	Madera County, CA	ptnonipm	96	-	-	-	-	-	-
	Merced County, CA	rwc	139	13	13	-	-	-	-
	San Joaquin County, CA								
	Stanislaus County, CA								
Ventura County, CA	-	afdust	529	51	-	-	51	5	51
		nonpt	354	63	-	-	63	41	63
		pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	94	7	-	-	7	7	7
		rwc	677	108	-	-	108	108	108
Yolo County, CA	Solano County, CA	afdust	808	30	-	-	-	-	-
		nonpt	335	35	-	-	-	-	-
		ptagfire	66	-	-	-	-	-	-
		ptnonipm	105	6	-	-	-	-	-
		rwc	248	13	-	-	-	-	-

					Selected PM2.5 Emissions Reductions				
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**	**12/35**	**10/35**	**10/30**	**9/35**	**8/35**
Yuba County, CA	Sutter County, CA	afdust	177	21	-	-	-	-	-
		nonpt	78	19	-	-	-	-	-
		ptagfire	47	-	-	-	-	-	-
		ptnonipm	17	-	-	-	-	-	-
		rwc	157	9	-	-	-	-	-
Adams County, CO	Denver County, CO	afdust	1,876	65	-	-	-	-	-
		nonpt	233	57	-	-	-	-	-
		np_oilgas	8	-	-	-	-	-	-
		pt_oilgas	21	-	-	-	-	-	-
		ptagfire	6	-	-	-	-	-	-
		ptnonipm	346	112	-	-	-	-	-
		rwc	360	36	-	-	-	-	-
Arapahoe County, CO	Denver County, CO	afdust	1,602	115	-	-	-	-	-
		nonpt	274	63	-	-	-	-	-
		ptnonipm	500	7	-	-	-	-	-
		rwc	450	43	-	-	-	-	-
Denver County, CO	-	afdust	1,453	-	-	-	-	-	-
		nonpt	389	88	-	-	-	-	88
		ptnonipm	204	43	-	-	-	-	43
		rwc	177	13	-	-	-	-	13
Jefferson County, CO	Denver County, CO	afdust	1,285	205	-	-	-	-	-
		nonpt	355	93	-	-	-	-	-
		ptnonipm	242	129	-	-	-	-	-
		rwc	601	64	-	-	-	-	-
Bartow County, GA	Floyd County, GA	afdust	464	59	-	-	-	-	59
		nonpt	147	43	-	-	-	-	43
		ptnonipm	44	23	-	-	-	-	23
		rwc	93	10	-	-	-	-	10
Bibb County, GA	-	afdust	232	34	-	-	-	-	34
		nonpt	150	33	-	-	-	-	33
		pt_oilgas	18	-	-	-	-	-	-
		ptnonipm	157	81	-	-	-	-	81
		rwc	90	9	-	-	-	-	9

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
Carroll County, GA	Fulton County, GA	afdust	590	89	-	-	-	-	89
		nonpt	126	43	-	-	-	-	43
		ptnonipm	40	11	-	-	-	-	11
		rwc	104	11	-	-	-	-	11
Chattahoochee County, GA	Muscogee County, GA	afdust	99	18	-	-	-	-	18
		nonpt	26	19	-	-	-	-	19
Chattooga County, GA	Floyd County, GA	afdust	207	34	-	-	-	-	34
		nonpt	99	81	-	-	-	-	81
		ptnonipm	8	-	-	-	-	-	-
		rwc	30	1	-	-	-	-	1
Cherokee County, GA	Fulton County, GA	afdust	525	78	-	-	-	-	78
		nonpt	181	51	-	-	-	-	51
		ptnonipm	8	-	-	-	-	-	-
		rwc	179	21	-	-	-	-	21
Clayton County, GA	Fulton County, GA	afdust	258	33	-	-	-	-	33
		nonpt	88	16	-	-	-	-	16
		ptnonipm	8	-	-	-	-	-	-
		rwc	103	9	-	-	-	-	9
Coweta County, GA	Fulton County, GA	afdust	364	62	-	-	-	-	62
		nonpt	128	46	-	-	-	-	46
		ptagfire	12	-	-	-	-	-	-
		rwc	110	13	-	-	-	-	13
Crawford County, GA	Bibb County, GA	afdust	141	25	-	-	-	-	25
		nonpt	100	88	-	-	-	-	88
		ptagfire	8	-	-	-	-	-	-
		rwc	14	-	-	-	-	-	-
Douglas County, GA	Fulton County, GA	afdust	235	35	-	-	-	-	35
		nonpt	88	25	-	-	-	-	25
		rwc	91	10	-	-	-	-	10
Fayette County, GA	Clayton County, GA Fulton County, GA	afdust	209	29	-	-	-	-	29
		nonpt	96	27	-	-	-	-	27
		ptnonipm	20	11	-	-	-	-	11
		rwc	84	10	-	-	-	-	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
Floyd County, GA	-	afdust	402	65	-	-	-	-	65
		nonpt	109	31	-	-	-	-	31
		ptagfire	6	-	-	-	-	-	-
		ptnonipm	316	294	-	-	-	-	294
		rwc	89	10	-	-	-	-	10
Forsyth County, GA	Fulton County, GA	afdust	342	40	-	-	-	-	40
		nonpt	127	33	-	-	-	-	33
		ptnonipm	6	-	-	-	-	-	-
		rwc	136	16	-	-	-	-	16
Fulton County, GA	Clayton County, GA	afdust	1,329	159	-	-	-	-	159
		nonpt	729	168	-	-	-	150	168
		ptnonipm	289	237	-	-	-	157	237
		rwc	371	36	-	-	-	36	36
Gordon County, GA	Floyd County, GA	afdust	341	43	-	-	-	-	43
		nonpt	123	75	-	-	-	-	75
		rwc	54	6	-	-	-	-	6
Harris County, GA	Muscogee County, GA	afdust	304	59	-	-	-	-	59
		nonpt	173	140	-	-	-	-	140
		pt_oilgas	17	-	-	-	-	-	-
		ptagfire	9	-	-	-	-	-	-
		rwc	47	5	-	-	-	-	5
Henry County, GA	Clayton County, GA	afdust	278	35	-	-	-	-	35
		nonpt	130	37	-	-	-	-	37
		pt_oilgas	54	-	-	-	-	-	-
		rwc	138	15	-	-	-	-	15
Houston County, GA	Bibb County, GA	afdust	282	38	-	-	-	-	38
		nonpt	271	189	-	-	-	-	189
		ptagfire	9	-	-	-	-	-	-
		ptnonipm	460	403	-	-	-	-	403
		rwc	111	11	-	-	-	-	11
Jones County, GA	Bibb County, GA	afdust	303	54	-	-	-	-	54
		nonpt	111	88	-	-	-	-	88
		ptagfire	8	-	-	-	-	-	-
		rwc	33	3	-	-	-	-	3

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
Monroe County, GA	Bibb County, GA	afdust	281	51	-	-	-	-	51
		nonpt	134	107	-	-	-	-	107
		ptagfire	13	-	-	-	-	-	-
		rwc	33	3	-	-	-	-	3
Muscogee County, GA	-	afdust	206	28	-	-	-	-	28
		nonpt	121	38	-	-	-	-	38
		ptnonipm	111	99	-	-	-	-	99
		rwc	108	11	-	-	-	-	11
Polk County, GA	Floyd County, GA	afdust	218	33	-	-	-	-	33
		nonpt	117	81	-	-	-	-	81
		ptnonipm	6	-	-	-	-	-	-
		rwc	45	4	-	-	-	-	4
Spalding County, GA	Clayton County, GA	afdust	176	29	-	-	-	-	29
		nonpt	132	88	-	-	-	-	88
		ptagfire	6	-	-	-	-	-	-
		rwc	50	5	-	-	-	-	5
Talbot County, GA	Muscogee County, GA	afdust	138	25	-	-	-	-	25
		nonpt	68	62	-	-	-	-	62
		ptagfire	8	-	-	-	-	-	-
		rwc	10	-	-	-	-	-	-
Twiggs County, GA	Bibb County, GA	afdust	208	32	-	-	-	-	32
		nonpt	150	116	-	-	-	-	116
		ptagfire	10	-	-	-	-	-	-
		ptnonipm	59	32	-	-	-	-	32
		rwc	10	-	-	-	-	-	-
Walker County, GA	Floyd County, GA	afdust	316	41	-	-	-	-	41
		nonpt	66	24	-	-	-	-	24
		ptagfire	11	-	-	-	-	-	-
		rwc	68	7	-	-	-	-	7
Benewah County, ID	Shoshone County, ID	afdust	859	131	-	-	131	131	131
		nonpt	33	2	-	-	2	2	2
		ptnonipm	30	-	-	-	-	-	-
		rwc	21	-	-	-	-	-	-

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
Bonner County, ID	Shoshone County, ID	afdust	2,200	424	-	-	-	-	-
		nonpt	149	49	-	-	-	-	-
		pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	13	-	-	-	-	-	-
		rwc	97	9	-	-	-	-	-
Butte County, ID	Lemhi County, ID	afdust	689	102	-	-	-	-	-
		rwc	8	-	-	-	-	-	-
Clark County, ID	Lemhi County, ID	afdust	299	36	-	-	-	-	-
		ptagfire	7	-	-	-	-	-	-
Clearwater County, ID	Shoshone County, ID	afdust	457	89	-	-	-	-	-
		nonpt	21	1	-	-	-	-	-
		ptagfire	48	-	-	-	-	-	-
		rwc	22	-	-	-	-	-	-
Custer County, ID	Lemhi County, ID	afdust	681	108	-	-	-	-	-
		nonpt	7	-	-	-	-	-	-
		rwc	15	-	-	-	-	-	-
Idaho County, ID	Lemhi County, ID	afdust	1,509	237	-	-	-	-	-
		nonpt	44	9	-	-	-	-	-
		ptagfire	138	-	-	-	-	-	-
		ptnonipm	14	5	-	-	-	-	-
		rwc	46	3	-	-	-	-	-
Kootenai County, ID	Benewah County, ID Shoshone County, ID	afdust	3,418	689	-	-	-	-	-
		nonpt	501	237	-	-	-	-	-
		ptnonipm	90	62	-	-	-	-	-
		rwc	150	13	-	-	-	-	-
Latah County, ID	Benewah County, ID Shoshone County, ID	afdust	1,850	215	-	-	-	-	-
		nonpt	54	15	-	-	-	-	-
		ptagfire	32	-	-	-	-	-	-
		ptnonipm	78	72	-	-	-	-	-
		rwc	37	2	-	-	-	-	-
Lemhi County, ID	-	afdust	728	116	116	-	-	-	-
		nonpt	10	-	-	-	-	-	-
		rwc	19	-	-	-	-	-	-

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
Shoshone County, ID	Benewah County, ID	afdust	573	96	96	-	-	-	-
		nonpt	24	11	11	-	-	-	-
		rwc	28	1	1	-	-	-	-
Valley County, ID	Lemhi County, ID	afdust	786	174	-	-	-	-	-
		nonpt	25	12	-	-	-	-	-
		rwc	28	2	-	-	-	-	-
Clinton County, IL	St. Clair County, IL	afdust	1,326	72	-	-	-	-	72
		nonpt	92	43	-	-	-	-	43
		pt_oilgas	15	-	-	-	-	-	-
		ptnonipm	15	-	-	-	-	-	-
		rwc	52	7	-	-	-	-	7
Monroe County, IL	St. Clair County, IL	afdust	889	68	-	-	-	-	68
		nonpt	79	37	-	-	-	-	37
		rwc	43	6	-	-	-	-	6
Randolph County, IL	St. Clair County, IL	afdust	964	49	-	-	-	-	49
		nonpt	80	36	-	-	-	-	36
		ptnonipm	35	-	-	-	-	-	-
		rwc	43	6	-	-	-	-	6
St. Clair County, IL	-	afdust	3,376	498	-	-	-	-	498
		nonpt	218	57	-	-	-	-	57
		ptnonipm	120	14	-	-	-	-	14
		rwc	107	10	-	-	-	-	10
Washington County, IL	St. Clair County, IL	afdust	1,249	69	-	-	-	-	69
		nonpt	45	16	-	-	-	-	16
		np_oilgas	5	-	-	-	-	-	-
		ptnonipm	5	-	-	-	-	-	-
		rwc	32	5	-	-	-	-	5
Boone County, IN	Marion County, IN	afdust	448	23	-	-	-	-	23
		nonpt	94	47	-	-	-	-	47
		rwc	73	5	-	-	-	3	5

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
Clay County, IN	Vigo County, IN	afdust	230	9	-	-	-	-	9
		nonpt	35	12	-	-	-	-	12
		ptnonipm	42	40	-	-	-	-	40
		rwc	50	4	-	-	-	-	4
Hamilton County, IN	Marion County, IN	afdust	786	62	-	-	-	-	62
		nonpt	350	195	-	-	-	-	195
		rwc	275	24	-	-	-	8	24
Hancock County, IN	Marion County, IN	afdust	324	23	-	-	-	-	23
		nonpt	86	46	-	-	-	-	46
		rwc	92	9	-	-	-	3	9
Hendricks County, IN	Marion County, IN	afdust	426	37	-	-	-	-	37
		nonpt	197	115	-	-	-	-	115
		ptnonipm	124	40	-	-	-	11	40
		rwc	169	15	-	-	-	6	15
Johnson County, IN	Marion County, IN	afdust	396	32	-	-	-	-	32
		nonpt	206	123	-	-	-	-	123
		rwc	139	13	-	-	-	4	13
LaPorte County, IN	St. Joseph County, IN	afdust	581	46	-	-	-	-	46
		nonpt	160	82	-	-	-	-	82
		ptnonipm	107	43	-	-	-	-	43
		rwc	139	15	-	-	-	-	15
Marion County, IN	-	afdust	1,534	146	-	-	-	146	146
		nonpt	521	92	-	-	-	92	92
		pt_oilgas	17	-	-	-	-	-	-
		ptnonipm	235	135	-	-	-	135	135
		rwc	330	32	-	-	-	32	32
Marshall County, IN	St. Joseph County, IN	afdust	305	18	-	-	-	-	18
		nonpt	94	42	-	-	-	-	42
		ptnonipm	78	55	-	-	-	-	55
		rwc	66	5	-	-	-	-	5
Morgan County, IN	Marion County, IN	afdust	376	28	-	-	-	-	28
		nonpt	120	71	-	-	-	-	71
		ptnonipm	105	99	-	-	-	8	99
		rwc	101	9	-	-	-	4	9

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
Parke County, IN	Vigo County, IN	afdust	233	8	-	-	-	-	8
		nonpt	36	20	-	-	-	-	20
		rwc	35	2	-	-	-	-	2
Shelby County, IN	Marion County, IN	afdust	279	15	-	-	-	-	15
		nonpt	69	31	-	-	-	-	31
		ptnonipm	410	350	-	-	-	-	350
		rwc	64	4	-	-	-	3	4
St. Joseph County, IN	-	afdust	531	45	-	-	-	-	45
		nonpt	266	116	-	-	-	-	116
		ptnonipm	72	18	-	-	-	-	18
		rwc	249	26	-	-	-	-	26
Starke County, IN	St. Joseph County, IN	afdust	134	9	-	-	-	-	9
		nonpt	46	22	-	-	-	-	22
		pt_oilgas	6	-	-	-	-	-	-
		rwc	43	4	-	-	-	-	4
Sullivan County, IN	Vigo County, IN	afdust	479	12	-	-	-	-	12
		nonpt	38	13	-	-	-	-	13
		ptnonipm	44	32	-	-	-	-	32
		rwc	31	1	-	-	-	-	1
Vermillion County, IN	Vigo County, IN	afdust	167	-	-	-	-	-	-
		nonpt	22	7	-	-	-	-	7
		ptnonipm	63	22	-	-	-	-	22
		rwc	30	1	-	-	-	-	1
Vigo County, IN	-	afdust	314	24	-	-	-	-	24
		nonpt	135	65	-	-	-	-	65
		ptnonipm	189	106	-	-	-	-	106
		rwc	128	12	-	-	-	-	12
Bossier Parish, LA	Caddo Parish, LA	afdust	433	58	-	-	-	-	58
		nonpt	423	174	-	-	-	-	174
		np_oilgas	46	-	-	-	-	-	-
		pt_oilgas	11	-	-	-	-	-	-
		ptnonipm	11	-	-	-	-	-	-
		rwc	52	5	-	-	-	-	5

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
Caddo Parish, LA	-	afdust	970	108	-	-	-	20	108
		nonpt	815	196	-	-	-	196	196
		np_oilgas	90	-	-	-	-	-	-
		ptnonipm	243	123	-	-	-	102	123
		rwc	87	9	-	-	-	9	9
De Soto Parish, LA	Caddo Parish, LA	afdust	444	57	-	-	-	-	57
		nonpt	120	38	-	-	-	-	38
		np_oilgas	112	-	-	-	-	-	-
		pt_oilgas	40	-	-	-	-	-	-
		ptnonipm	439	64	-	-	-	-	64
		rwc	15	-	-	-	-	-	-
East Feliciana Parish, LA	West Baton Rouge Parish, LA	afdust	281	38	-	-	-	-	38
		nonpt	68	29	-	-	-	-	29
		pt_oilgas	25	-	-	-	-	-	-
		rwc	11	-	-	-	-	-	-
Pointe Coupee Parish, LA	West Baton Rouge Parish, LA	afdust	553	53	-	-	-	-	53
		nonpt	63	19	-	-	-	-	19
		pt_oilgas	11	-	-	-	-	-	-
		ptagfire	89	-	-	-	-	-	-
		ptnonipm	318	8	-	-	-	-	8
		rwc	10	-	-	-	-	-	-
Red River Parish, LA	Caddo Parish, LA	afdust	202	22	-	-	-	-	22
		nonpt	52	10	-	-	-	-	10
		np_oilgas	22	-	-	-	-	-	-
		pt_oilgas	41	-	-	-	-	-	-
		ptnonipm	987	970	-	-	-	-	970
West Baton Rouge Parish, LA	-	afdust	255	35	-	-	-	-	35
		nonpt	265	68	-	-	-	-	68
		pt_oilgas	35	2	-	-	-	-	2
		ptagfire	44	-	-	-	-	-	-
		ptnonipm	420	288	-	-	-	-	288
		rwc	9	-	-	-	-	-	-

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
West Feliciana Parish, LA	West Baton Rouge Parish, LA	afdust	196	27	-	-	-	-	27
		nonpt	56	24	-	-	-	-	24
		ptnonipm	144	70	-	-	-	-	70
		rwc	6	-	-	-	-	-	-
Macomb County, MI	Wayne County, MI	afdust	689	104	-	-	-	-	104
		nonpt	1,338	264	-	-	-	56	264
		pt_oilgas	9	-	-	-	-	-	-
		ptnonipm	120	-	-	-	-	-	-
		rwc	500	42	-	-	-	3	42
Monroe County, MI	Wayne County, MI	afdust	829	112	-	-	-	-	112
		nonpt	254	82	-	-	-	-	82
		ptnonipm	309	251	-	-	-	233	251
		rwc	172	17	-	-	-	7	17
Oakland County, MI	Wayne County, MI	afdust	1,425	176	-	-	-	-	176
		nonpt	1,955	691	-	-	-	43	691
		ptnonipm	140	5	-	-	-	-	5
		rwc	897	82	-	-	-	13	82
Washtenaw County, MI	Wayne County, MI	afdust	784	112	-	-	-	-	112
		nonpt	610	222	-	-	-	42	222
		pt_oilgas	5	-	-	-	-	-	-
		ptnonipm	40	-	-	-	-	-	-
		rwc	273	30	-	-	-	10	30
Wayne County, MI	-	afdust	945	-	-	-	-	-	-
		nonpt	1,719	214	-	-	-	214	214
		ptnonipm	1,106	376	-	15	15	376	376
		rwc	506	55	-	-	-	55	55
St. Louis city, MO	-	afdust	682	55	-	-	-	-	55
		nonpt	240	35	-	-	-	-	35
		ptnonipm	237	58	-	-	-	-	58
		rwc	82	9	-	-	-	-	9
Beaverhead County, MT	Ravalli County, MT Silver Bow County, MT	afdust	1,211	89	-	-	-	-	-
		nonpt	17	3	-	-	-	-	-
		ptnonipm	5	-	-	-	-	-	-
		rwc	19	1	-	-	-	-	-

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
Broadwater County, MT	Lewis and Clark County, MT	afdust	967	162	-	-	-	-	-
		nonpt	16	4	-	-	-	-	-
		ptnonipm	30	13	-	-	-	-	-
		rwc	16	-	-	-	-	-	-
Cascade County, MT	Lewis and Clark County, MT	afdust	2,387	331	-	-	-	-	-
		nonpt	118	39	-	-	-	-	-
		ptagfire	52	-	-	-	-	-	-
		ptnonipm	50	19	-	-	-	-	-
		rwc	84	9	-	-	-	-	-
Deer Lodge County, MT	Ravalli County, MT Silver Bow County, MT	afdust	336	58	-	-	-	-	-
		nonpt	12	-	-	-	-	-	-
		rwc	14	-	-	-	-	-	-
Flathead County, MT	Lewis and Clark County, MT Lincoln County, MT	afdust	4,042	760	-	-	-	-	-
		nonpt	276	109	-	-	-	-	-
		ptagfire	5	-	-	-	-	-	-
		ptnonipm	136	71	-	-	-	-	-
		rwc	180	21	-	-	-	-	-
Granite County, MT	Ravalli County, MT	afdust	317	37	-	-	-	-	-
		nonpt	11	-	-	-	-	-	-
		rwc	9	-	-	-	-	-	-
Jefferson County, MT	Lewis and Clark County, MT Silver Bow County, MT	afdust	613	86	-	-	-	-	-
		nonpt	30	8	-	-	-	-	-
		ptnonipm	138	123	-	-	-	-	-
		rwc	31	2	-	-	-	-	-
Lewis and Clark County, MT	-	afdust	1,677	302	252	-	17	-	-
		nonpt	138	64	-	-	64	-	-
		ptagfire	5	-	-	-	-	-	-
		rwc	86	10	1	-	5	-	-
Lincoln County, MT	-	afdust	1,023	206	-	206	206	206	206
		nonpt	43	12	-	12	12	12	12
		rwc	67	7	-	7	7	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
Madison County, MT	Silver Bow County, MT	afdust	1,280	182	-	-	-	-	-
		nonpt	19	6	-	-	-	-	-
		ptnonipm	83	-	-	-	-	-	-
		rwc	25	2	-	-	-	-	-
Meagher County, MT	Lewis and Clark County, MT	afdust	441	36	-	-	-	-	-
		rwc	6	-	-	-	-	-	-
Powell County, MT	Lewis and Clark County, MT	afdust	677	104	-	-	-	-	-
		nonpt	18	3	-	-	-	-	-
		ptnonipm	22	10	-	-	-	-	-
		rwc	11	-	-	-	-	-	-
Ravalli County, MT	-	afdust	1,755	358	301	-	18	-	-
		nonpt	100	29	-	-	29	-	26
		rwc	94	11	-	-	11	-	6
Sanders County, MT	Lincoln County, MT	afdust	999	190	-	-	-	-	-
		nonpt	29	8	-	-	-	-	-
		ptnonipm	12	-	-	-	-	-	-
		rwc	43	5	-	-	-	-	-
Silver Bow County, MT	-	afdust	461	76	-	-	-	-	76
		nonpt	54	19	-	-	-	-	19
		ptnonipm	62	34	-	-	25	-	34
		rwc	44	5	-	-	-	-	5
Teton County, MT	Lewis and Clark County, MT	afdust	1,188	67	-	-	-	-	-
		nonpt	13	4	-	-	-	-	-
		ptagfire	221	-	-	-	-	-	-
		ptnonipm	5	-	-	-	-	-	-
		rwc	15	-	-	-	-	-	-
Atlantic County, NJ	Camden County, NJ	afdust	264	48	-	-	-	-	48
		nonpt	129	20	-	-	-	-	20
		ptnonipm	17	-	-	-	-	-	-
		rwc	262	31	-	-	-	7	31
Burlington County, NJ	Camden County, NJ	afdust	435	70	-	-	-	-	70
		nonpt	229	34	-	-	-	-	34
		ptnonipm	49	12	-	-	-	12	12
		rwc	562	67	-	-	-	13	67

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
Camden County, NJ	-	afdust	251	37	-	-	-	37	37
		nonpt	245	37	-	-	-	37	37
		ptnonipm	18	-	-	-	-	-	-
		rwc	240	35	-	-	-	35	35
Essex County, NJ	Union County, NJ	afdust	317	46	-	-	-	-	46
		nonpt	388	59	-	-	-	-	59
		ptnonipm	35	-	-	-	-	-	-
		rwc	155	10	-	-	-	-	10
Gloucester County, NJ	Camden County, NJ	afdust	250	34	-	-	-	-	34
		nonpt	147	22	-	-	-	-	22
		ptnonipm	262	185	-	-	-	20	185
		rwc	296	33	-	-	-	7	33
Hudson County, NJ	Union County, NJ	afdust	181	24	-	-	-	-	24
		nonpt	305	50	-	-	-	-	50
		ptnonipm	21	-	-	-	-	-	-
		rwc	11	-	-	-	-	-	-
Middlesex County, NJ	Union County, NJ	afdust	540	78	-	-	-	-	78
		nonpt	442	69	-	-	-	-	69
		ptnonipm	202	115	-	-	-	-	115
		rwc	267	39	-	-	-	-	39
Morris County, NJ	Union County, NJ	afdust	346	52	-	-	-	-	52
		nonpt	281	48	-	-	-	-	48
		ptnonipm	6	-	-	-	-	-	-
		rwc	624	64	-	-	-	-	64
Somerset County, NJ	Union County, NJ	afdust	234	7	-	-	-	-	7
		nonpt	189	28	-	-	-	-	28
		ptnonipm	8	-	-	-	-	-	-
		rwc	313	34	-	-	-	-	34
Union County, NJ	-	afdust	314	47	-	-	-	-	47
		nonpt	282	43	-	-	-	-	43
		pt_oilgas	11	-	-	-	-	-	-
		ptnonipm	246	66	-	-	-	-	66
		rwc	100	12	-	-	-	-	12

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
Bronx County, NY	New York County, NY	afdust	275	30	-	-	-	-	30
		nonpt	476	61	-	-	-	-	61
		ptnonipm	17	-	-	-	-	-	-
Kings County, NY	New York County, NY	afdust	455	55	-	-	-	-	55
		nonpt	1,232	160	-	-	-	-	160
		ptnonipm	35	-	-	-	-	-	-
		rwc	5	-	-	-	-	-	-
New York County, NY	-	afdust	996	-	-	-	-	-	-
		nonpt	1,640	261	-	-	-	-	261
		ptnonipm	51	7	-	-	-	-	7
Queens County, NY	New York County, NY	afdust	678	70	-	-	-	-	70
		nonpt	1,212	153	-	-	-	-	153
		ptnonipm	21	-	-	-	-	-	-
		rwc	13	-	-	-	-	-	-
Belmont County, OH	Jefferson County, OH	afdust	488	54	-	-	-	10	54
		nonpt	126	59	-	-	-	59	59
		np_oilgas	18	-	-	-	-	-	-
		pt_oilgas	9	-	-	-	-	-	-
		rwc	120	12	-	-	-	12	12
Butler County, OH	Hamilton County, OH	afdust	643	68	-	-	-	21	68
		nonpt	376	160	-	-	-	159	160
		ptnonipm	627	446	-	-	-	360	446
		rwc	350	31	-	-	-	31	31
Carroll County, OH	Jefferson County, OH	afdust	311	35	-	-	-	7	35
		nonpt	50	16	-	-	-	15	16
		np_oilgas	18	-	-	-	-	-	-
		pt_oilgas	28	-	-	-	-	-	-
		ptnonipm	22	13	-	-	-	6	13
		rwc	64	5	-	-	-	5	5
Clermont County, OH	Hamilton County, OH	afdust	499	64	-	-	-	-	64
		nonpt	329	192	-	-	-	-	192
		ptnonipm	8	-	-	-	-	-	-
		rwc	262	23	-	-	-	-	23

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
Columbiana County, OH	Jefferson County, OH	afdust	522	60	-	-	-	31	60
		nonpt	194	95	-	-	-	95	95
		np_oilgas	8	-	-	-	-	-	-
		pt_oilgas	9	-	-	-	-	-	-
		ptnonipm	41	-	-	-	-	-	-
		rwc	181	18	-	-	-	18	18
Cuyahoga County, OH	-	afdust	949	-	-	-	-	-	-
		nonpt	986	157	-	40	40	157	157
		ptnonipm	948	616	-	96	96	616	616
		rwc	457	52	-	3	3	52	52
Geauga County, OH	Cuyahoga County, OH	afdust	567	85	-	-	-	-	85
		nonpt	265	151	-	-	-	-	151
		rwc	196	20	-	-	-	9	20
Hamilton County, OH	Butler County, OH	afdust	1,192	92	-	-	-	-	92
		nonpt	829	295	-	-	-	-	295
		ptnonipm	155	11	-	-	-	-	11
		rwc	372	41	-	-	-	-	41
Harrison County, OH	Jefferson County, OH	afdust	308	31	-	-	-	-	31
		nonpt	34	10	-	-	-	10	10
		np_oilgas	16	-	-	-	-	-	-
		pt_oilgas	102	55	-	-	-	-	55
		ptnonipm	12	12	-	-	-	-	12
		rwc	40	2	-	-	-	2	2
Jefferson County, OH	-	afdust	239	-	-	-	-	-	-
		nonpt	115	61	-	-	-	61	61
		ptnonipm	72	19	-	-	-	19	19
		rwc	130	13	-	-	-	13	13
Lake County, OH	Cuyahoga County, OH	afdust	338	33	-	-	-	-	33
		nonpt	297	120	-	-	-	-	120
		ptnonipm	66	7	-	-	-	-	7
		rwc	237	24	-	-	-	6	24

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
Lorain County, OH	Cuyahoga County, OH	afdust	644	85	-	-	-	-	85
		nonpt	323	155	-	-	-	107	155
		ptnonipm	115	27	-	-	-	27	27
		rwc	337	34	-	-	-	11	34
Medina County, OH	Cuyahoga County, OH	afdust	692	93	-	-	-	-	93
		nonpt	373	221	-	-	-	-	221
		ptnonipm	40	-	-	-	-	-	-
		rwc	245	26	-	-	-	9	26
Montgomery County, OH	Butler County, OH	afdust	752	70	-	-	-	-	70
		nonpt	515	179	-	-	-	-	179
		ptnonipm	44	15	-	-	-	-	15
		rwc	426	38	-	-	-	-	38
Portage County, OH	Cuyahoga County, OH	afdust	558	73	-	-	-	-	73
		nonpt	296	157	-	-	-	-	157
		ptnonipm	121	35	-	-	-	7	35
		rwc	216	22	-	-	-	8	22
Preble County, OH	Butler County, OH	afdust	461	46	-	-	-	-	46
		nonpt	76	29	-	-	-	-	29
		ptnonipm	27	-	-	-	-	-	-
		rwc	72	6	-	-	-	-	6
Warren County, OH	Butler County, OH	afdust	521	59	-	-	-	-	59
	Hamilton County, OH	nonpt	446	284	-	-	-	-	284
		pt_oilgas	24	-	-	-	-	-	-
		ptnonipm	9	-	-	-	-	-	-
		rwc	252	23	-	-	-	-	23
Crook County, OR	Harney County, OR	afdust	1,126	209	-	-	209	-	126
		nonpt	28	16	9	-	7	-	-
		rwc	92	9	3	-	5	-	-
Deschutes County, OR	Crook County, OR	afdust	4,882	1,093	-	-	-	-	-
	Harney County, OR	nonpt	292	214	-	-	-	-	-
	Lake County, OR	pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	7	-	-	-	-	-	-
		rwc	689	72	-	-	-	-	-

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
Grant County, OR	Crook County, OR	afdust	679	110	-	-	-	-	-
	Harney County, OR	nonpt	23	6	-	-	-	-	-
		rwc	48	5	-	-	-	-	-
Harney County, OR	Crook County, OR	afdust	1,332	146	-	-	49	-	146
	Lake County, OR	nonpt	7	-	-	-	-	-	-
		rwc	32	2	-	-	-	-	2
Jefferson County, OR	Crook County, OR	afdust	1,423	300	-	-	-	-	-
		nonpt	32	17	-	-	-	-	-
		ptagfire	60	-	-	-	-	-	-
		rwc	93	9	-	-	-	-	-
Lake County, OR	Harney County, OR	afdust	1,106	141	141	-	-	-	-
		nonpt	11	4	4	-	-	-	-
		rwc	36	3	3	-	-	-	-
Malheur County, OR	Harney County, OR	afdust	2,371	336	-	-	-	-	-
		nonpt	30	11	-	-	-	-	-
		ptagfire	16	-	-	-	-	-	-
		ptnonipm	51	42	-	-	-	-	-
		rwc	78	8	-	-	-	-	-
Wheeler County, OR	Crook County, OR	afdust	222	34	-	-	-	-	-
		rwc	10	-	-	-	-	-	-
Allegheny County, PA	Armstrong County, PA	afdust	1,401	-	-	-	-	-	-
		nonpt	1,865	664	-	664	663	664	664
		np_oilgas	19	-	-	-	-	-	-
		ptnonipm	1,269	864	-	93	246	824	864
		rwc	878	85	-	85	85	85	85
Armstrong County, PA	Allegheny County, PA	afdust	279	18	-	-	-	18	18
		nonpt	125	49	-	-	-	49	49
		np_oilgas	132	-	-	-	-	-	-
		pt_oilgas	12	-	-	-	-	-	-
		ptnonipm	80	61	-	-	-	61	61
		rwc	130	15	-	-	-	15	15

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
Bedford County, PA	Cambria County, PA	afdust	419	28	-	-	-	-	28
		nonpt	155	79	-	-	-	-	79
		pt_oilgas	6	-	-	-	-	-	-
		rwc	142	14	-	-	-	-	14
Blair County, PA	Cambria County, PA	afdust	298	19	-	-	-	-	19
		nonpt	424	264	-	-	-	-	264
		ptnonipm	94	59	-	-	-	-	59
		rwc	203	22	-	-	-	-	22
Bucks County, PA	Philadelphia County, PA	afdust	829	68	-	-	-	-	68
		nonpt	1,043	401	-	-	-	-	401
		ptnonipm	111	65	-	-	-	-	65
		rwc	502	47	-	-	-	-	47
Butler County, PA	Allegheny County, PA	afdust	549	43	-	-	-	-	43
	Armstrong County, PA	nonpt	695	419	-	-	-	-	419
		np_oilgas	42	-	-	-	-	-	-
		pt_oilgas	16	-	-	-	-	-	-
		ptnonipm	413	140	-	-	-	24	140
		rwc	274	29	-	-	-	10	29
Cambria County, PA	-	afdust	260	27	-	-	-	-	27
		nonpt	273	124	-	-	-	34	124
		np_oilgas	7	-	-	-	-	-	-
		pt_oilgas	5	-	-	-	-	-	-
		ptnonipm	29	13	-	-	-	-	13
		rwc	253	27	-	-	-	-	27
Clarion County, PA	Armstrong County, PA	afdust	230	17	-	-	-	-	17
		nonpt	114	56	-	-	-	-	56
		np_oilgas	43	-	-	-	-	-	-
		ptnonipm	38	7	-	-	-	-	7
		rwc	86	10	-	-	-	4	10
Clearfield County, PA	Cambria County, PA	afdust	265	26	-	-	-	-	26
		nonpt	197	92	-	-	-	-	92
		np_oilgas	62	-	-	-	-	-	-
		ptnonipm	47	35	-	-	-	-	35
		rwc	186	19	-	-	-	-	19

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
Delaware County, PA	Philadelphia County, PA	afdust	388	38	-	-	-	38	38
		nonpt	478	58	-	-	-	58	58
		ptnonipm	270	165	-	-	-	165	165
		rwc	136	17	-	-	-	17	17
Indiana County, PA	Armstrong County, PA Cambria County, PA	afdust	356	29	-	-	-	-	29
		nonpt	206	91	-	-	-	-	91
		np_oilgas	163	-	-	-	-	-	-
		pt_oilgas	8	-	-	-	-	-	-
		ptnonipm	171	158	-	-	-	48	158
		rwc	147	16	-	-	-	6	16
Jefferson County, PA	Armstrong County, PA	afdust	226	16	-	-	-	-	16
		nonpt	133	55	-	-	-	-	55
		np_oilgas	73	-	-	-	-	-	-
		ptnonipm	192	177	-	-	-	-	177
		rwc	99	11	-	-	-	5	11
Lancaster County, PA	Lebanon County, PA	afdust	1,871	95	-	-	-	-	95
		nonpt	1,310	530	-	1	1	529	530
		pt_oilgas	10	-	-	-	-	-	-
		ptnonipm	494	272	-	58	58	235	272
		rwc	419	41	-	15	15	41	41
Lebanon County, PA	Lancaster County, PA	afdust	441	31	-	-	-	-	31
		nonpt	310	135	-	-	-	34	135
		ptnonipm	28	-	-	-	-	-	-
		rwc	152	15	-	-	-	10	15
Montgomery County, PA	Delaware County, PA Philadelphia County, PA	afdust	1,057	75	-	-	-	75	75
		nonpt	1,352	377	-	-	-	377	377
		pt_oilgas	11	-	-	-	-	-	-
		ptnonipm	328	143	-	-	-	143	143
		rwc	433	38	-	-	-	38	38
Philadelphia County, PA	Delaware County, PA	afdust	633	57	-	-	-	-	57
		nonpt	1,098	162	-	-	-	-	162
		ptnonipm	988	674	-	-	-	524	674
		rwc	42	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
Schuylkill County, PA	Lebanon County, PA	afdust	430	38	-	-	-	-	38
		nonpt	427	214	-	-	-	-	214
		ptnonipm	104	10	-	-	-	-	10
		rwc	255	25	-	-	-	-	25
Somerset County, PA	Cambria County, PA	afdust	479	25	-	-	-	-	25
		nonpt	257	146	-	-	-	-	146
		ptnonipm	89	15	-	-	-	-	15
		rwc	173	17	-	-	-	-	17
Westmoreland County, PA	Allegheny County, PA Armstrong County, PA Cambria County, PA	afdust	640	58	-	-	-	-	58
		nonpt	765	356	-	-	-	-	356
		np_oilgas	88	-	-	-	-	-	-
		pt_oilgas	33	-	-	-	-	-	-
		ptnonipm	228	135	-	-	-	18	135
		rwc	561	60	-	-	-	20	60
Brooks County, TX	Hidalgo County, TX	afdust	467	66	-	-	-	66	66
		np_oilgas	9	-	-	-	-	-	-
Cameron County, TX	Hidalgo County, TX	afdust	910	83	-	-	-	83	83
		nonpt	200	63	-	-	-	63	63
		ptagfire	94	-	-	-	-	-	-
		ptnonipm	26	-	-	-	-	-	-
		rwc	36	2	-	-	-	2	2
El Paso County, TX	-	afdust	1,592	-	-	-	-	-	-
		nonpt	442	169	-	-	-	10	169
		pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	234	65	-	-	-	21	65
		rwc	60	6	-	-	-	1	6
Hidalgo County, TX	Cameron County, TX	afdust	1,758	170	-	22	22	170	170
		nonpt	430	156	-	156	156	156	156
		np_oilgas	30	-	-	-	-	-	-
		pt_oilgas	9	-	-	-	-	-	-
		ptagfire	128	-	-	-	-	-	-
		ptnonipm	117	74	-	21	21	74	74
		rwc	60	6	-	6	6	6	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
Hudspeth County, TX	El Paso County, TX	afdust	245	31	-	-	-	-	31
		pt_oilgas	19	-	-	-	-	-	-
Kenedy County, TX	Hidalgo County, TX	afdust	269	43	-	-	-	43	43
Starr County, TX	Hidalgo County, TX	afdust	474	47	-	-	-	47	47
		nonpt	47	16	-	-	-	16	16
		np_oilgas	28	-	-	-	-	-	-
		pt_oilgas	9	-	-	-	-	-	-
		ptagfire	5	-	-	-	-	-	-
		rwc	8	-	-	-	-	-	-
Willacy County, TX	Cameron County, TX	afdust	355	22	-	-	-	22	22
	Hidalgo County, TX	nonpt	10	-	-	-	-	-	-
		ptagfire	32	-	-	-	-	-	-
Cache County, UT	Weber County, UT	afdust	1,603	225	-	-	225	-	-
		nonpt	53	9	-	-	9	-	-
		rwc	26	2	-	-	2	-	-
Davis County, UT	Salt Lake County, UT	afdust	455	43	-	-	43	-	-
	Weber County, UT	nonpt	125	23	-	-	23	-	-
		ptnonipm	95	9	-	-	9	-	-
		rwc	67	5	-	-	5	-	-
Morgan County, UT	Davis County, UT	afdust	201	32	-	-	-	-	-
	Salt Lake County, UT	nonpt	6	-	-	-	-	-	-
	Weber County, UT	ptnonipm	26	-	-	-	-	-	-
Rich County, UT	Cache County, UT	afdust	345	29	-	-	-	-	-
	Weber County, UT								
Salt Lake County, UT	Davis County, UT	afdust	1,649	83	-	-	83	-	-
		nonpt	445	84	22	-	12	-	-
		ptnonipm	789	263	206	-	57	-	-
		rwc	234	14	2	-	10	-	-
Summit County, UT	Salt Lake County, UT	afdust	635	92	-	-	-	-	-
		nonpt	40	8	-	-	-	-	-
		ptnonipm	61	-	-	-	-	-	-
		rwc	12	-	-	-	-	-	-

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
Tooele County, UT	Davis County, UT	afdust	641	104	-	-	-	-	-
	Salt Lake County, UT	nonpt	26	2	-	-	-	-	-
	Weber County, UT	ptnonipm	773	42	-	-	-	-	-
		rwc	15	-	-	-	-	-	-
Wasatch County, UT	Salt Lake County, UT	afdust	756	144	-	-	-	-	-
		nonpt	15	2	-	-	-	-	-
		rwc	9	-	-	-	-	-	-
Weber County, UT	Cache County, UT	afdust	557	19	-	-	19	-	-
	Davis County, UT	nonpt	91	15	-	-	15	-	-
		ptnonipm	65	-	-	-	-	-	-
		rwc	59	5	-	-	5	-	-
Benton County, WA	Yakima County, WA	afdust	1,539	63	-	-	-	-	-
		nonpt	139	24	-	-	-	-	-
		ptagfire	71	-	-	-	-	-	-
		rwc	108	9	-	-	-	-	-
Chelan County, WA	Kittitas County, WA	afdust	329	44	-	-	-	-	-
	Okanogan County, WA	nonpt	81	14	-	-	-	-	-
		ptagfire	26	-	-	-	-	-	-
		rwc	227	27	-	-	-	-	-
Douglas County, WA	Kittitas County, WA	afdust	2,049	186	-	-	-	-	-
	Okanogan County, WA	nonpt	23	2	-	-	-	-	-
		ptagfire	12	-	-	-	-	-	-
		ptnonipm	10	-	-	-	-	-	-
		rwc	84	9	-	-	-	-	-
Ferry County, WA	Okanogan County, WA	afdust	397	63	-	-	-	-	-
		nonpt	9	-	-	-	-	-	-
		rwc	41	5	-	-	-	-	-
Grant County, WA	Kittitas County, WA	afdust	3,242	169	-	-	-	-	-
	Okanogan County, WA	nonpt	78	13	-	-	-	-	-
	Yakima County, WA	ptagfire	264	-	-	-	-	-	-
		ptnonipm	68	43	-	-	-	-	-
		rwc	109	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
Kittitas County, WA	Yakima County, WA	afdust	472	47	47	-	-	-	-
		nonpt	51	8	8	-	-	-	-
		ptagfire	9	-	-	-	-	-	-
		rwc	113	13	13	-	-	-	-
Klickitat County, WA	Yakima County, WA	afdust	568	54	-	-	-	-	-
		nonpt	20	1	-	-	-	-	-
		ptagfire	14	-	-	-	-	-	-
		ptnonipm	44	8	-	-	-	-	-
		rwc	55	6	-	-	-	-	-
Lewis County, WA	Yakima County, WA	afdust	550	65	-	-	-	-	-
		nonpt	82	15	-	-	-	-	-
		ptnonipm	94	20	-	-	-	-	-
		rwc	226	24	-	-	-	-	-
Lincoln County, WA	Okanogan County, WA	afdust	2,537	130	-	-	-	-	-
		nonpt	10	-	-	-	-	-	-
		ptagfire	40	-	-	-	-	-	-
		rwc	26	3	-	-	-	-	-
Okanogan County, WA	-	afdust	771	113	-	-	113	-	-
		nonpt	42	9	-	-	9	-	-
		ptagfire	12	-	-	-	-	-	-
		rwc	154	17	-	-	17	-	-
Pierce County, WA	Kittitas County, WA Yakima County, WA	afdust	1,540	7	-	-	-	-	-
		nonpt	574	103	-	-	-	-	-
		ptnonipm	200	99	-	-	-	-	-
		rwc	1,047	93	-	-	-	-	-
Skagit County, WA	Okanogan County, WA	afdust	626	67	-	-	-	-	-
		nonpt	131	24	-	-	-	-	-
		pt_oilgas	6	-	-	-	-	-	-
		ptnonipm	252	137	-	-	-	-	-
		rwc	237	26	-	-	-	-	-
Skamania County, WA	Yakima County, WA	afdust	122	18	-	-	-	-	-
		nonpt	8	-	-	-	-	-	-
		rwc	57	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
Whatcom County, WA	Okanogan County, WA	afdust	874	69	-	-	-	-	-
		nonpt	227	48	-	-	-	-	-
		pt_oilgas	8	-	-	-	-	-	-
		ptnonipm	851	762	-	-	-	-	-
		rwc	365	35	-	-	-	-	-
Yakima County, WA	Kittitas County, WA	afdust	1,845	100	100	-	-	-	-
		nonpt	193	41	41	-	-	-	-
		ptagfire	177	-	-	-	-	-	-
		rwc	345	39	39	-	-	-	-
Brooke County, WV	-	afdust	90	12	-	-	-	-	12
		nonpt	44	19	-	-	-	-	19
		ptnonipm	127	76	-	-	-	-	76
		rwc	103	13	-	-	-	-	13
Hancock County, WV	Brooke County, WV	afdust	58	8	-	-	-	-	8
		nonpt	51	9	-	-	-	-	9
		ptnonipm	32	-	-	-	-	-	-
		rwc	122	15	-	-	-	-	15
Marshall County, WV	-	afdust	179	24	-	-	-	-	24
		nonpt	46	13	-	-	-	-	13
		np_oilgas	14	-	-	-	-	-	-
		pt_oilgas	13	-	-	-	-	-	-
		ptnonipm	109	92	-	-	-	-	92
		rwc	158	19	-	-	-	-	19
Ohio County, WV	Brooke County, WV Marshall County, WV	afdust	238	40	-	-	-	-	40
		nonpt	97	38	-	-	-	-	38
		np_oilgas	26	-	-	-	-	-	-
		rwc	143	18	-	-	-	-	18
Wetzel County, WV	Marshall County, WV	afdust	77	12	-	-	-	-	12
		nonpt	41	22	-	-	-	-	22
		np_oilgas	35	-	-	-	-	-	-
		pt_oilgas	8	-	-	-	-	-	-
		rwc	82	11	-	-	-	-	11

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 proposed annual and current 24-hour alternative standard levels of 10/35 µg/m^3 and 9/35 µg/m^3, as well as the following two more stringent alternative standard levels: 8/35 µg/m^3 and 10/30 µg/m^3. Because the EPA is proposing that the current secondary PM standards be retained, 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 alternative standards analyzed we applied control measures 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 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 control measures needed to estimate engineering costs; and (iii) the future year baseline emissions from which the emissions reductions are measured.

For the proposed alternative standard level of 10/35 µg/m^3, because 15 of the 24 counties that need emissions reductions are counties in California, the majority of the estimated costs are incurred in California. 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 (and less so in the west and California because availability of additional controls is limited), those areas account for a relatively higher proportion of estimated costs. For example, for 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 their adjacent counties and the southeast and their adjacent counties. The estimated costs for those areas are higher than the estimated costs for the west and California. Note that in the northeast and southeast we identified control measures 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 also contributes to the higher proportion of the estimated costs. Lastly, for the more stringent alternative standard level of 8/35 $\mu g/m^3$, across all areas the largest share of estimated costs is from controls for area fugitive dust emissions.

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 control technologies 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 proposed and more stringent alternative standard levels. As discussed in this analysis, the control technologies 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 control technologies or measures 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 proposed 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 $\mu g/m^3$ 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 measures 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

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[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 measure and the interest rate incorporated into the CRF. Annualized costs represent an equal stream of yearly costs over the period the control technology 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 control technologies and measures presented in Chapter 3 that include 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

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[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.

4-5 reflect the engineering costs annualized at 7 percent, to the extent possible.[4] When calculating the annualized costs we would like to use the interest rates faced by firms; however, we do not know what those rates are. As such we use 7 percent as a conservative estimate.

By area, Table 4-1 includes a summary of estimated control costs from control applications for the alternative standard levels analyzed. Tables 4A-1 through 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 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	$7.3	$12.8	$183.5	$560.2
Northeast (Adjacent Counties)	$0	$0	$22.3	$539.7
Southeast	$4.1	$4.1	$50.4	$250.6
Southeast (Adjacent Counties)	$0	$0	$18.2	$186.5
West	$19.0	$150.0	$34.2	$121.8
CA	$64.1	$90.4	$84.7	$162.9
Total	$94.5	$257.2	$393.3	$1,821.7

For the proposed alternative standard level of 10/35 μg/m^3, the majority of the estimated costs are incurred in California because 15 of the 24 counties that need emissions reductions are located in California. Looking at the more stringent alternative standard level of 10/30 μg/m^3 in the west, an additional 20 counties need emissions reductions, and the estimated costs increase significantly; estimated costs for the proposed alternative standard level 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 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

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[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).

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

As discussed in Chapter 3, in the northeast and southeast when we applied the emissions reductions from adjacent counties, we applied a ratio of 4:1. That is, it is assumed that 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. Application of this ratio contributes to the higher cost estimates for alternative standard levels of 9/35 μg/m^3 and 8/35 μg/m^3. Naturally, it is anticipated that states will first attempt to find emissions reductions within the counties that actually 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 alternative standard levels analyzed. For all of the alternative standard levels analyzed, controls for area fugitive dust emissions comprise the largest share of the estimated costs, ranging from 49 to 81 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 alternative standard levels analyzed. For the more stringent alternative standard level 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 alternative 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 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	$10.2	$21.2	$144.3	$423.7
Oil & Gas Point	$0	$0	$0	$5.0
Non-Point (Area)	$15.8	$21.4	$46.3	$189.2
Residential Wood Combustion	$3.1	$5.6	$11.3	$36.7
Area Source Fugitive Dust	$65.4	$209.1	$191.5	$1,167.0
Total	$94.5	$257.2	$393.3	$1,821.7

Table 4-3 By Area and by Emissions Inventory Sector, Summary of Annualized Control Costs for 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	$1.7	$7.3	$125.0	$232.8
	Non-Point (Area)	$4.6	$4.6	$16.8	$56.4
	Residential Wood Combustion	$1.0	$1.0	$4.1	$10.5
	Area Source Fugitive Dust	$0	$0	$37.7	$260.5
Northeast (Adjacent Counties)	Non-EGU Point	$0	$0	$4.0	$65.3
	Oil & Gas Point	$0	$0	$0	$5.0
	Non-Point (Area)	$0	$0	$4.4	$50.5
	Residential Wood Combustion	$0	$0	$0.8	$10.6
	Area Source Fugitive Dust	$0	$0	$13.1	$408.4
Southeast	Non-EGU Point	$1.2	$1.2	$6.2	$81.4
	Oil & Gas Point	$0	$0	$0	$0.02
	Non-Point (Area)	$2.0	$2.0	$10.1	$37.7
	Residential Wood Combustion	$0.3	$0.3	$0.6	$2.4
	Area Source Fugitive Dust	$0.7	$0.7	$33.6	$129.0
Southeast (Adjacent Counties)	Non-EGU Point	$0	$0	$0	$17.9
	Non-Point (Area)	$0	$0	$0.1	$10.0
	Residential Wood Combustion	$0	$0	$0	$1.4
	Area Source Fugitive Dust	$0	$0	$18.1	$157.3
West	Non-EGU Point	$0	$5.4	$0.6	$11.9
	Non-Point (Area)	$0.06	$3.6	$2.1	$13.4
	Residential Wood Combustion	$0.03	$1.1	$0.4	$2.8
	Area Source Fugitive Dust	$19.0	$139.9	$31.0	$93.7
CA	Non-EGU Point	$7.3	$7.3	$8.4	$14.5
	Non-Point (Area)	$9.2	$11.2	$12.8	$21.2
	Residential Wood Combustion	$1.9	$3.3	$5.5	$9.0
	Area Source Fugitive Dust	$45.8	$68.5	$58.0	$118.2
Total		$94.5	$257.2	$393.3	$1,821.7

By control technology, Table 4-4 includes a summary of the estimated costs from control applications for the alternative standard levels analyzed. Across all of the alternative standard levels analyzed, the control technologies that comprise more than 80 percent of the cost estimates include Pave Existing Shoulders at 25% rule penetration (RP) (area fugitive dust inventory sector), Pave Unpaved Roads at 25% RP (area fugitive dust inventory sector), Fabric Filter-All Types (non-EGU point inventory sector), and Electrostatic Precipitator at 25% RP (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 alternative 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 at 25% RP 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 at 25% RP 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 at 25% and Pave Unpaved Roads at 25% result in the highest portion of estimated costs for that inventory sector.

Table 4-4 By Control Technology, Summary of Annualized Control Costs for 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$)

Control Technology	10/35	10/30	9/35	8/35
Add-on Scrubber at 25% RP	$0.06	$0.06	$0	$0
Annual tune-up at 10% RP	$0	$0.01	$0.01	$0.01
Annual tune-up at 25% RP	$0.6	$0.7	$3.4	$12.0
Biennial tune-up at 10% RP	$0.0	$0.0	$0.0	$0.3
Biennial tune-up at 25% RP	$0.1	$0.3	$0.3	$2.0
Catalytic oxidizers at 25% RP	$0.3	$0.4	$1.1	$1.4
Chemical Stabilizer at 10% RP	$0.7	$2.2	$1.3	$46.8
Chemical Stabilizer at 25% RP	$0	$0	$1.6	$49.8
Convert to Gas Logs at 25% RP	$2.6	$4.4	$9.5	$29.0
Dust Suppressants at 10% RP	$0	$0	$0	$0.02
Dust Suppressants at 25% RP	$0	$0	$0	$5.4
Electrostatic Precipitator-All Types	$0.4	$0	$0.4	$0.7
Electrostatic Precipitator at 10% RP	$0	$0	$0.1	$0.01
Electrostatic Precipitator at 25% RP	$10.7	$13.1	$20.4	$80.6
EPA-certified wood stove at 10% RP	$0	$0	$0	$0.01
EPA Phase 2 Qualified Units at 10% RP	$0	$0	$0.2	$0.03
EPA Phase 2 Qualified Units at 25% RP	$0.2	$0.2	$0	$0.7
Fabric Filter-All Types	$9.0	$18.9	$129.1	$397.2
HEPA filters at 10% RP	$0.01	$0.01	$0.01	$0.02
HEPA filters at 25% RP	$0.02	$0	$0.09	$0.4
Install Cleaner Hydronic Heaters at 10% RP	$0	$0.0	$0	$0
Install Cleaner Hydronic Heaters at 25% RP	$0.02	$0.03	$0.2	$0.7
Install new drift eliminator at 10% RP	$0	$0	$0.02	$0.01
Install new drift eliminator at 25% RP	$0.5	$0.5	$0.6	$1.3
Install Retrofit Devices at 10% RP	$0	$0	$0.1	$0.06
Install Retrofit Devices at 25% RP	$0.1	$0.1	$0	$0.08
New gas stove or gas logs at 10% RP	$0.03	$0.4	$0.4	$0.7
New gas stove or gas logs at 25% RP	$0.2	$0.5	$0.9	$5.4
Pave existing shoulders at 10% RP	$0	$0	$0	$7.6
Pave existing shoulders at 25% RP	$31.1	$95.0	$119.6	$755.0
Pave Unpaved Roads at 25% RP	$33.7	$111.8	$69.0	$302.5
Smokeless Broiler at 10% RP	$0.4	$0.6	$1.1	$0.3
Smokeless Broiler at 25% RP	$0	$0	$3.1	$1.3
Substitute chipping for burning	$3.5	$6.1	$16.6	$90.6
Venturi Scrubber	$0.3	$1.7	$14.3	$29.7
Total	$94.5	$257.2	$393.3	$1,821.7

Note - The 10% RP and 25% RP indicate the rule penetration percent, or the percent of the non-point (area), residential wood combustion, or area fugitive dust inventory emissions that the control measure is applied to at a specified percent control efficiency.

Table 4-5 By Emissions Inventory Sector and Control Technology, Summary of Annualized Control Costs for 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$)

Inventory Sector	Control Technology	10/35	10/30	9/35	8/35
Non-EGU Point	Electrostatic Precipitator-All Types	$0.4	$0	$0.4	$0.7
	Fabric Filter-All Types	$9.0	$18.9	$129.0	$392.0
	Install new drift eliminator at 10% RP	$0	$0	$0.02	$0.01
	Install new drift eliminator at 25% RP	$0.5	$0.5	$0.6	$1.3
	Venturi Scrubber	$0.3	$1.7	$14.3	$29.7
Oil & Gas Point	Fabric Filter-All Types	$0	$0	$0	$5.0
	Install new drift eliminator at 25% RP	$0	$0	$0	$0.02
Non-Point (Area)	Add-on Scrubber at 25% RP	$0.06	$0.06	$0	$0
	Annual tune-up at 10% RP	$0	$0.01	$0.01	$0.01
	Annual tune-up at 25% RP	$0.6	$0.7	$3.4	$12.0
	Biennial tune-up at 10% RP	$0.0	$0.0	$0.0	$0.3
	Biennial tune-up at 25% RP	$0.1	$0.3	$0.3	$2.0
	Catalytic oxidizers at 25% RP	$0.3	$0.4	$1.1	$1.4
	Electrostatic Precipitator at 10% RP	$0	$0	$0.1	$0.01
	Electrostatic Precipitator at 25% RP	$10.7	$13.1	$20.4	$80.6
	Fabric Filter-All Types	$0	$0	$0.09	$0.2
	HEPA filters at 10% RP	$0.01	$0.01	$0.01	$0.02
	HEPA filters at 25% RP	$0.02	$0	$0.09	$0.4
	Smokeless Broiler at 10% RP	$0.4	$0.6	$1.1	$0.3
	Smokeless Broiler at 25% RP	$0	$0	$3.1	$1.3
	Substitute chipping for burning	$3.5	$6.1	$16.6	$90.6
Residential Wood Combustion	Convert to Gas Logs at 25% RP	$2.6	$4.4	$9.5	$29.0
	EPA-certified wood stove at 10% RP	$0	$0	$0	$0.01
	EPA Phase 2 Qualified Units at 10% RP	$0	$0	$0.2	$0.03
	EPA Phase 2 Qualified Units at 25% RP	$0.2	$0.2	$0	$0.7
	Install Cleaner Hydronic Heaters at 10% RP	$0	$0.0	$0	$0
	Install Cleaner Hydronic Heaters at 25% RP	$0.02	$0.03	$0.2	$0.7
	Install Retrofit Devices at 10% RP	$0	$0	$0.1	$0.06
	Install Retrofit Devices at 25% RP	$0.1	$0.1	$0	$0.08
	New gas stove or gas logs at 10% RP	$0.03	$0.4	$0.4	$0.7
	New gas stove or gas logs at 25% RP	$0.2	$0.5	$0.9	$5.4
Area Source Fugitive Dust	Chemical Stabilizer at 10% RP	$0.7	$2.2	$1.3	$46.8
	Chemical Stabilizer at 25% RP	$0	$0	$1.6	$49.8
	Dust Suppressants at 10% RP	$0	$0	$0	$0.02
	Dust Suppressants at 25% RP	$0	$0	$0	$5.4
	Pave existing shoulders at 10% RP	$0	$0	$0	$7.6
	Pave existing shoulders at 25% RP	$31.1	$95.0	$119.6	$755.0
	Pave Unpaved Roads at 25% RP	$33.7	$111.8	$69.0	$302.5
Total		$94.5	$257.2	$393.3	$1,821.7

Note - The 10% RP and 25% RP indicate the rule penetration percent, or the percent of the non-point (area), residential wood combustion, or area fugitive dust inventory emissions that the control measure is applied to at a specified percent control efficiency.

As discussed in Chapter 2, Section 2.4 and Chapter 3, Section 3.2.6, for the proposed alternative standard levels of 10/35 μg/m^3 and 9/35 μg/m^3 there are remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California; the areas include a county in Pennsylvania affected by local sources, 3 counties in border areas, 5 counties in small western mountain valleys, and 13 counties in California's air basins and districts. The characteristics of the air quality challenges for these areas include features of local source-to-monitor impacts, 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, which include the following:

- **Exclusions from the cost analysis**: As mentioned above, recordkeeping, reporting, testing and monitoring costs are not included. The costs some states will incur both designing SIPs and implementing new control strategies to meet a revised standard are also not included.

- **Cost and effectiveness of control measures**: We are not able to account for regional or local variation in capital and annual cost items such as energy, labor, or materials. Our estimates of control measure costs may over- or under-estimate the costs depending on how the difficulty of actual retrofitting and equipment life compares with our control assumptions. In addition, our estimates of control efficiencies for the controls assume that the control devices are properly installed and maintained. Further, our estimates of control efficiencies do not account for differences in individual applications as we use a single value for each control that does not account for differences in individual applications – sometimes a control operates more or less effectively than the specified efficiency. There is also variability in scale of application that 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, 2010). 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 its net impact on society.

Computable General Equilibrium (CGE) models are analytical tools that can be used to evaluate the broad impacts of a regulatory action and are therefore often used to estimate social costs. While this section includes a qualitative discussion of social costs and economic impact modeling, CGE modeling was not conducted for this analysis because EPA's current CGE model, discussed later in this section, does not have the resolution needed to accurately model the emissions inventory sectors being controlled (e.g., area fugitive dust inventory sector, residential wood combustion inventory sector). However, the EPA continues to be committed to the use of CGE models to evaluate the economy-wide effects of its regulations.

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

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[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.

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 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 alternative standard levels analyzed are anticipated to impact multiple markets in many places over time. CGE models are one possible tool for evaluating the impacts of a regulation on the broader economy because this class of models explicitly captures 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. 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 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 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.

The SAB also noted that the case for using CGE models to evaluate a regulation's effects is strongest when the industry sector has strong linkages to the rest of the economy. The report also noted that the extent to which CGE models add value to the analysis depends on data availability. CGE models provide aggregated representations of the entire economy and are designed to capture substitution possibilities between production, consumption, and trade; interactions between economic sectors; and interactions between a policy shock and pre-existing distortions, such as taxes. However, one also needs to adequately represent a regulation in the model to estimate its effects.

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 EPA now has a peer-reviewed CGE model for analyzing the potential economy-wide effects of regulations, we did not use the model in the RIA for this proposal, but the EPA continue to be committed to the use of CGE models to evaluate the economy-wide effects of its regulations.

Lastly, 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 this 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.

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 alternative annual and 24-hour standard levels in this regulatory impact analysis (RIA) -- 10/35 µg/m^3, 10/30 µg/m^3, 9/35 µg/m^3, and 8/35 µg/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 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 would like to use the interest rates faced by firms; however, we do not know what those rates are. As such we use 7 percent as a conservative estimate.

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 northeast 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 (57 counties) for 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$)

County	10/35	10/30	9/35	8/35
New Castle County, DE	$0	$0	$0	$0.8
Cook County, IL	$0	$0	$2.1	$13.7
Madison County, IL	$0	$0	$0	$23.8
St. Clair County, IL	$0	$0	$0	$48.8
Allen County, IN	$0	$0	$0	$0.2

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[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
Clark County, IN	$0	$0	$0	$1.9
Elkhart County, IN	$0	$0	$0	$9.7
Floyd County, IN	$0	$0	$0	$0.2
Lake County, IN	$0	$0	$0	$0.7
Marion County, IN	$0	$0	$31.1	$31.1
St. Joseph County, IN	$0	$0	$0	$10.0
Vanderburgh County, IN	$0	$0	$0	$7.4
Vigo County, IN	$0	$0	$0	$6.6
Jefferson County, KY	$0	$0	$0	$22.0
Baltimore city, MD	$0	$0	$0	$0.3
Howard County, MD	$0	$0	$0	$10.0
Kent County, MI	$0	$0	$0	$1.3
Wayne County, MI	$0.02	$0.02	$15.1	$15.1
Buchanan County, MO	$0	$0	$0	$0.9
Jackson County, MO	$0	$0	$0	$0.07
Jefferson County, MO	$0	$0	$0	$1.4
St. Louis city, MO	$0	$0	$0	$10.5
St. Louis County, MO	$0	$0	$0	$11.0
Camden County, NJ	$0	$0	$6.6	$6.6
Union County, NJ	$0	$0	$0	$8.3
New York County, NY	$0	$0	$0	$4.0
Butler County, OH	$0	$0	$13.3	$31.8
Cuyahoga County, OH	$0.4	$0.4	$23.5	$23.5
Franklin County, OH	$0	$0	$0	$0.5
Hamilton County, OH	$0	$0	$0	$16.9
Jefferson County, OH	$0	$0	$1.0	$1.0
Lucas County, OH	$0	$0	$0	$11.5
Mahoning County, OH	$0	$0	$0	$0.6
Stark County, OH	$0	$0	$0	$18.4
Summit County, OH	$0	$0	$0	$11.5
Allegheny County, PA	$6.8	$12.3	$60.3	$65.8
Armstrong County, PA	$0	$0	$4.1	$4.1
Beaver County, PA	$0	$0	$0	$7.5
Berks County, PA	$0	$0	$0	$0.4
Cambria County, PA	$0	$0	$0.2	$5.5
Chester County, PA	$0	$0	$0	$17.1
Dauphin County, PA	$0	$0	$0	$1.4
Delaware County, PA	$0	$0	$15.8	$15.8
Lackawanna County, PA	$0	$0	$0	$0.08
Lancaster County, PA	$0.08	$0.08	$8.1	$27.2
Lebanon County, PA	$0	$0	$0.2	$5.6
Lehigh County, PA	$0	$0	$0	$0.4
Mercer County, PA	$0	$0	$0	$6.3
Philadelphia County, PA	$0	$0	$2.2	$22.5
Washington County, PA	$0	$0	$0	$1.2
York County, PA	$0	$0	$0	$1.6
Providence County, RI	$0	$0	$0	$1.0
Davidson County, TN	$0	$0	$0	$0.4
Knox County, TN	$0	$0	$0	$1.3

County	10/35	10/30	9/35	8/35
Berkeley County, WV	$0	$0	$0	$0.5
Brooke County, WV	$0	$0	$0	$6.4
Marshall County, WV	$0	$0	$0	$6.0
Total	$7.3	$12.8	$183.5	$560.2

Table 4A-2 Summary of Estimated Annual Control Costs for Adjacent Counties in the Northeast (75 counties) for 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
Clinton County, IL	Madison County, IL St. Clair County, IL	$0	$0	$0	$7.1
DuPage County, IL	Cook County, IL	$0	$0	$0	$1.5
Kane County, IL	Cook County, IL	$0	$0	$0	$1.1
Lake County, IL	Cook County, IL	$0	$0	$0	$11.3
McHenry County, IL	Cook County, IL	$0	$0	$0	$0.9
Monroe County, IL	St. Clair County, IL	$0	$0	$0	$6.7
Randolph County, IL	St. Clair County, IL	$0	$0	$0	$4.8
Washington County, IL	St. Clair County, IL	$0	$0	$0	$6.7
Will County, IL	Cook County, IL	$0	$0	$0	$11.7
Boone County, IN	Marion County, IN	$0	$0	$0.0	$3.9
Clay County, IN	Vigo County, IN	$0	$0	$0	$2.2
Gibson County, IN	Vanderburgh County, IN	$0	$0	$0	$0.2
Hamilton County, IN	Marion County, IN	$0	$0	$0.01	$11.1
Hancock County, IN	Marion County, IN	$0	$0	$0.0	$3.8
Hendricks County, IN	Marion County, IN	$0	$0	$0.02	$10.3
Johnson County, IN	Marion County, IN	$0	$0	$0.0	$5.8
LaPorte County, IN	St. Joseph County, IN	$0	$0	$0	$8.9
Marshall County, IN	Elkhart County, IN St. Joseph County, IN	$0	$0	$0	$5.8
Morgan County, IN	Marion County, IN	$0	$0	$0.01	$7.4
Parke County, IN	Vigo County, IN	$0	$0	$0	$1.3
Posey County, IN	Vanderburgh County, IN	$0	$0	$0	$3.9
Shelby County, IN	Marion County, IN	$0	$0	$0.0	$10.1
Starke County, IN	St. Joseph County, IN	$0	$0	$0	$1.5
Sullivan County, IN	Vigo County, IN	$0	$0	$0	$2.8
Vermillion County, IN	Vigo County, IN	$0	$0	$0	$0.06
Warrick County, IN	Vanderburgh County, IN	$0	$0	$0	$4.8
Bullitt County, KY	Jefferson County, KY	$0	$0	$0	$0.08
Hardin County, KY	Jefferson County, KY	$0	$0	$0	$0.1
Oldham County, KY	Jefferson County, KY	$0	$0	$0	$0.06
Shelby County, KY	Jefferson County, KY	$0	$0	$0	$0.07
Spencer County, KY	Jefferson County, KY	$0	$0	$0	$0.06
Montgomery County, MD	Howard County, MD	$0	$0	$0	$0.0
Macomb County, MI	Wayne County, MI	$0	$0	$0.3	$15.8
Monroe County, MI	Wayne County, MI	$0	$0	$0.9	$14.4
Oakland County, MI	Wayne County, MI	$0	$0	$0.2	$30.5

County	Adjacent Counties	10/35	10/30	9/35	8/35
Washtenaw County, MI	Wayne County, MI	$0	$0	$0.2	$14.9
Atlantic County, NJ	Camden County, NJ	$0	$0	$0.01	$6.4
Burlington County, NJ	Camden County, NJ	$0	$0	$0.02	$10.3
Essex County, NJ	Union County, NJ	$0	$0	$0	$8.0
Gloucester County, NJ	Camden County, NJ	$0	$0	$0.03	$8.1
Hudson County, NJ	Union County, NJ	$0	$0	$0	$4.3
Middlesex County, NJ	Union County, NJ	$0	$0	$0	$13.5
Morris County, NJ	Union County, NJ	$0	$0	$0	$8.7
Somerset County, NJ	Union County, NJ	$0	$0	$0	$1.5
Bronx County, NY	New York County, NY	$0	$0	$0	$5.3
Kings County, NY	New York County, NY	$0	$0	$0	$10.4
Queens County, NY	New York County, NY	$0	$0	$0	$12.6
Belmont County, OH	Jefferson County, OH	$0	$0	$0.7	$7.1
Carroll County, OH	Jefferson County, OH Stark County, OH	$0	$0	$0.3	$4.7
Clermont County, OH	Hamilton County, OH	$0	$0	$0	$9.2
Columbiana County, OH	Jefferson County, OH Mahoning County, OH Stark County, OH	$0	$0	$1.6	$7.6
Geauga County, OH	Cuyahoga County, OH Summit County, OH	$0	$0	$0.01	$10.8
Harrison County, OH	Jefferson County, OH	$0	$0	$0.05	$9.1
Lake County, OH	Cuyahoga County, OH	$0	$0	$0.01	$6.0
Lorain County, OH	Cuyahoga County, OH	$0	$0	$0.6	$11.8
Medina County, OH	Cuyahoga County, OH Summit County, OH	$0	$0	$0.01	$13.0
Montgomery County, OH	Butler County, OH	$0	$0	$0	$14.2
Portage County, OH	Cuyahoga County, OH Mahoning County, OH Stark County, OH Summit County, OH	$0	$0	$0.04	$11.7
Preble County, OH	Butler County, OH	$0	$0	$0	$5.9
Warren County, OH	Butler County, OH Hamilton County, OH	$0	$0	$0	$9.6
Bedford County, PA	Cambria County, PA	$0	$0	$0	$4.9
Blair County, PA	Cambria County, PA	$0	$0	$0	$8.3
Bucks County, PA	Lehigh County, PA Philadelphia County, PA	$0	$0	$0	$14.1
Butler County, PA	Allegheny County, PA Armstrong County, PA Beaver County, PA Mercer County, PA	$0	$0	$0.03	$14.5
Clarion County, PA	Armstrong County, PA	$0	$0	$0.0	$3.4
Clearfield County, PA	Cambria County, PA	$0	$0	$0	$5.6
Indiana County, PA	Armstrong County, PA Cambria County, PA	$0	$0	$0.06	$6.8
Jefferson County, PA	Armstrong County, PA	$0	$0	$0.0	$6.9

County	Adjacent Counties	10/35	10/30	9/35	8/35
Montgomery County, PA	Berks County, PA Chester County, PA Delaware County, PA Lehigh County, PA Philadelphia County, PA	$0	$0	$17.2	$17.2
Schuylkill County, PA	Berks County, PA Dauphin County, PA Lebanon County, PA Lehigh County, PA	$0	$0	$0	$7.2
Somerset County, PA	Cambria County, PA	$0	$0	$0	$5.2
Westmoreland County, PA	Allegheny County, PA Armstrong County, PA Cambria County, PA Washington County, PA	$0	$0	$0.03	$17.4
Hancock County, WV	Brooke County, WV	$0	$0	$0	$0.9
Ohio County, WV	Brooke County, WV Marshall County, WV	$0	$0	$0	$4.4
Wetzel County, WV	Marshall County, WV	$0	$0	$0	$1.4
Total		$0	$0	$22.3	$539.7

Table 4A-3 Summary of Estimated Annual Control Costs for the Southeast (35 counties) for 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	$0.7	$4.5
Talladega County, AL	$0	$0	$0	$0.3
Pulaski County, AR	$0	$0	$0	$12.8
Union County, AR	$0	$0	$0	$0.3
District of Columbia	$0	$0	$0	$7.1
Bibb County, GA	$0	$0	$0	$7.8
Clayton County, GA	$0	$0	$0	$5.4
Cobb County, GA	$0	$0	$0	$0.3
DeKalb County, GA	$0	$0	$0	$0.3
Dougherty County, GA	$0	$0	$0	$2.4
Floyd County, GA	$0	$0	$0	$15.4
Fulton County, GA	$0	$0	$3.1	$29.9
Gwinnett County, GA	$0	$0	$0	$0.1
Muscogee County, GA	$0	$0	$0	$8.5
Richmond County, GA	$0	$0	$0	$5.6
Wilkinson County, GA	$0	$0	$0	$14.0
Wyandotte County, KS	$0	$0	$0	$0.2
Caddo Parish, LA	$0	$0	$2.9	$16.7
East Baton Rouge Parish, LA	$0	$0	$0	$2.9
Iberville Parish, LA	$0	$0	$0	$0.02
St. Bernard Parish, LA	$0	$0	$0	$0.9
West Baton Rouge Parish, LA	$0	$0	$0	$11.7

County	10/35	10/30	9/35	8/35
Hinds County, MS	$0	$0	$0	$0.2
Davidson County, NC	$0	$0	$0	$3.3
Mecklenburg County, NC	$0	$0	$0	$0.5
Wake County, NC	$0	$0	$0	$0.3
Tulsa County, OK	$0	$0	$0	$0.4
Greenville County, SC	$0	$0	$0	$0.6
Cameron County, TX	$0	$0	$11.2	$11.2
Dallas County, TX	$0	$0	$0	$0.2
El Paso County, TX	$0	$0	$0.2	$4.7
Harris County, TX	$1.4	$1.4	$5.5	$25.0
Hidalgo County, TX	$2.7	$2.7	$26.6	$26.6
Nueces County, TX	$0	$0	$0	$25.4
Travis County, TX	$0	$0	$0.2	$4.9
Total	$4.1	$4.1	$50.4	$250.6

Table 4A-4 Summary of Estimated Annual Control Costs for Adjacent Counties in the Southeast (32 counties) for 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
Bartow County, GA	Cobb County, GA Floyd County, GA	$0	$0	$0	$8.4
Carroll County, GA	Fulton County, GA	$0	$0	$0	$11.1
Chattahoochee County, GA	Muscogee County, GA	$0	$0	$0	$1.9
Chattooga County, GA	Floyd County, GA	$0	$0	$0	$4.0
Cherokee County, GA	Cobb County, GA Fulton County, GA	$0	$0	$0	$10.3
Coweta County, GA	Fulton County, GA	$0	$0	$0	$7.8
Crawford County, GA	Bibb County, GA	$0	$0	$0	$3.0
Douglas County, GA	Cobb County, GA Fulton County, GA	$0	$0	$0	$5.0
Fayette County, GA	Clayton County, GA Fulton County, GA	$0	$0	$0	$4.1
Forsyth County, GA	Fulton County, GA Gwinnett County, GA	$0	$0	$0	$6.8
Gordon County, GA	Floyd County, GA	$0	$0	$0	$5.3
Harris County, GA	Muscogee County, GA	$0	$0	$0	$7.0
Henry County, GA	Clayton County, GA DeKalb County, GA	$0	$0	$0	$5.9
Houston County, GA	Bibb County, GA	$0	$0	$0	$11.0
Jones County, GA	Bibb County, GA Wilkinson County, GA	$0	$0	$0	$6.1
Monroe County, GA	Bibb County, GA	$0	$0	$0	$6.1
Polk County, GA	Floyd County, GA	$0	$0	$0	$4.1
Spalding County, GA	Clayton County, GA	$0	$0	$0	$4.0
Talbot County, GA	Muscogee County, GA	$0	$0	$0	$2.9

County	Adjacent Counties	10/35	10/30	9/35	8/35
Twiggs County, GA	Bibb County, GA Wilkinson County, GA	$0	$0	$0	$5.9
Walker County, GA	Floyd County, GA	$0	$0	$0	$4.8
Bossier Parish, LA	Caddo Parish, LA	$0	$0	$0	$8.0
De Soto Parish, LA	Caddo Parish, LA	$0	$0	$0	$8.2
East Feliciana Parish, LA	East Baton Rouge Parish, LA West Baton Rouge Parish, LA	$0	$0	$0	$4.2
Pointe Coupee Parish, LA	Iberville Parish, LA West Baton Rouge Parish, LA	$0	$0	$0	$5.9
Red River Parish, LA	Caddo Parish, LA	$0	$0	$0	$5.4
West Feliciana Parish, LA	West Baton Rouge Parish, LA	$0	$0	$0	$7.8
Brooks County, TX	Hidalgo County, TX	$0	$0	$6.6	$6.6
Hudspeth County, TX	El Paso County, TX	$0	$0	$0	$3.3
Kenedy County, TX	Hidalgo County, TX	$0	$0	$4.3	$4.3
Starr County, TX	Hidalgo County, TX	$0	$0	$5.1	$5.1
Willacy County, TX	Cameron County, TX Hidalgo County, TX	$0	$0	$2.3	$2.3
Total		$0	$0	$18.2	$186.5

Table 4A-5 Summary of Estimated Annual Control Costs for the West (36 counties) for 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	$1.4	$7.4
Pinal County, AZ	$0	$1.0	$0	$0.3
Santa Cruz County, AZ	$0	$0	$0	$0.09
Denver County, CO	$0	$0	$0	$2.2
Weld County, CO	$0	$0	$0	$0.05
Benewah County, ID	$0	$12.1	$12.1	$12.1
Canyon County, ID	$0	$1.1	$0	$9.7
Lemhi County, ID	$0	$0	$0	$0
Shoshone County, ID	$0	$0	$0	$0
Lewis and Clark County, MT	$0	$3.1	$0	$0
Lincoln County, MT	$19.0	$19.0	$19.0	$19.0
Missoula County, MT	$0	$0	$1.1	$15.8
Ravalli County, MT	$0	$3.0	$0	$0.1
Silver Bow County, MT	$0	$0.03	$0	$7.8
Douglas County, NE	$0	$0	$0	$0.02
Sarpy County, NE	$0	$0	$0	$0.1
Dona Ana County, NM	$0	$0	$0	$6.9
Clark County, NV	$0	$0	$0.3	$5.5
Crook County, OR	$0	$19.3	$0	$5.4
Harney County, OR	$0	$1.5	$0	$13.4
Jackson County, OR	$0	$0	$0.3	$8.4
Klamath County, OR	$0	$0.5	$0	$6.2
Lake County, OR	$0	$0	$0	$0

County	10/35	10/30	9/35	8/35
Lane County, OR	$0	$0	$0	$0.04
Box Elder County, UT	$0	$14.6	$0	$0
Cache County, UT	$0	$22.0	$0	$0
Davis County, UT	$0	$7.1	$0	$0
Salt Lake County, UT	$0	$16.0	$0	$0
Utah County, UT	$0	$12.3	$0	$0
Weber County, UT	$0	$3.2	$0	$0
King County, WA	$0	$0	$0	$0.8
Kittitas County, WA	$0	$0	$0	$0
Okanogan County, WA	$0	$13.3	$0	$0
Snohomish County, WA	$0	$0.7	$0	$0
Spokane County, WA	$0	$0	$0	$0.4
Yakima County, WA	$0	$0	$0	$0
Total	$19.0	$150.0	$34.2	$121.8

Table 4A-6 Summary of Estimated Annual Control Costs for California (26 counties) for 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	Air District	10/35	10/30	9/35	8/35
Alameda County, CA	Bay Area AQMD	$0.03	$0.03	$2.0	$14.5
Contra Costa County, CA	Bay Area AQMD	$0	$0	$0.04	$0.4
Marin County, CA	Bay Area AQMD	$0	$0	$0	$0.05
Napa County, CA	Bay Area AQMD	$0.2	$0.2	$1.7	$1.7
Santa Clara County, CA	Bay Area AQMD	$0	$0	$1.0	$16.8
Solano County, CA	Bay Area AQMD	$0	$0	$0	$6.7
Butte County, CA	Butte County AQMD	$0	$0	$0	$0.3
Sutter County, CA	Feather River AQMD	$0	$0	$0	$3.6
Imperial County, CA	Imperial County APCD	$0	$0	$0	$0
Plumas County, CA	Northern Sierra AQMD	$0	$0	$0	$0
Sacramento County, CA	Sacramento Metro AQMD	$0	$0.2	$0.4	$2.3
San Diego County, CA	San Diego County APCD	$0	$0	$0.7	$30.3
Fresno County, CA	San Joaquin Valley APCD	$30.1	$30.1	$30.1	$30.1
Kern County, CA	San Joaquin Valley APCD	$0	$0	$0	$0
Kings County, CA	San Joaquin Valley APCD	$0	$0	$0	$0
Madera County, CA	San Joaquin Valley APCD	$9.1	$9.1	$9.1	$9.1
Merced County, CA	San Joaquin Valley APCD	$9.0	$9.0	$9.0	$9.0
San Joaquin County, CA	San Joaquin Valley APCD	$0.03	$0.03	$11.9	$11.9
Stanislaus County, CA	San Joaquin Valley APCD	$2.9	$2.9	$2.9	$2.9
Tulare County, CA	San Joaquin Valley APCD	$0	$0	$0	$0
San Luis Obispo County, CA	San Luis Obispo County APCD	$0	$0	$1.2	$1.2
Siskiyou County, CA	Siskiyou County APCD	$0	$16.9	$0	$0
Los Angeles County, CA	South Coast AQMD	$12.9	$12.9	$12.9	$12.9
Riverside County, CA	South Coast AQMD	$0	$0	$0	$0
San Bernardino County, CA	South Coast AQMD	$0	$0	$0	$0
Ventura County, CA	Ventura County APCD	$0	$9.1	$1.8	$9.1
Total		$64.1	$90.4	$84.7	$162.9

CHAPTER 5: BENEFITS ANALYSIS APPROACH AND RESULTS

Overview

This chapter presents the estimated human health-related and welfare benefits of meeting the proposed National Ambient Air Quality Standards (NAAQS) for particulate matter (PM). In this Regulatory Impact Analysis (RIA), we are analyzing the proposed annual and current 24-hour alternative standard levels of 10/35 μg/m^3 and 9/35 μg/m^3, as well as the following two more stringent alternative standard levels: (1) an 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) an alternative 24-hour standard level of 30 μg/m^3 in combination with the proposed annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). We quantify the number and economic value of the estimated avoided premature deaths and illnesses attributable to applying hypothetical national control strategies for the 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, U.S. EPA, 2022a) and reduce the ecological effects of nitrogen and sulfur deposition. Because the EPA is proposing that the current secondary PM NAAQS standards be retained, we did not evaluate alternative secondary standard levels in this RIA, or any visibility-, climate change-, or materials-damage-related benefits of the proposed 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 <u>from applying hypothetical national control strategies</u> for a more stringent $PM_{2.5}$ NAAQS? This chapter presents these results. As discussed in Chapter 3, Section 3.2.5, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the proposed 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 3.2.6, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$.

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 proposed and alternative $PM_{2.5}$ NAAQS? 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 a Technical Support Document (TSD) accompanying this RIA we specify in detail our approach for identifying, selecting, and parametrizing concentration-response relationships and economic unit values to support this benefits analysis. Below in Section 5.1 we summarize this information for readers, describing how we updated our methods for quantifying the number and value of PM-related benefits to reflect the information reported in the PM ISA and supplement to the PM ISA.

This chapter contains a subset of the estimated health benefits of the proposed 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 5.5.

As described in Chapter 1, the analytical objectives of the NAAQS RIA are unique as compared to other RIAs, such as the recent Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2020c). 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 proposed 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 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 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 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 measures or strategies that might result in meeting the range of revised annual and 24-hour alternative standard levels in the proposal.

Whereas the main analysis in this chapter presents the benefits of the applied control strategies for the 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 alternative standard levels; the tables in Appendix 5A present potential health benefits regardless of whether the technology or control measures to achieve them is 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 Proposed and Alternative Combinations of 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	$20 + B	$43 + B	$95 + B
7% discount rate	$16 + B	$18 + B	$39 + B	$86 + 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	$9.6 + B	$21 + B	$46 + B
7% discount rate	$7.6 + B	$8.6 + B	$19 + B	$41 + 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 control measures 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 measures, we do not quantitatively estimate CO_2-related climate benefits in this RIA.

5.1 Updated Methodology Presented in the RIA

In 2021, EPA published a TSD titled "Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits" that accompanied the RIA for the Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2021). As noted above, that TSD described the EPA's approach for quantifying the number and value of air pollution-related premature deaths and illnesses. Since publishing the Revised Cross-State Air Pollution Rule Update TSD, the EPA released a Supplement to the PM ISA (U.S. EPA, 2022a). EPA evaluated the new evidence reported in the Supplement to the PM ISA and revised the TSD accordingly; this process is described in detail within the TSD. The updated TSD will be published as a new document alongside this RIA. Key changes from the most recent version of the TSD are summarized below:

1. *Incorporated alternative long-term exposure mortality studies.* We selected a hazard ratio from an analysis of the National Health Interview Survey (NHIS) (Pope III et al., 2019). Compared to the American Cancer Society study it replaces (Turner et al., 2016), the NHIS cohort reflects more recent years of $PM_{2.5}$ concentrations and produces a larger number of estimated PM-attributable deaths. We also selected a hazard ratio from an extended analysis of the Medicare cohort (Wu et al., 2020). Compared to the study it replaces (Di et al., 2017), the Wu et al., 2020 analysis includes additional, and more current, years of $PM_{2.5}$ concentrations and more person-time; this newer study produces a similar number of estimated PM-attributable deaths. We elaborate on our rationale for these choices in section 5.3.3.1 of the TSD.
2. *Altered our approach for estimating counts of Acute Myocardial Infarctions.* We selected a risk estimate from an analysis of the Medicare cohort (Wei et al., 2019), in which the authors performed a case-crossover analysis of over 95 million Medicare inpatient hospital claims from 2000-2012. The risk estimate from this study replaces a pooled estimate of single- and multi-city studies that accounted for a smaller population, more limited geographic coverage and less recent $PM_{2.5}$ concentrations; that latter approach yielded a range of estimated non-fatal heart attacks whose upper bound was significantly larger than the estimate reported in this RIA.

5.2 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.

5.2.1 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, U.S. EPA, 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)[2]	✓	✓	PM ISA
	Hospital admissions - Parkinson’s disease (>64) [2]	✓	✓	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)[2]	✓	✓	PM ISA
	Out-of-hospital cardiac arrest (all)[2]	✓	—	PM ISA
	Stroke incidence (50-79)[2]	✓	✓	PM ISA
	New onset asthma (<12)[2]	✓	✓	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.

[2] Quantified endpoints have been added since the 2021 version of the Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits TSD. Full details of the updates can be found in the TSD published alongside this RIA.

5.2.2 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

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[1] The 2032 air quality modeling surface input files, configuration files and BenMAP script to produce the health benefits analyses in Chapters 5 and Appendix 5A are available upon request.

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.

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

$$y_{ij} = \Sigma_a \, y_{ija}$$

$$y_{ija} = mo_{ija} \times (e^{\beta \cdot \Delta C_{ij}} - 1) \times P_{ija}, \quad Eq[1]$$

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

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[2] In this illustrative example, the air quality is resolved at the county level. For this RIA, we simulate air quality concentrations at 12km by 12km grids. The BenMAP-CE tool assigns the rates of baseline death and disease stored at the county level to the 12km by 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, 2022b).

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.

5.2.3 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.

5.3 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. We indicate where we have updated key data inputs since the benefits analysis conducted for the Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2020c).

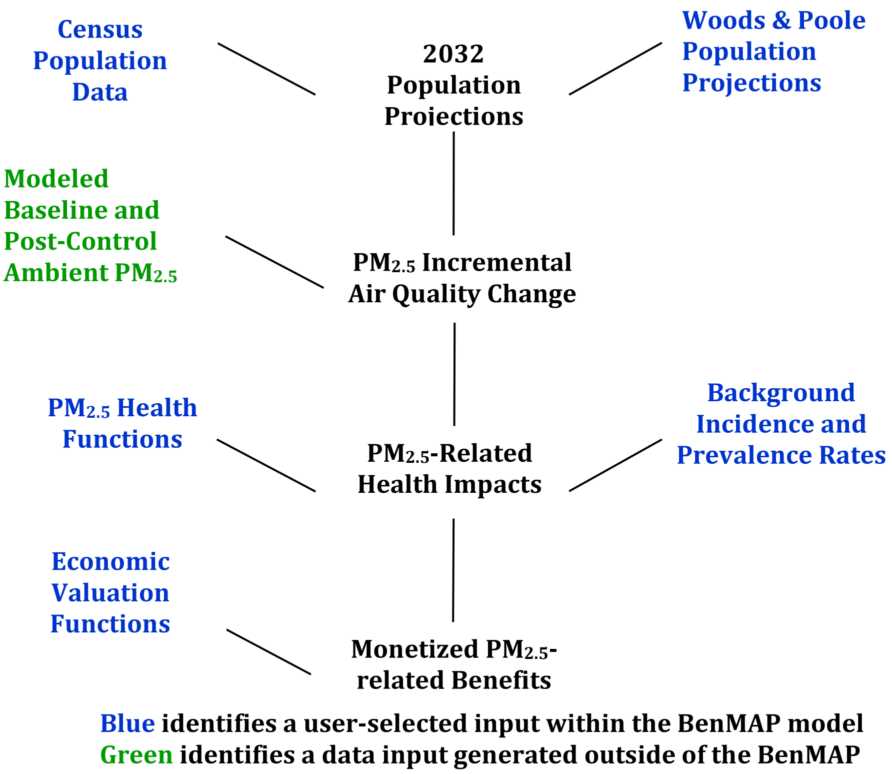

Figure 5-1 Data Inputs and Outputs for the BenMAP-CE Model

5.3.1 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.

5.3.2 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,

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[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.

necessary to convert this relative change into a number of cases, is the estimate of the 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 from the TSD (reproduced below as Table 5-3) 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

		Rates	
Endpoint	**Parameter**	**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
Nonfatal Acute Myocardial Infarction	Daily nonfatal AMI incidence rate per person aged 18-99	Age-, region-, state-, and county- stratified rates	AHRQ, 2016

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[4] Data availability from HCUP has changed since the last 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**
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	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
Minor Restricted-Activity Days	Daily MRAD incidence rate per person (18-64)	0.02137	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, 2018). Further information regarding this procedure may be found in the TSD for this RIA and the appendices to the BenMAP user manual (U.S. EPA, 2022b).

The baseline incidence rates for hospital admissions and emergency department visits reflect the revised rates first applied in the Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2021). In addition, we revised the baseline incidence rates for acute myocardial infarction. These revised rates are more recent (AHRQ, 2016) than the rates they replace and more accurately represent the rates at which populations of different ages, and in different locations, visit the hospital and emergency department for air pollution-related illnesses. Lastly, these rates reflect unscheduled hospital admissions only, which represents a conservative assumption that most air pollution-related visits are likely to be unscheduled. If air pollution-related hospital admissions are scheduled, this assumption would underestimate these benefits.

5.3.3 Effect Coefficients

Our approach for selecting and parametrizing effect coefficients for the benefits analysis is described fully in the TSD accompanying this RIA. 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.

5.3.3.1 $PM_{2.5}$ 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 prolonging life make mortality risk reduction 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 accompanying this RIA that is generally consistent with previous RIAs (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 three identified studies and hazard ratios 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.

EPA has historically used estimated Hazard Ratios from extended analyses of the ACS cohort (Pope et al., 1995, Pope III et al., 2002, Krewski et al, 2009) to estimate PM-related risk of premature death. More recent ACS analyses (Pope et al., 2015, Turner et al., 2016):

- extended the follow-up period of the ACS CSP-II to 22 years (1982-2004),
- evaluated 669,046 participants over 12,662,562 person-years of follow up and 237,201 observed deaths, and
- applied a more advanced exposure estimation approach than had previously been used when analyzing the ACS cohort, combining the geostatistical Bayesian Maximum Entropy framework with national-level land use regression models.

The total mortality hazard ratio best estimating risk from these ACS cohort studies was based on a random-effects Cox proportional hazard model incorporating multiple individual and ecological covariates (relative risk =1.06, 95% confidence intervals 1.04–1.08 per 10µg/m3 increase in $PM_{2.5}$) from Turner et al., 2016. The relative risk estimate is identical to a risk estimate drawn from earlier ACS analysis of all-cause long-term exposure $PM_{2.5}$-attributable mortality (Krewski et al., 2009). However, as the ACS hazard ratio is quite similar to the Medicare estimate of (1.066, 1.058-1.074), especially when considering the broader age range (>29 vs >64), only the Wu et all., 2020 and Pope III et al., 2019 are included in the main benefits assessments, with Wu et al., 2020 representing results from both the Medicare and ACS cohorts.

5.3.4 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 alternative 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, U.S. EPA, 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, U.S. EPA, 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 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. 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 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.

5.3.5 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

Effect Category	Causal Determination
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
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

5.3.5.1 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 associated with the proposal would be likely to have a significant impact on visibility in urban areas or Class I areas.

5.3.6 Climate Effects of $PM_{2.5}$

In the climate section of Chapter 5 of the 2020 $PM_{2.5}$ Primary NAAQS Policy Assessment it states "Thus, as in the last review, the data remain insufficient to conduct quantitative analyses for PM effects on climate in the current review." (U.S. EPA, 2020d) 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.

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. Depending on the particle's composition, the timing of emissions, and where it is in the atmosphere determine if it contributes to cooling or warming. 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).

5.3.6.1 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).

5.3.6.2 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.

5.3.7 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, 2014a).

5.4 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 accompanying this RIA details our approach to characterizing uncertainty in both quantitative and qualitative terms. That 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).

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);

Effect modification of PM2.5-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.

5.4.1 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 estimated using 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.

5.4.2 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.

5.5 Benefits Results

5.5.1 Benefits of the Applied Control Strategies for the 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 proposed alternative standard level of 9/35 $\mu g/m^3$, for the northeast we were able to identify approximately 97 percent of the reductions needed. For the southeast we were able to identify approximately 76 percent of the reductions needed. For the west, we were able to identify approximately 31 percent of the reductions needed, and for California the percentage is approximately 17 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 3.2.6). Second, Table 5A-1 through 5A-5 in Appendix 5A present the potential benefits associated with fully meeting the proposed and alternative standards.

Table 5-5 through Table 5-9 present the benefits results of applying the control strategies for the proposed annual and current 24-hour alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$, as well as 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 the proposed 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 each of the 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 each of the alternative standard levels, both nationally and by region. The regional monetized benefits in Table 5-8 are presented in four regions: 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]

For a more detailed description of the geographic distribution of the emissions reductions needed for each of the alternative standard levels, see the discussion in Chapter

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[5] The health and monetized benefits of fully attaining the alternative standard levels in all areas can be found in Appendix 5A.

3, Section 3.2.5. The estimated $PM_{2.5}$ emissions reductions from control applications do not result in all counties in the northeast, southeast, west, and California meeting the proposed and more stringent alternative standard levels. For the proposed alternative standard level of 10/35 $\mu g/m^3$, the northeast and southeast have sufficient *estimated* emissions reductions to reach attainment. For the west, the *estimated* emissions reductions are approximately 27 percent of the total needed to reach attainment, and for California the *estimated* emissions reductions are approximately 18 percent of the total needed to reach attainment.

Table 5-5 Estimated Avoided PM-Related Premature Mortalities and Illnesses of the Applied Control Strategies for the Proposed and More Stringent 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)	1,900 (1,400 to 2,400)	4,200 (3,000 to 5,300)	9,200 (6,600 to 12,000)
Wu et al., 2020 (adult mortality ages 65-99 years)	810 (710 to 900)	920 (810 to 1,000)	2,000 (1,800 to 2,200)	4,400 (3,900 to 4,900)
Woodruff et al., 2008 (infant mortality)	1.6 (-0.99 to 4.0)	1.8 (-1.1 to 4.6)	4.7 (-3.0 to 12)	11 (-6.9 to 28)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	140 (100 to 170)	150 (110 to 190)	310 (230 to 400)	660 (480 to 840)
Hospital admissions—respiratory	93 (31 to 150)	100 (35 to 170)	210 (74 to 350)	460 (160 to 740)
ED visits--cardiovascular	260 (-100 to 610)	290 (-110 to 670)	630 (-240 to 1,500)	1,400 (-530 to 3,200)
ED visits—respiratory	490 (95 to 1,000)	530 (100 to 1,100)	1,200 (240 to 2,600)	2,700 (540 to 5,700)
Acute Myocardial Infarction	29 (5.9 to 17)	32 (19 to 45)	67 (39 to 94)	140 (83 to 200)
Cardiac arrest	15 (-5.9 to 33)	16 (-6.6 to 37)	34 (-14 to 76)	72 (-29 to 160)
Hospital admissions--Alzheimer's Disease	360 (270 to 440)	390 (300 to 480)	850 (640 to 1,000)	1,900 (1,500 to 2,400)
Hospital admissions--Parkinson's Disease	48 (25 to 70)	54 (28 to 79)	120 (63 to 180)	270 (140 to 390)
Stroke	55 (14 to 94)	61 (16 to 110)	130 (33 to 220)	270 (71 to 470)
Lung cancer	65 (20 to 110)	73 (22 to 120)	150 (46 to 250)	320 (99 to 530)
Hay Fever/Rhinitis	15,000 (3,500 to 25,000)	16,000 (4,000 to 28,000)	35,000 (8,500 to 60,000)	75,000 (18,000 to 130,000)
Asthma Onset	2,200 (2,100 to 2,300)	2,500 (2,400 to 2,600)	5,400 (5,100 to 5,600)	11,000 (11,000 to 12,000)
Asthma symptoms – Albuterol use	310,000 (-150,000 to 750,000)	350,000 (-170,000 to 850,000)	740,000 (-360,000 to 1,800,000)	1,600,000 (-780,000 to 3,900,000)
Lost work days	110,000 (97,000 to 130,000)	130,000 (110,000 to 150,000)	270,000 (230,000 to 310,000)	580,000 (490,000 to 660,000)
Minor restricted-activity days[d,f]	680,000 (550,000 to 800,000)	750,000 (610,000 to 890,000)	1,600,000 (1,300,000 to 1,900,000)	3,400,000 (2,700,000 to 4,000,000)

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 Proposed and More Stringent Alternative Primary $PM_{2.5}$ Standard Levels 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)	20,000 (1,800 to 53,000)	43,000 (3,900 to 120,000)	94,000 (8,600 to 260,000)
Wu et al., 2020 (adult mortality ages 65-99 years)	8,300 (770 to 22,000)	9,400 (870 to 25,000)	20,000 (1,900 to 54,000)	45,000 (4,200 to 120,000)
Woodruff et al., 2008 (infant mortality)	18 (-9.9 to 70)	20 (-11 to 80)	53 (-30 to 210)	120 (-69 to 490)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	2.3 (1.7 to 2.9)	2.5 (1.8 to 3.2)	5.2 (3.7 to 6.5)	11 (7.9 to 14)
Hospital admissions—respiratory	1.6 (0.35 to 2.7)	1.7 (0.39 to 3.0)	3.6 (0.81 to 6.2)	7.6 (1.7 to 13)
ED visits--cardiovascular	0.32 (-0.12 to 0.75)	0.35 (-0.14 to 0.83)	0.78 (-0.3 to 1.8)	1.7 (-0.65 to 4)
ED visits—respiratory	0.45 (0.089 to 0.94)	0.5 (0.098 to 1)	1.2 (0.23 to 2.4)	2.6 (0.5 to 5.3)
Acute Myocardial Infarction	1.5 (0.88 to 2.1)	1.7 (0.97 to 2.4)	3.5 (2.0 to 4.9)	7.4 (4.3 to 10)
Cardiac arrest	0.55 (-0.23 to 1.3)	0.62 (-0.25 to 1.4)	1.3 (-0.52 to 2.9)	2.7 (-1.1 to 6.2)
Hospital admissions--Alzheimer's Disease	4.6 (3.5 to 5.7)	5 (3.8 to 6.2)	11 (8.3 to 13)	25 (19 to 31)
Hospital admissions--Parkinson's Disease	0.66 (0.34 to 0.96)	0.74 (0.38 to 1.1)	1.7 (0.86 to 2.4)	3.7 (1.9 to 5.3)
Stroke	2 (0.51 to 3.4)	2.2 (0.58 to 3.8)	4.6 (1.2 to 7.8)	9.9 (2.6 to 17)
Lung cancer	1 (0.31 to 1.7)	1.1 (0.35 to 1.9)	2.3 (0.71 to 3.8)	4.9 (1.5 to 8.1)
Hay Fever/Rhinitis	9.3 (2.3 to 16)	11 (2.5 to 18)	22 (5.4 to 38)	48 (12 to 82)
Asthma Onset	100 (98 to 110)	120 (110 to 130)	250 (240 to 270)	540 (510 to 570)
Asthma symptoms – Albuterol use	0.11 (-0.055 to 0.28)	0.13 (-0.062 to 0.31)	0.27 (-0.13 to 0.66)	0.59 (-0.29 to 1.4)
Lost work days	21 (17 to 24)	23 (19 to 26)	48 (41 to 56)	100 (88 to 120)
Minor restricted-activity days	53 (28 to 80)	59 (31 to 89)	120 (64 to 190)	260 (140 to 400)

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 Proposed and More Stringent Alternative Primary $PM_{2.5}$ Standard Levels 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 to 42,000)	18,000 (1,600 to 47,000)	38,000 (3,500 to 100,000)	85,000 (7,700 to 230,000)
Wu et al., 2020 (adult mortality ages 65-99 years)	7,500 (690 to 20,000)	8,500 (780 to 22,000)	18,000 (1,700 to 49,000)	41,000 (3,800 to 110,000)
Woodruff et al., 2008 (infant mortality)	18 (-9.9 to 70)	20 (-11 to 80)	53 (-30 to 210)	120 (-69 to 490)

Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	2.3 (1.7 to 2.9)	2.5 (1.8 to 3.2)	5.2 (3.7 to 6.5)	11 (7.9 to 14)
Hospital admissions—respiratory	1.6 (0.35 to 2.7)	1.7 (0.39 to 3.0)	3.6 (0.81 to 6.2)	7.6 (1.7 to 13)
ED visits--cardiovascular	0.32 (-0.12 to 0.75)	0.35 (-0.14 to 0.83)	0.78 (-0.3 to 1.8)	1.7 (-0.65 to 4)
ED visits—respiratory	0.45 (0.089 to 0.94)	0.5 (0.098 to 1)	1.2 (0.23 to 2.4)	2.6 (0.5 to 5.3)
Acute Myocardial Infarction	1.5 (0.86 to 2.1)	1.6 (0.97 to 2.4)	3.4 (2.0 to 4.8)	7.3 (4.2 to 10)
Cardiac arrest	0.55 (-0.22 to 1.2)	0.61 (-0.25 to 1.4)	1.3 (-0.51 to 2.8)	2.7 (-1.1 to 6.1)
Hospital admissions--Alzheimer's Disease	4.6 (3.5 to 5.7)	5 (3.8 to 6.2)	11 (8.3 to 13)	25 (19 to 31)
Hospital admissions--Parkinson's Disease	0.66 (0.34 to 0.96)	0.74 (0.38 to 1.1)	1.7 (0.86 to 2.4)	3.7 (1.9 to 5.3)
Stroke	2 (0.51 to 3.4)	2.2 (0.58 to 3.8)	4.6 (1.2 to 7.8)	9.9 (2.6 to 17)
Lung cancer	0.72 (0.22 to 1.2)	0.8 (0.25 to 1.3)	1.6 (0.5 to 2.7)	3.4 (1.1 to 5.7)
Hay Fever/Rhinitis	9.3 (2.3 to 16)	11 (2.5 to 18)	22 (5.4 to 38)	48 (12 to 82)
Asthma Onset	65 (60 to 69)	73 (68 to 78)	160 (150 to 170)	340 (310 to 360)
Asthma symptoms – Albuterol use	0.11 (-0.055 to 0.28)	0.13 (-0.062 to 0.31)	0.27 (-0.13 to 0.66)	0.59 (-0.29 to 1.4)
Lost work days	21 (17 to 24)	23 (19 to 26)	48 (41 to 56)	100 (88 to 120)
Minor restricted-activity days	53 (28 to 80)	59 (31 to 89)	120 (64 to 190)	260 (140 to 400)

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 Proposed and More Stringent Alternative Combinations of 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	$20 + B	$43 + B	$95 + B
7% discount rate	$16 + B	$18 + B	$39 + B	$86 + 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	$9.6 + B	$21 + B	$46 + B
7% discount rate	$7.6 + B	$8.6 + B	$19 + B	$41 + 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 each of the alternative standard levels by four regions: California, the Northeast, the Southeast, and the West. The monetized benefits differ regionally and by each alternative standard level. For the proposed alternative standard level of 10/35 µg/-m³, because 15 of the 24 counties that need emissions reductions are counties in California, the majority of the benefits are incurred in California (Table 5-9). For California, we were able to identify approximately 18 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 alternative standard levels of 9/35 µg/m³ and 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 the costs for the west and California.

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[6] Note that in the northeast and southeast we identified control measures 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 $PM_{2.5}$

Table 5-9 Estimated Monetized Benefits by Region of the Applied Control Strategies for the Proposed and More Stringent Alternative Combinations of Primary $PM_{2.5}$ Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	Region	10 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 24-hour	10 $\mu g/m^3$ annual & 30 $\mu g/m^3$ 24-hour	9 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 24-hour	8 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 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	***California***	$13 + B	$14 + B	$17 + B	$23 + B
	Northeast	$2.3 + B	$2.6 + B	$15 + B	$40 + B
	Southeast	$1.8 + B	$1.8 + B	$8.8 + B	$22 + B
	West	$0.018 + B	$1.1 + B	$2.2 + B	$11 + B
7% discount rate	***California***	$12 + B	$13 + B	$16 + B	$21 + B
	Northeast	$2 + B	$2.3 + B	$13 + B	$36 + B
	Southeast	$1.6 + B	$1.6 + B	$7.9 + B	$20 + B
	West	$0.016 + B	$1 + B	$2 + B	$9.5 + 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	***California***	$6.5 + B	$6.9 + B	$8.4 + B	$11 + B
	Northeast	$1.1 + B	$1.3 + B	$7.3 + B	$19 + B
	Southeast	$0.84 + B	$0.84 + B	$4.1 + B	$10 + B
	West	$0.0092 + B	$0.56 + B	$1.1 + B	$5.1 + B
7% discount rate	***California***	$5.8 + B	$6.2 + B	$7.5 + B	$10 + B
	Northeast	$1 + B	$1.2 + B	$6.6 + B	$17 + B
	Southeast	$0.75 + B	$0.75 + B	$3.6 + B	$9.2 + B
	West	$0.0082 + B	$0.5 + B	$0.97 + B	$4.6 + 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.

5.6 Discussion

The estimated benefits to human health and the environment of the 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 proposed annual primary standards would decrease the number of $PM_{2.5}$-related premature deaths and illnesses. The emissions reduction strategies will also yield significant welfare benefits (see Section 5.3.5), though this RIA does not quantify those endpoints.

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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.

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, such as the Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2020c). 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 (see: Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2020c)). 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 such as the RCU 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.

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APPENDIX 5A: BENEFITS OF THE PROPOSED AND ALTERNATIVE STANDARD LEVELS

Overview

In this Appendix, we estimate the potential health benefits resulting from identifying controls and emissions reductions to comply with the proposed 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 $\mu g/m^3$ and a 24-hour standard of 35 $\mu g/m^3$). In contrast the main analysis in Chapter 5, we present the national health impacts and monetized benefits <u>resulting only from the applied control strategies identified in Chapter 3</u> for each of the 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 10/35, 10/30, 9/35 and 8/35 alternative standard levels. Additional information on estimating the emission reductions needed to meet each of the 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 3.2.5. Lastly, Chapter 2, Section 2.4 and Chapter 3, Section 3.2.6 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 proposed 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 and alternative NAAQS standard levels are just met were developed to estimate the emission changes resulting from fully meeting each of the proposed and more stringent alternative standard levels. Using the methods described in Chapter 5 of this RIA and the "Technical Support Document (TSD) for the $PM_{2.5}$ NAAQS Proposal: Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits" that will be published with this RIA, we estimate health benefits from achieving the proposed 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 Proposed 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 proposed 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 each alternative standard level 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 each alternative standard level in 2032.

Tables 5A-4 and 5A-5 present a summary of the monetized benefits nationally and by region of achieving the alternative standard levels. The regional monetized benefits in Table 5A-5 are presented in four regions: California, the Northeast, the Southeast, and the West. 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 Proposed and More Stringent 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)	3,200 (2,300 to 4,100)	3,800 (2,700 to 4,800)	7,300 (5,200 to 9,300)	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)	3.4 (-2.1 to 8.6)	3.9 (-2.5 to 10)	8.3 (-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 330)	300 (220 to 380)	570 (410 to 720)	1,200 (840 to 1,500)
Hospital admissions—respiratory	180 (64 to 300)	210 (72 to 330)	400 (140 to 650)	810 (280 to 1,300)
ED visits--cardiovascular	500 (-190 to 1,200)	570 (-220 to 1,300)	1,100 (-430 to 2,600)	2,300 (-900 to 5,500)
ED visits—respiratory	990 (200 to 2,100)	1,100 (220 to 2,300)	2,300 (450 to 4,700)	4,700 (920 to 9,800)
Acute Myocardial Infarction	57 (33 to 80)	65 (38 to 91)	120 (72 to 170)	250 (150 to 350)
Cardiac arrest	28 (-11 to 63)	32 (-13 to 73)	61 (-25 to 140)	130 (-51 to 280)
Hospital admissions--Alzheimer's Disease	610 (470 to 740)	690 (520 to 840)	1,400 (1,000 to 1,700)	3,000 (2,300 to 3,600)
Hospital admissions--Parkinson's Disease	87 (45 to 120)	100 (53 to 150)	200 (100 to 290)	430 (220 to 610)
Stroke	100 (27 to 180)	120 (31 to 210)	230 (59 to 390)	470 (120 to 810)
Lung cancer	120 (38 to 200)	140 (44 to 230)	270 (83 to 440)	550 (170 to 890)
Hay Fever/Rhinitis	30,000 (7,400 to 52,000)	35,000 (8,500 to 60,000)	66,000 (16,000 to 110,000)	130,000 (33,000 to 230,000)
Asthma Onset	4,600 (4,400 to 4,800)	5,300 (5,100 to 5,500)	10,000 (9,700 to 10,000)	20,000 (19,000 to 21,000)
Asthma symptoms – Albuterol use	650,000 (-320,000 to 1,600,000)	750,000 (-360,000 to 1,800,000)	1,400,000 (-690,000 to 3,400,000)	2,900,000 (-1,400,000 to 7,000,000)
Lost work days	230,000 (190,000 to 260,000)	260,000 (220,000 to 300,000)	500,000 (420,000 to 570,000)	1,000,000 (850,000 to 1,200,000)
Minor restricted-activity days	1,300,000 (1,100,000 to 1,600,000)	1,500,000 (1,200,000 to 1,800,000)	2,900,000 (2,400,000 to 3,400,000)	5,900,000 (4,800,000 to 7,000,000)

Note: Values rounded to two significant figures.

Table 5A-2 Monetized Avoided PM-Related Premature Mortalities and Illnesses of Meeting the Proposed and More Stringent 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)	33,000 (3,000 to 89,000)	39,000 (3,500 to 100,000)	75,000 (6,800 to 200,000)	160,000 (14,000 to 430,000)
Wu et al. (adult mortality ages 65-99 years)	16,000 (1,400 to 41,000)	18,000 (1,700 to 49,000)	36,000 (3,300 to 94,000)	76,000 (7,000 to 200,000)
Woodruff et al. (infant mortality)	38 (-21 to 150)	44 (-25 to 180)	94 (-52 to 370)	200 (-110 to 800)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	4.3 (3.1 to 5.4)	4.9 (3.5 to 6.2)	9.3 (6.8 to 12)	19 (14 to 24)
Hospital admissions—respiratory	3.0 (0.70 to 5.3)	3.4 (0.79 to 5.9)	6.6 (1.5 to 11)	13 (3.1 to 23)
ED visits--cardiovascular	0.62 (-0.24 to 1.4)	0.7 (-0.27 to 1.6)	1.4 (-0.54 to 3.2)	2.9 (-1.1 to 6.7)
ED visits—respiratory	0.92 (0.18 to 1.9)	1 (0.2 to 2.2)	2.1 (0.42 to 4.4)	4.4 (0.86 to 9.1)
Acute Myocardial Infarction	3.0 (1.7 to 4.1)	3.4 (2.0 to 4.7)	6.4 (3.7 to 9.0)	13 (7.6 to 18)
Cardiac arrest	1.1 (-0.43 to 2.4)	1.2 (-0.5 to 2.8)	2.3 (-0.95 to 5.2)	4.8 (-2 to 11)
Hospital admissions--Alzheimer's Disease	7.8 (6 to 9.5)	8.8 (6.7 to 11)	18 (13 to 21)	38 (29 to 46)
Hospital admissions--Parkinson's Disease	1.2 (0.62 to 1.7)	1.4 (0.72 to 2)	2.7 (0.86 to 2.4)	5.8 (3.1 to 8.3)
Stroke	3.7 (0.97 to 6.4)	4.4 (1.1 to 7.5)	8.3 (2.1 to 14)	17 (4.4 to 29)
Lung cancer	1.9 (0.59 to 3.1)	2.2 (0.68 to 3.6)	4.1 (1.3 to 6.7)	8.4 (2.6 to 14)
Hay Fever/Rhinitis	19 (4.7 to 33)	22 (5.4 to 38)	42 (10 to 73)	85 (21 to 150)
Asthma Onset	220 (200 to 230)	250 (230 to 260)	470 (440 to 500)	950 (890 to 1,000)
Asthma symptoms – Albuterol use	0.24 (-0.12 to 0.58)	0.27 (-0.13 to 0.67)	0.52 (-0.25 to 1.3)	1.1 (-0.51 to 2.6)
Lost work days	41 (35 to 47)	47 (40 to 54)	90 (76 to 100)	180 (150 to 210)
Minor restricted-activity days	100 (55 to 160)	120 (63 to 180)	230 (120 to 350)	460 (240 to 700)

Note: Values rounded to two significant figures.

Table 5A-3 Monetized Avoided PM-Related Premature Mortalities and Illnesses of Meeting the Proposed and More Stringent 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)	30,000 (2,700 to 80,000)	35,000 (3,100 to 94,000)	67,000 (6,100 to 180,000)	140,000 (13,000 to 380,000)
Wu et al. (adult mortality ages 65-99 years)	14,000 (1,300 to 37,000)	17,000 (1,500 to 44,000)	32,000 (3,000 to 85,000)	68,000 (6,300 to 180,000)
Woodruff et al. (infant mortality)	38 (-21 to 150)	44 (-25 to 180)	94 (-52 to 370)	200 (-110 to 800)
Avoided Morbidity	**10/35**	**10/30**	**9/35**	**8/35**
Hospital admissions—cardiovascular (age > 18)	4.3 (3.1 to 5.4)	4.9 (3.5 to 6.2)	9.3 (6.8 to 12)	19 (14 to 24)
Hospital admissions—respiratory	3.0 (0.70 to 5.3)	3.4 (0.79 to 5.9)	6.6 (1.5 to 11)	13 (3.1 to 23)
ED visits--cardiovascular	0.62 (-0.24 to 1.4)	0.7 (-0.27 to 1.6)	1.4 (-0.54 to 3.2)	2.9 (-1.1 to 6.7)
ED visits—respiratory	0.92 (0.18 to 1.9)	1 (0.2 to 2.2)	2.1 (0.42 to 4.4)	4.4 (0.86 to 9.1)
Acute Myocardial Infarction	2.9 (1.7 to 4.0)	3.3 (1.9 to 4.6)	6.3 (3.6 to 8.8)	13 (7.4 to 18)
Cardiac arrest	1 (-0.43 to 2.4)	1.2 (-0.5 to 2.7)	2.3 (-0.94 to 5.2)	4.7 (-1.9 to 11)
Hospital admissions--Alzheimer's Disease	7.8 (6 to 9.5)	8.8 (6.7 to 11)	18 (13 to 21)	38 (29 to 46)
Hospital admissions--Parkinson's Disease	1.2 (0.62 to 1.7)	1.4 (0.72 to 2)	2.7 (1.4 to 3.9)	5.8 (3.1 to 8.3)
Stroke	3.7 (0.97 to 6.4)	4.4 (1.1 to 7.5)	8.3 (2.1 to 14)	17 (4.4 to 29)
Lung cancer	1.3 (0.41 to 2.2)	1.5 (0.48 to 2.5)	2.9 (0.9 to 4.7)	5.9 (1.8 to 9.6)
Hay Fever/Rhinitis	19 (4.7 to 33)	22 (5.4 to 38)	42 (10 to 73)	85 (21 to 150)
Asthma Onset	130 (130 to 140)	160 (140 to 160)	290 (270 to 310)	590 (550 to 630)
Asthma symptoms – Albuterol use	0.24 (-0.12 to 0.58)	0.27 (-0.13 to 0.67)	0.52 (-0.25 to 1.3)	1.1 (-0.51 to 2.6)
Lost work days	41 (35 to 47)	47 (40 to 54)	90 (76 to 100)	180 (150 to 210)
Minor restricted-activity days	100 (55 to 160)	120 (63 to 180)	230 (120 to 350)	460 (240 to 700)

Note: Values rounded to two significant figures.

Table 5A-4 Total Estimated Monetized Benefits of Meeting the Proposed and More Stringent Alternative Primary Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	10 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 24-hour	10 $\mu g/m^3$ annual & 30 $\mu g/m^3$ 24-hour	9 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 24-hour	8 $\mu g/m^3$ annual & 35 $\mu g/m^3$ 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	\$33 + B	\$39 + B	\$76 + B	\$160 + B
7% discount rate	\$30 + B	\$35 + B	\$68 + 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	\$36 + B	\$77 + B
7% discount rate	\$14 + B	\$17 + B	\$33 + B	\$69 + 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 Region of Meeting the Proposed and More Stringent Alternative Primary Standard Levels in 2032, Incremental to Attainment of 12/35 (billions of 2017$)

Benefits Estimate	Region	10 µg/m^3 annual & 35 µg/m^3 24-hour	10 µg/m^3 annual & 30 µg/m^3 24-hour	9 µg/m^3 annual & 35 µg/m^3 24-hour	8 µg/m^3 annual & 35 µg/m^3 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	***California***	$29 + B	$32 + B	$49 + B	$76 + B
	Northeast	$2.3 + B	$2.6 + B	$15 + B	$46 + B
	Southeast	$1.8 + B	$1.8 + B	$9.6 + B	$26 + B
	West	$0.086 + B	$2.8 + B	$2.4 + B	$12 + B
7% discount rate	***California***	$26 + B	$28 + B	$44 + B	$68 + B
	Northeast	$2 + B	$2.3 + B	$13 + B	$41 + B
	Southeast	$1.6 + B	$1.6 + B	$8.6 + B	$23 + B
	West	$0.077 + B	$2.6 + B	$2.2 + B	$11 + 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	***California***	$14 + B	$15 + B	$24 + B	$37 + B
	Northeast	$1.1 + B	$1.3 + B	$7.2 + B	$23 + B
	Southeast	$0.84 + B	$0.84 + B	$4.4 + B	$12 + B
	West	$0.044 + B	$1.4 + B	$1.2 + B	$5.9 + B
7% discount rate	***California***	$13 + B	$14 + B	$21 + B	$33 + B
	Northeast	$1 + B	$1.2 + B	$6.4 + B	$20 + B
	Southeast	$0.75 + B	$0.75 + B	$4 + B	$11 + B
	West	$0.04 + B	$1.3 + B	$1.1 + B	$5.3 + 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

Pope III, CA, Lefler, JS, Ezzati, M, Higbee, JD, Marshall, JD, Kim, S-Y, Bechle, M, Gilliat, KS, Vernon, SE and Robinson, AL (2019). Mortality risk and fine particulate air pollution in a large, representative cohort of US adults. Environmental health perspectives 127(7): 077007.

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CHAPTER 6: ENVIRONMENTAL JUSTICE

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). The EPA defines EJ as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. 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".[1] Meaningful involvement means that: (1) potentially affected populations have an appropriate opportunity to participate in decisions about a proposed 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.[2] 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

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[1] See, e.g., "Environmental Justice." *Epa.gov*, U.S. Environmental Protection Agency, 4 Mar. 2021, https://www.epa.gov/environmentaljustice.

[2] See https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.

proposed 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 minority populations, low-income populations, and/or Indigenous peoples; (2) exacerbate existing disproportionate impacts on minority populations, low-income populations, and/or Indigenous peoples; or (3) present opportunities to address existing disproportionate impacts on minority populations, low-income populations, and/or Indigenous peoples through the action under development.

The Presidential Memorandum on Modernizing Regulatory Review (86 FR 7223; January 20, 2021) calls for procedures to "take into account the distributional consequences of regulations, including as part of a quantitative or qualitative analysis of the costs and benefits of regulations, to ensure that regulatory initiatives appropriately benefit, and do not inappropriately burden disadvantaged, vulnerable, or marginalized communities." Under Executive Order 13563, federal agencies may consider equity, human dignity, fairness, and distributional considerations, where appropriate and permitted by law. For purposes of analyzing regulatory impacts, the EPA relies upon its June 2016 "Technical Guidance for Assessing Environmental Justice in Regulatory Analysis,"[3] 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:

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[3] See https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.

1. Baseline: Describes the current (pre-control) distribution of exposures and risk, 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.

6.1 Analyzing EJ Impacts in This Proposal

In addition to the benefits assessment (Chapter 5), the EPA considers potential EJ concerns of this proposed rulemaking. A potential EJ concern is defined as "the actual or potential lack of fair treatment or meaningful involvement of minority populations, low-income populations, tribes, and indigenous peoples in the development, implementation and enforcement of environmental laws, regulations and policies" (U.S. EPA, 2015). For analytical purposes, this concept refers more specifically to "disproportionate impacts on minority populations, low-income populations, and/or indigenous peoples that may exist prior to or that may 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 proposed 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 alternative standard levels analyzed. The alternative standard levels evaluated in the RIA are more stringent than the current standards. This means that in 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 6.2) and health effect (Section 6.3) 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 proposed action at the national scale. Recognizing, however, that only some areas of the U.S. are projected to exceed the proposed alternative standard levels, the EPA conducted a case study analysis to further examine the impacts of this proposed action on populations living in areas with the highest exposures and health risks in the baseline. By focusing on locations that are projected to exceed one of the analytical alternatives examined, this case study analysis considers the magnitude of exposure and health effect disparities across the smaller geographical scale where the impacts of alternative standard levels are expected (Section 6.4).[4]

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

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[4] Input data (e.g., air quality surfaces, configuration files, and command line scripts) used to prepare the EJ analysis described in this chapter are available upon request.

requires less a priori information, we were able to include a broad array of demographic characteristics. Estimating actual 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, U.S. EPA, 2020, U.S. EPA, 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, BMI, etc.) across groups, due to limitations on the underlying data.[5] 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 $PM_{2.5}$ concentrations and do not evaluate whether concentrations experienced by different groups persist across the distribution of daily $PM_{2.5}$ exposures. Additionally, the EJ health effects analysis is subject to additional uncertainties related to concentration-response relationships and baseline incidence data.

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 evaluates implications of air quality surfaces associated with the illustrative emission control strategies for both current (i.e., baseline) and alternative standard levels. However, the illustrative control strategies do not result in all counties identifying emissions reductions needed to meet either the current or more stringent alternative standard levels (Chapters 3). As such, the appendix to this chapter provides EJ implications of air quality scenarios associated with meeting the standards (labelled in some Section 6.6 figures as “Standards”) and allows for direct comparison with results associated with the illustrative emissions control strategies (labelled in some Section 6.6 figures as “Controls”).

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

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[5] 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.

of uncertainty (Chapter 5, Section 5.4). 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.

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- and county-levels, potentially masking tract- or block-level EJ impacts. Additional uncertainties are briefly discussed in the summary of this analysis (Section 6.5).

6.2 EJ Analysis of Exposures Under Current Standard 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 perspectives, which correspond to the three EJ questions listed in Section 6.1. Specifically, the following questions are addressed:

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[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 km 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.

1) Are there disproportionate $PM_{2.5}$ exposures under baseline/current PM NAAQS standard levels (question 1)?

2) Are there disproportionate $PM_{2.5}$ 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 include race/ethnicity, poverty status, educational attainment, age, and sex (Table 6-1). The results presented below reflect the control strategies described in Chapter 3.

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
Poverty Status	Above the poverty line; Below the poverty line
Age	Children (0-17); Adults (18-64); Older Adults (65-99)
Sex	Female; Male

6.2.1 Total Exposure

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. Estimated exposures as measured by the projected national and regional ambient $PM_{2.5}$ concentrations experienced by various demographic populations for the current standards or alternative standard levels analyzed are provided in Sections 6.2.1.1 and 6.2.1.2, respectively. Information regarding identified emissions controls, as well as areas where air quality has been adjusted, is available in Chapters 2 and 3.

6.2.1.1 National

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 US (national).[9] Figure 6-1 shows the national average annual $PM_{2.5}$ concentrations associated with the control strategy baseline scenario for the current annual standard of 12 $\mu g/m^3$ and current 24-hour standard of 35 $\mu g/m^3$ (12/35) as a heat map, with higher estimated annual $PM_{2.5}$ concentrations shown in darker shades of blue. 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, and adults 18-64). On average, Asians, Blacks, Hispanics, and those over 25 without a high school education live in areas with higher annual $PM_{2.5}$ concentrations than the reference population, with Hispanic and Asian populations experiencing the highest relative concentrations. The most substantial discrepancy in national average annual $PM_{2.5}$ exposures is noted between Hispanic populations and non-Hispanic populations. It is noteworthy that the national average annual exposures for all demographic groups are well below the current annual NAAQS.

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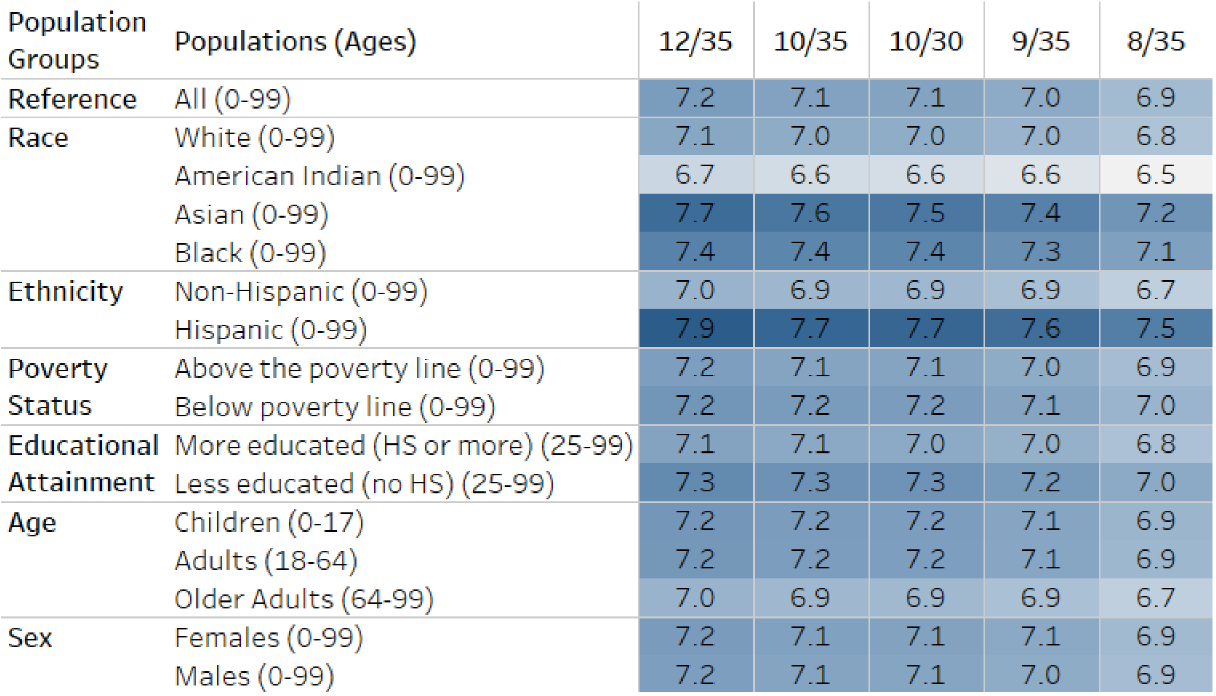
[9] We initially included children (ages 0-18) for each demographic group in the analyses, but as the 0-18 age range $PM_{2.5}$ concentrations appeared very similar to the 0-99 age range $PM_{2.5}$ concentrations, only the 0-99 age range is presented.



Population Groups	Populations (Ages)	12/35	10/35	10/30	9/35	8/35
Reference	All (0-99)	7.2	7.1	7.1	7.0	6.9
Race	White (0-99)	7.1	7.0	7.0	7.0	6.8
	American Indian (0-99)	6.7	6.6	6.6	6.6	6.5
	Asian (0-99)	7.7	7.6	7.5	7.4	7.2
	Black (0-99)	7.4	7.4	7.4	7.3	7.1
Ethnicity	Non-Hispanic (0-99)	7.0	6.9	6.9	6.9	6.7
	Hispanic (0-99)	7.9	7.7	7.7	7.6	7.5
Poverty Status	Above the poverty line (0-99)	7.2	7.1	7.1	7.0	6.9
	Below poverty line (0-99)	7.2	7.2	7.2	7.1	7.0
Educational Attainment	More educated (HS or more) (25-99)	7.1	7.1	7.0	7.0	6.8
	Less educated (no HS) (25-99)	7.3	7.3	7.3	7.2	7.0
Age	Children (0-17)	7.2	7.2	7.2	7.1	6.9
	Adults (18-64)	7.2	7.2	7.2	7.1	6.9
	Older Adults (64-99)	7.0	6.9	6.9	6.9	6.7
Sex	Females (0-99)	7.2	7.1	7.1	7.1	6.9
	Males (0-99)	7.2	7.1	7.1	7.0	6.9

Figure 6-1 Heat Map of National Average Annual $PM_{2.5}$ Concentrations (µg/m^3) by Demographic for Current and Alternative PM NAAQS Levels (10/35, 10/30, 9/35, and 8/35) After Application of Controls

Figure 6-1 also shows the national average total $PM_{2.5}$ concentrations associated with control strategies applied for the potential alternative annual and 24-hour standard levels: 10/35, 10/30, 9/35, and 8/35. Although average concentrations under 10/35 and 10/30 are similar, most demographic groups are projected to experience greater annual $PM_{2.5}$ concentration reductions after implementing the illustrative control strategies for lower alternative annual standard levels. However, after implementing the illustrative control strategies associated with all alternative standard levels evaluated, Asians, Blacks, Hispanics, those over 25 without a high school education, and those under the poverty level live in areas with higher projected annual $PM_{2.5}$ concentrations than the reference population, again with Hispanic and Asian populations experiencing the highest average concentrations. This suggests that while emissions reductions associated with more stringent standard levels will result in air quality improvements across the board, disparities seen in the baseline likely remain, at least when considering the *average* national exposure levels by demographic group. These annual average exposures are also well below the current standards and all alternative standard levels evaluated.

While average $PM_{2.5}$ concentrations can provide some insight when comparing population impacts, information on the full distribution of concentrations affords a more comprehensive understanding. This is because both demographic groups and ambient concentrations are unevenly distributed, meaning that average exposures may mask important disparities that occur on a more 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 different subpopulations. Distributional figures present the running sum of each population, converted to a percentage, on the y-axes (i.e., cumulative percent). 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 ($\mu g/m^3$) from low to high. For Figure 6-2, $PM_{2.5}$ concentrations are county-level averages from all counties in the contiguous U.S. In other words, plots compare the running sum of each population against increasing annual $PM_{2.5}$ concentrations.

Information on the distribution of county-level $PM_{2.5}$ concentrations associated with the illustrative control strategies associated with the current and alternative PM standard levels across and within populations can be found in Figure 6-2. The reference population in the top row shows that 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 $\mu g/m^3$ under air quality scenarios associated with the control strategies for current standards (12/35). Lower $PM_{2.5}$ concentrations remain similar across lower alternative standard levels, while higher concentrations are reduced.

To evaluate differential exposures, populations of potential EJ concern are shown with a colored line and can be compared to the respective reference population shown with a black line. Colored lines to the right of a black line suggest that the potential EJ population is experiencing disproportionately higher $PM_{2.5}$ concentrations. The greatest disproportionate exposures are observed when considering ethnicity. The Hispanic population (dark orange) is predicted to experience higher $PM_{2.5}$ concentrations than the non-Hispanic population (black) across a large portion of the exposure distribution. This difference is approximately 1 μg/m^3 at all concentrations above 6 μg/m^3.

Similarly, when considering race across the various standard levels evaluated, portions of the Asian (bright orange) and Black (blue) populations live in areas with higher $PM_{2.5}$ concentrations than the White (black) population, and portions of the American Indian (light orange) population live in areas with lower $PM_{2.5}$ concentrations. Interestingly, Black and White population exposures are very similar at concentrations above about 8 μg/m^3 under air quality scenarios associated with controls for 12/35 and about 7.5 μg/m^3 air quality scenarios associated with controls for 8/35. This could suggest that exposure disparities in the Black population occur in rural areas with lower $PM_{2.5}$ concentrations. The Asian population experiences higher $PM_{2.5}$ concentrations across a larger portion of the distribution, but higher exposures become more similar to the White distribution at lower alternative PM standard levels. Those living below the poverty level, those over 25 without a high school diploma, and the two sexes experience virtually identical distributions of exposure of all standard levels.

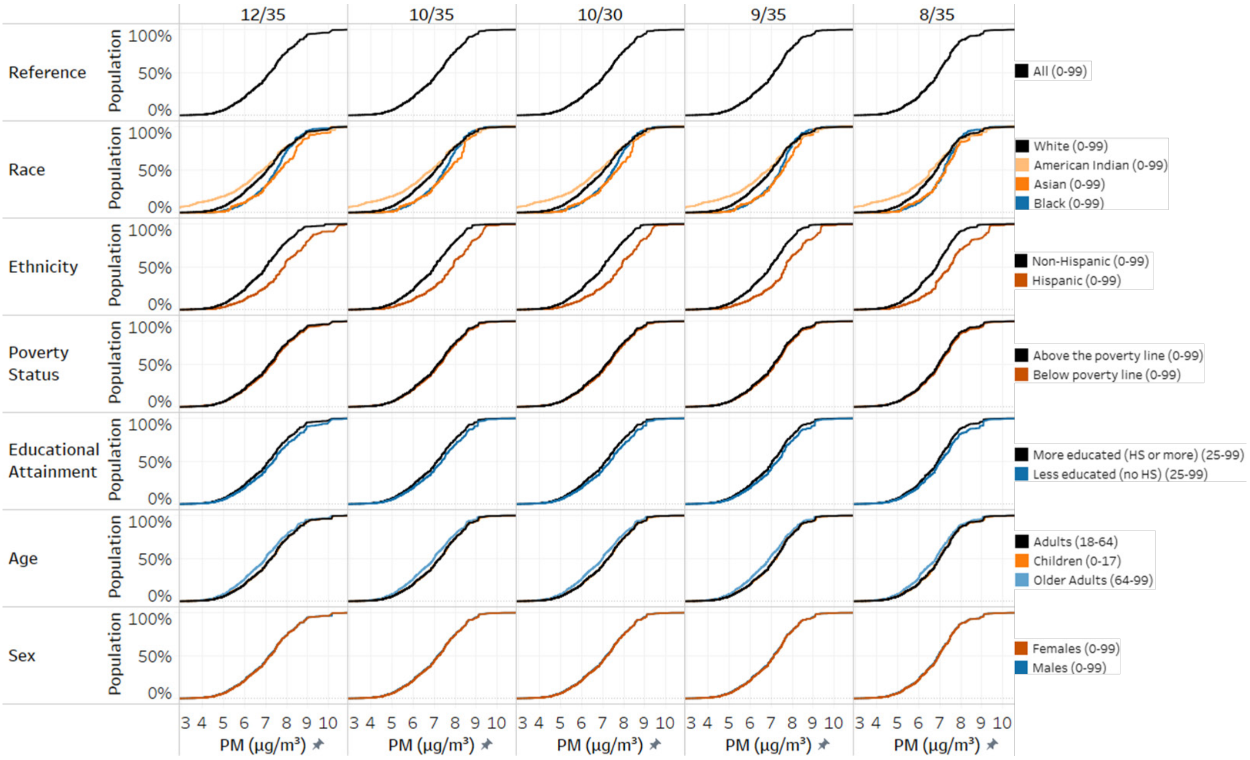


Figure 6-2 National Distributions of Annual $PM_{2.5}$ Concentrations by Demographic for Current and Alternative PM NAAQS Levels After Application of Controls

6.2.1.2 Regional

As both emissions changes and overrepresentation 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 (southeast [SE], northeast [NE], west [W], and California [CA]) (Figure 6-3 and Figure 6-4).[10,11] Across all current and alternative standard levels, average annual reference $PM_{2.5}$ concentrations are highest in CA, followed by the SE and NE, and are lowest in the W (Figure 6-3). Comparing populations of potential EJ concern with their respective references within each region, disparities are observed in all four regions, though not all for the same demographic populations.

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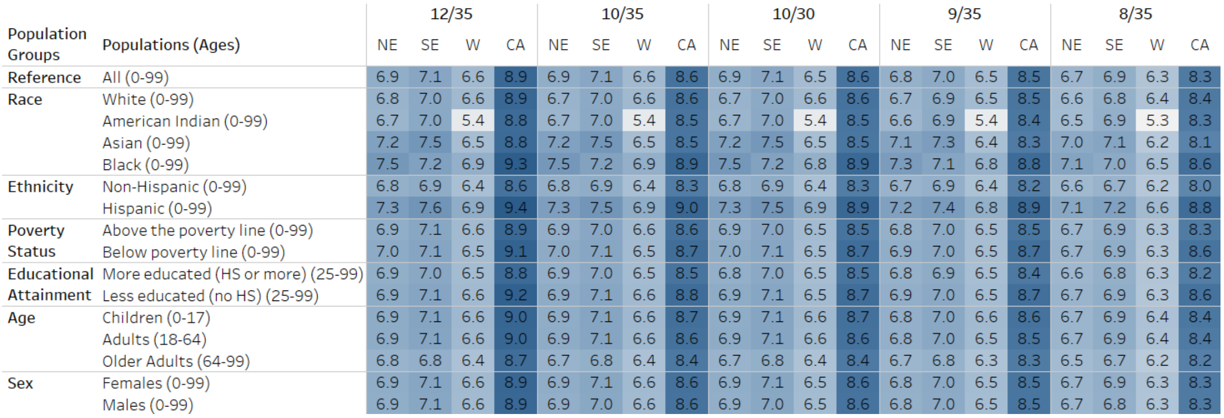
[10] Regions used here are consistent with regions used in the costs and benefits chapters of this RIA and were selected for reasons associated with identification of emission controls.

[11] Distributions for the reference, male, and female populations were excluded from Figure 6-4 as they closely reflect overall distributions.

Regarding racial and ethnic disparities, annual $PM_{2.5}$ concentrations for Black populations are substantially higher in the NE across the full distribution, but only slightly higher in the W and in CA. Also, concentrations for Black populations are slightly higher than concentrations for White populations only in the lowest ~50 percent of the populations in the SE. $PM_{2.5}$ concentrations among Hispanics are higher than concentrations for Non-Hispanic populations in all four regions, although disparities are largest at higher $PM_{2.5}$ concentrations in CA and smallest at lower $PM_{2.5}$ concentrations in the NE. Total $PM_{2.5}$ concentrations for Asian populations in the NE and SE are higher than the reference $PM_{2.5}$ concentrations, but similar in the W and CA.

People living below the poverty level and people over 25 without a high school diploma experience similar annual $PM_{2.5}$ concentrations to those above the poverty line and with a high school diploma in the NE, SE, and W, but experience higher $PM_{2.5}$ concentrations in CA under controls associated with the current standards (12/35). Older adults (65-99) experience slightly lower $PM_{2.5}$ concentrations associated with the illustrative control strategies for the more stringent alternative standard levels in all regions. Children experience higher annual $PM_{2.5}$ concentrations in some areas in the W.



Population Groups	Populations (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)	6.9	7.1	6.6	8.9	6.9	7.1	6.6	8.6	6.9	7.1	6.5	8.6	6.8	7.0	6.5	8.5	6.7	6.9	6.3	8.3
Race	White (0-99)	6.8	7.0	6.6	8.9	6.7	7.0	6.6	8.6	6.7	7.0	6.6	8.6	6.7	6.9	6.5	8.5	6.6	6.8	6.4	8.4
	American Indian (0-99)	6.7	7.0	5.4	8.8	6.7	7.0	5.4	8.5	6.7	7.0	5.4	8.5	6.6	6.9	5.4	8.4	6.5	6.9	5.3	8.3
	Asian (0-99)	7.2	7.5	6.5	8.8	7.2	7.5	6.5	8.5	7.2	7.5	6.5	8.5	7.1	7.3	6.4	8.3	7.0	7.1	6.2	8.1
	Black (0-99)	7.5	7.2	6.9	9.3	7.5	7.2	6.9	8.9	7.5	7.2	6.8	8.9	7.3	7.1	6.8	8.8	7.1	7.0	6.5	8.6
Ethnicity	Non-Hispanic (0-99)	6.8	6.9	6.4	8.6	6.8	6.9	6.4	8.3	6.8	6.9	6.4	8.3	6.7	6.9	6.4	8.2	6.6	6.7	6.2	8.0
	Hispanic (0-99)	7.3	7.6	6.9	9.4	7.3	7.5	6.9	9.0	7.3	7.5	6.9	8.9	7.2	7.4	6.8	8.9	7.1	7.2	6.6	8.8
Poverty Status	Above the poverty line (0-99)	6.9	7.1	6.6	8.9	6.9	7.0	6.6	8.6	6.9	7.0	6.5	8.5	6.8	7.0	6.5	8.5	6.7	6.9	6.3	8.3
	Below poverty line (0-99)	7.0	7.1	6.5	9.1	7.0	7.1	6.5	8.7	7.0	7.1	6.5	8.7	6.9	7.0	6.5	8.7	6.7	6.9	6.3	8.6
Educational Attainment	More educated (HS or more) (25-99)	6.9	7.0	6.5	8.8	6.9	7.0	6.5	8.5	6.8	7.0	6.5	8.5	6.8	6.9	6.5	8.4	6.6	6.8	6.3	8.2
	Less educated (no HS) (25-99)	6.9	7.1	6.6	9.2	6.9	7.1	6.6	8.8	6.9	7.1	6.5	8.7	6.9	7.0	6.5	8.7	6.7	6.9	6.3	8.6
Age	Children (0-17)	6.9	7.1	6.6	9.0	6.9	7.1	6.6	8.7	6.9	7.1	6.6	8.7	6.8	7.0	6.6	8.6	6.7	6.9	6.4	8.4
	Adults (18-64)	6.9	7.1	6.6	9.0	6.9	7.1	6.6	8.6	6.9	7.1	6.6	8.6	6.8	7.0	6.5	8.5	6.7	6.9	6.4	8.4
	Older Adults (64-99)	6.8	6.8	6.4	8.7	6.7	6.8	6.4	8.4	6.7	6.8	6.4	8.4	6.7	6.8	6.3	8.3	6.5	6.7	6.2	8.2
Sex	Females (0-99)	6.9	7.1	6.6	8.9	6.9	7.1	6.6	8.6	6.9	7.1	6.5	8.6	6.8	7.0	6.5	8.5	6.7	6.9	6.3	8.3
	Males (0-99)	6.9	7.1	6.6	8.9	6.9	7.0	6.6	8.6	6.9	7.0	6.5	8.6	6.8	7.0	6.5	8.5	6.7	6.8	6.3	8.3

Figure 6-3 Heat Map of Regional Average Annual $PM_{2.5}$ Concentrations ($\mu g/m^3$) by Demographic for Current (12/35) and Alternative PM NAAQS Levels (10/35, 10/30, 9/35, and 8/35) After Application of Controls

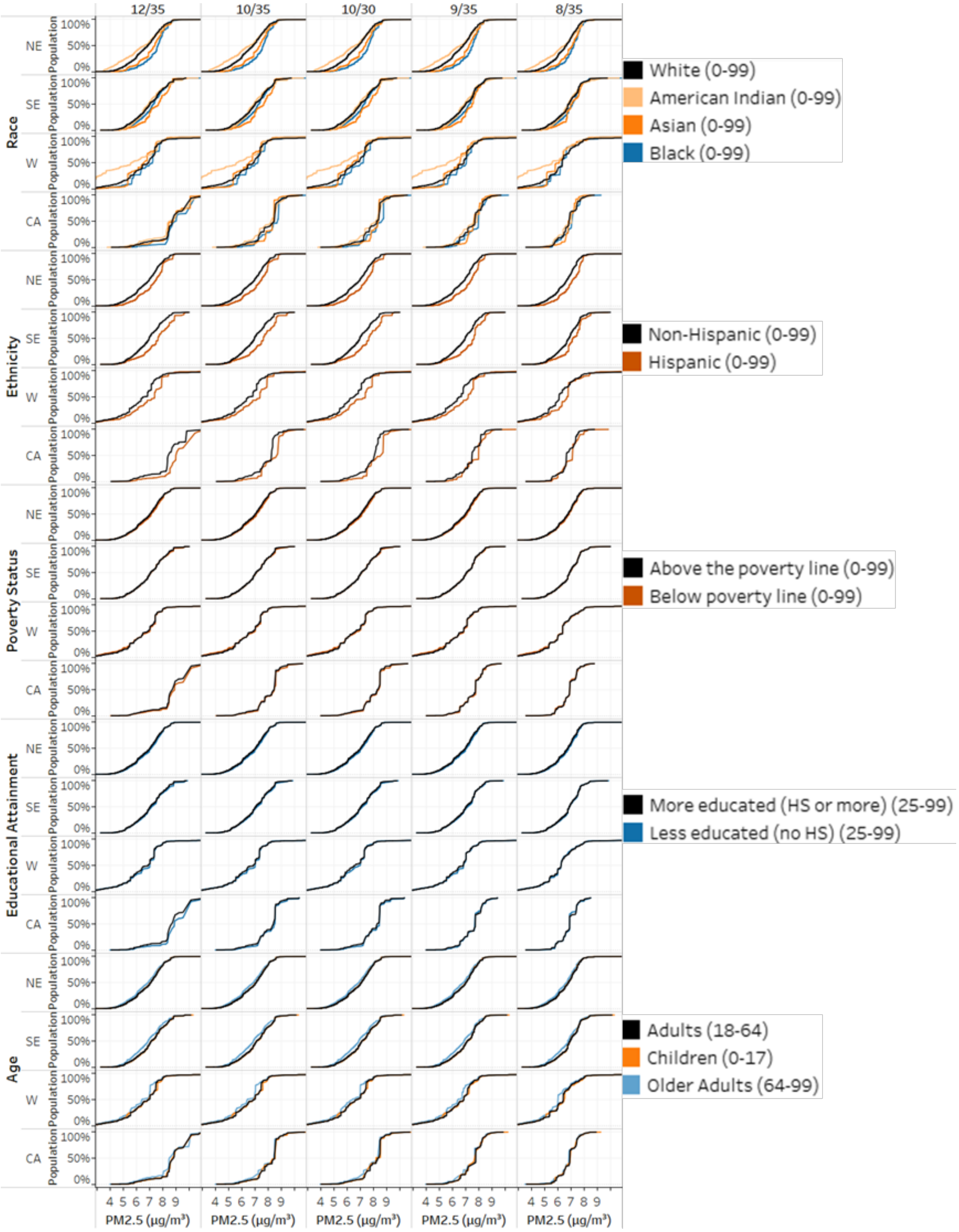


Figure 6-4 **Regional Distributions of Annual $PM_{2.5}$ Concentrations by Demographic for Current and Alternative PM NAAQS Levels After Application of Controls**

6.2.2 Exposure Changes

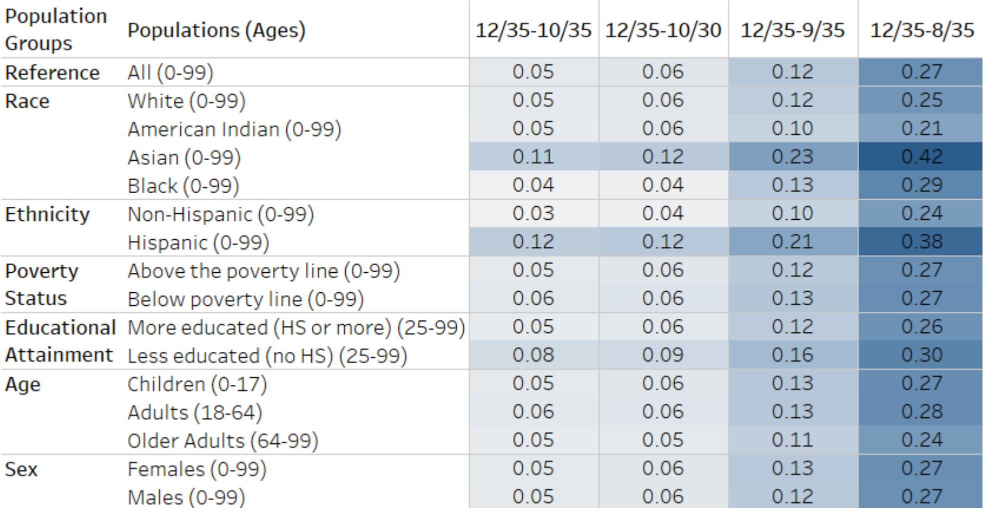
In addition to evaluating total/absolute exposures under control strategies associated with current/baseline and potential alternative standard levels (Section 6.2), we evaluate the extent to which exposures *change* for each demographic population, to compare improvements in air quality among populations. This begins to 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) under alternative standard levels. The national and regional changes in $PM_{2.5}$ concentrations experienced by different demographic populations for the current and alternative standard levels are provided in Sections 6.2.2.1 and 6.2.2.2, respectively.

6.2.2.1 National

First, we consider how average exposures change across different demographic groups at the national level. Figure 6-5 shows the average $PM_{2.5}$ concentration reduction and Figure 6-6 shows the distributions of county-level $PM_{2.5}$ concentration exposure reductions for each population when moving from the current standard to alternative standard levels. The magnitude of these numbers is quite small because they are national averages and include individuals residing in 12km x 12km gridded areas not predicted to experience $PM_{2.5}$ concentration reductions. For example, Figure 6-6 shows that only ~15% of the non-Hispanic population will experience $PM_{2.5}$ concentration reductions when moving from the baseline of control strategies associated with the current standards to control strategies associated with the alternative standard levels of 10/35, whereas ~30% of the Hispanic population will experience $PM_{2.5}$ concentration reductions under air quality scenarios associated with the same control strategies. Figure 6-6 also shows that greater reductions are expected in the ~30% of the Hispanic population projected to experience $PM_{2.5}$ concentration reductions than the ~15% of the non-Hispanic population projected to experience $PM_{2.5}$ concentration reductions. Together, these differences lead to an estimated four-fold greater reduction in average $PM_{2.5}$ concentrations when moving from the baseline of air quality associated with control strategies for the current standards of 12/35 to control strategies associated with the proposed alternative standard level of 10/35 (12/35-

10/35) in Figure 6-5. 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.

In general, populations with higher total $PM_{2.5}$ exposures (Section 6.2.1) are also expected to see the greatest reductions in average $PM_{2.5}$ concentrations under the alternative standard levels. On average nationwide, Asians, Hispanics, and those over 25 without a high school diploma 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. Black populations may experience slightly smaller $PM_{2.5}$ concentration reductions for alternative standard levels of 12/35-10/35 and 12/35-10/30 as compared to either the reference/overall population or other populations (Asian, Hispanic, and those over 25 without a high school diploma), but that disparity is smaller for control strategies associated with 12/35-9/35 or 12/35-8/35, and in fact average $PM_{2.5}$ concentration improvements are on par or slightly greater than in the reference population for these more stringent alternative standard levels.



Population Groups	Populations (Ages)	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
Reference	All (0-99)	0.05	0.06	0.12	0.27
Race	White (0-99)	0.05	0.06	0.12	0.25
	American Indian (0-99)	0.05	0.06	0.10	0.21
	Asian (0-99)	0.11	0.12	0.23	0.42
	Black (0-99)	0.04	0.04	0.13	0.29
Ethnicity	Non-Hispanic (0-99)	0.03	0.04	0.10	0.24
	Hispanic (0-99)	0.12	0.12	0.21	0.38
Poverty Status	Above the poverty line (0-99)	0.05	0.06	0.12	0.27
	Below poverty line (0-99)	0.06	0.06	0.13	0.27
Educational Attainment	More educated (HS or more) (25-99)	0.05	0.06	0.12	0.26
	Less educated (no HS) (25-99)	0.08	0.09	0.16	0.30
Age	Children (0-17)	0.05	0.06	0.13	0.27
	Adults (18-64)	0.06	0.06	0.13	0.28
	Older Adults (64-99)	0.05	0.05	0.11	0.24
Sex	Females (0-99)	0.05	0.06	0.13	0.27
	Males (0-99)	0.05	0.06	0.12	0.27

Figure 6-5 Heat Map of National Reductions in Average Annual $PM_{2.5}$ Concentrations ($\mu g/m^3$) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

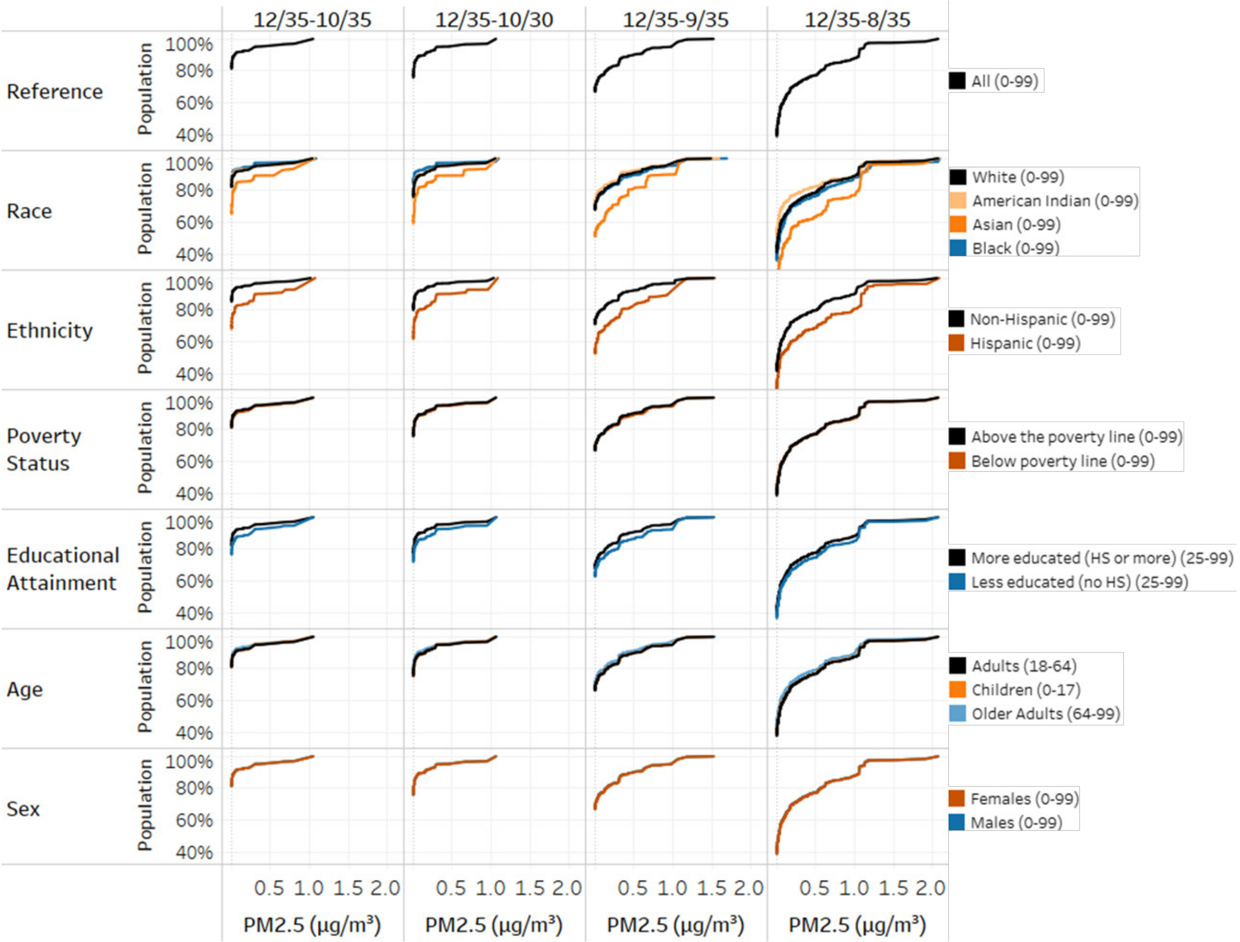


Figure 6-6 **National Distributions of Annual $PM_{2.5}$ Concentration Reductions for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls**

6.2.2.2 Regional

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 standard to control strategies associated with alternative standard levels are available in Figure 6-7 and Figure 6-8, respectively.[12] 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 6.2.1.2), average $PM_{2.5}$ concentration reductions also follow the same order. Comparing how these

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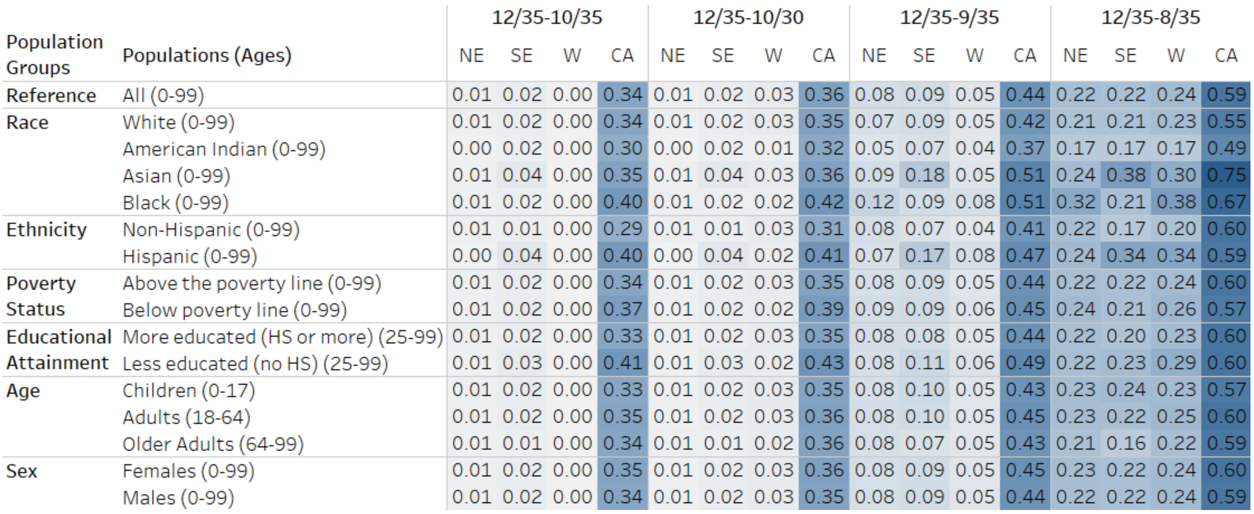
[12] Distributions for the reference, male, and female populations were excluded from Figure 6-8 as they closely reflect overall distributions.

reductions affect populations of potential EJ concern with 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 Blacks, Hispanics, those below the poverty line, 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.



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)	0.01	0.02	0.00	0.34	0.01	0.02	0.03	0.36	0.08	0.09	0.05	0.44	0.22	0.22	0.24	0.59
Race	White (0-99)	0.01	0.02	0.00	0.34	0.01	0.02	0.03	0.35	0.07	0.09	0.05	0.42	0.21	0.21	0.23	0.55
	American Indian (0-99)	0.00	0.02	0.00	0.30	0.00	0.02	0.01	0.32	0.05	0.07	0.04	0.37	0.17	0.17	0.17	0.49
	Asian (0-99)	0.01	0.04	0.00	0.35	0.01	0.04	0.03	0.36	0.09	0.18	0.05	0.51	0.24	0.38	0.30	0.75
	Black (0-99)	0.01	0.02	0.00	0.40	0.01	0.02	0.02	0.42	0.12	0.09	0.08	0.51	0.32	0.21	0.38	0.67
Ethnicity	Non-Hispanic (0-99)	0.01	0.01	0.00	0.29	0.01	0.01	0.03	0.31	0.08	0.07	0.04	0.41	0.22	0.17	0.20	0.60
	Hispanic (0-99)	0.00	0.04	0.00	0.40	0.00	0.04	0.02	0.41	0.07	0.17	0.08	0.47	0.24	0.34	0.34	0.59
Poverty Status	Above the poverty line (0-99)	0.01	0.02	0.00	0.34	0.01	0.02	0.03	0.35	0.08	0.09	0.05	0.44	0.22	0.22	0.24	0.60
	Below poverty line (0-99)	0.01	0.02	0.00	0.37	0.01	0.02	0.02	0.39	0.09	0.09	0.06	0.45	0.24	0.21	0.26	0.57
Educational Attainment	More educated (HS or more) (25-99)	0.01	0.02	0.00	0.33	0.01	0.02	0.03	0.35	0.08	0.08	0.05	0.44	0.22	0.20	0.23	0.60
	Less educated (no HS) (25-99)	0.01	0.03	0.00	0.41	0.01	0.03	0.02	0.43	0.08	0.11	0.06	0.49	0.22	0.23	0.29	0.60
Age	Children (0-17)	0.01	0.02	0.00	0.33	0.01	0.02	0.03	0.35	0.08	0.10	0.05	0.43	0.23	0.24	0.23	0.57
	Adults (18-64)	0.01	0.02	0.00	0.35	0.01	0.02	0.03	0.36	0.08	0.10	0.05	0.45	0.23	0.22	0.25	0.60
	Older Adults (64-99)	0.01	0.01	0.00	0.34	0.01	0.01	0.02	0.36	0.08	0.07	0.05	0.43	0.21	0.16	0.22	0.59
Sex	Females (0-99)	0.01	0.02	0.00	0.35	0.01	0.02	0.03	0.36	0.08	0.09	0.05	0.45	0.23	0.22	0.24	0.60
	Males (0-99)	0.01	0.02	0.00	0.34	0.01	0.02	0.03	0.35	0.08	0.09	0.05	0.44	0.22	0.22	0.24	0.59

Figure 6-7 Heat Map of Regional Reductions in $PM_{2.5}$ Concentrations (μg/m³) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

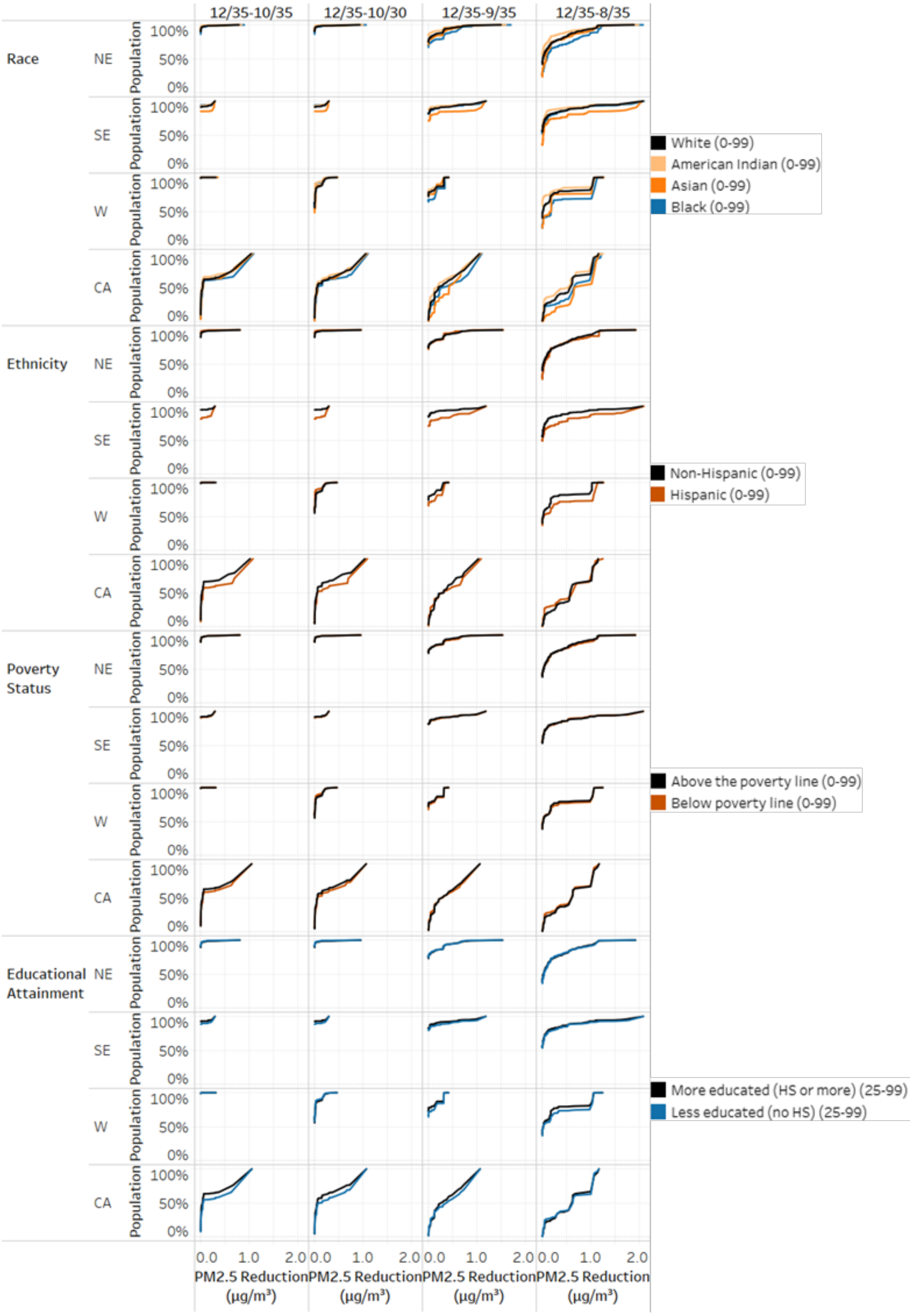


Figure 6-8 **Regional Distributions of Total $PM_{2.5}$ for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls**

6.2.3 Proportional Changes in Exposure

To put the changes in exposure discussed in section 6.2.2 in perspective, especially in light of the disparities in the exposure baseline across population groups as discussed in section 6.2.1, 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 standard to a potential alternative standard level, like those shown in section 6.2.2.

In this section, the proportionality of $PM_{2.5}$ concentration changes when moving from the current (baseline) to alternative standard levels under air quality scenarios associated with the illustrative emission control strategies is directly calculated.[13] To compare air quality improvements on a percentage basis, first exposures under the current standard are divided by exposures under the alternative standard levels 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 7 under control strategies associated with the current standard and 6 under an alternative standard level, 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 6 under the current standard and 5 under an alternative standard level, 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 been representative of the distributions, for simplicity we only present the average proportional reduction for each population and scenario, at the national and regional levels (6.2.3.1 and 6.2.3.2).

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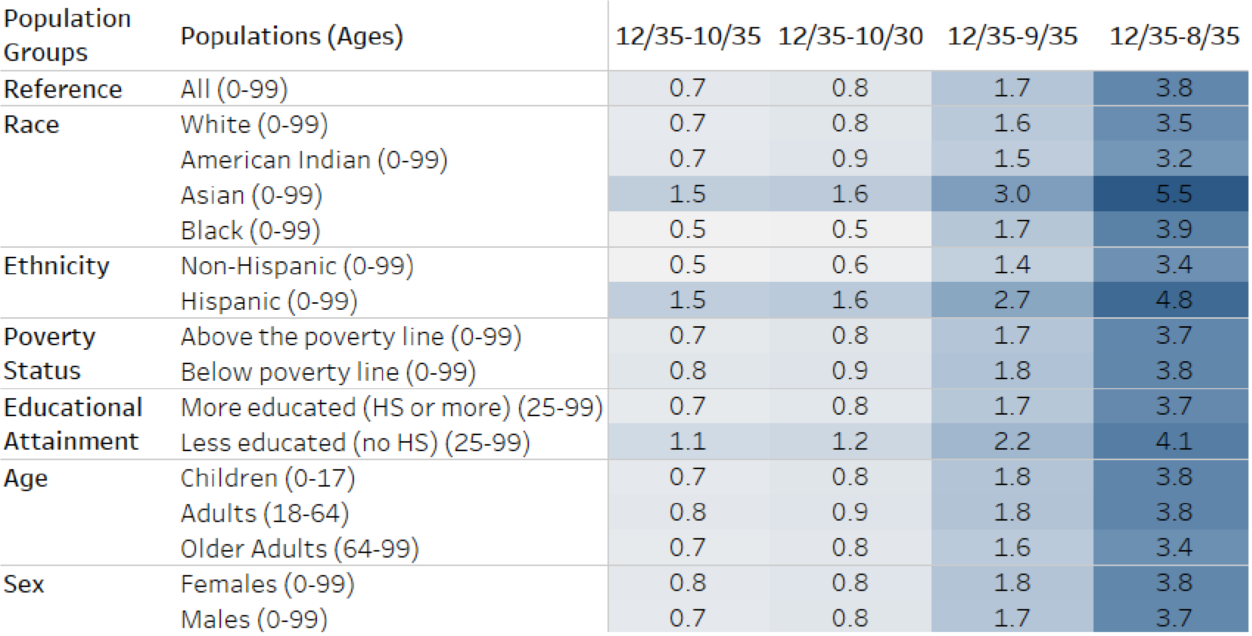
[13] Results for air quality scenarios associated with meeting the standards can be found in the Appendix to this chapter.

6.2.3.1 National

Nationally, alternative PM standard levels associated with control strategies reduce the average $PM_{2.5}$ exposure concentrations experienced by the reference population by an increasing percentage as the alternative standards are lowered, with a 0.7% improvement for 12/35-10/35 and a 3.8% improvement for 12/35-8/35 (Figure 6-9). Non-Hispanics experience slightly smaller proportional reductions, 0.5% for 12/35-10/35 and 3.4% for 12/35-8/35. Hispanics and Asian populations are predicted to experience the proportionally largest reductions in $PM_{2.5}$ concentrations under all alternative standard levels evaluated, followed by those less educated. Black populations experience smaller proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-10/35 or 12/35-10/30, but greater proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-9/35 or 12/35-8/35. This is likely due to the fact that gaps between the $PM_{2.5}$ concentrations experienced by Black populations vs. those experienced by White populations in the baseline is greater at lower ambient $PM_{2.5}$ concentrations (Figure 6-2, Figure 6-4, Figure 6-6, and Figure 6-8), with Black populations experiencing higher $PM_{2.5}$ levels relative to Whites throughout the distribution but particularly at lower ambient concentrations. This leads to proportionally greater improvements for Black populations (i.e., a narrowing of disparities as compared to White populations) at lower alternative $PM_{2.5}$ standards. Native Americans are estimated to experience the opposite, with slightly greater proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-10/35 or 12/35-10/30, and smaller proportional $PM_{2.5}$ concentration improvements than Whites when moving from 12/35-9/35 or 12/35-8/35. Older adults are estimated to experience proportionally smaller reductions in $PM_{2.5}$ concentrations under all alternative standard levels evaluated; however older adults experience lower $PM_{2.5}$ concentrations under air quality scenarios associated with control strategies for the baseline and all alternative NAAQS (Figure 6-1 through Figure 6-8).

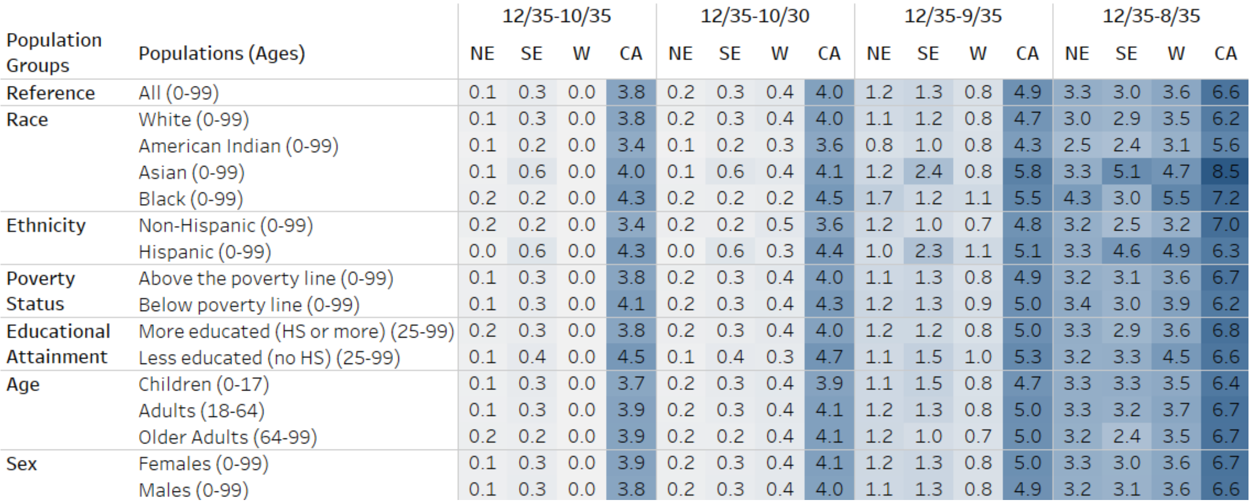


Population Groups	Populations (Ages)	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
Reference	All (0-99)	0.7	0.8	1.7	3.8
Race	White (0-99)	0.7	0.8	1.6	3.5
	American Indian (0-99)	0.7	0.9	1.5	3.2
	Asian (0-99)	1.5	1.6	3.0	5.5
	Black (0-99)	0.5	0.5	1.7	3.9
Ethnicity	Non-Hispanic (0-99)	0.5	0.6	1.4	3.4
	Hispanic (0-99)	1.5	1.6	2.7	4.8
Poverty Status	Above the poverty line (0-99)	0.7	0.8	1.7	3.7
	Below poverty line (0-99)	0.8	0.9	1.8	3.8
Educational Attainment	More educated (HS or more) (25-99)	0.7	0.8	1.7	3.7
	Less educated (no HS) (25-99)	1.1	1.2	2.2	4.1
Age	Children (0-17)	0.7	0.8	1.8	3.8
	Adults (18-64)	0.8	0.9	1.8	3.8
	Older Adults (64-99)	0.7	0.8	1.6	3.4
Sex	Females (0-99)	0.8	0.8	1.8	3.8
	Males (0-99)	0.7	0.8	1.7	3.7

Figure 6-9 Heat Map of National Percent Reductions in Average Annual $PM_{2.5}$ Concentrations (µg/m^3) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

6.2.3.2 Regional

Regionally the greatest proportional reductions are estimated for CA when moving from the current to all alternative standards under air quality associated with the illustrative emission control strategies (Figure 6-10). Like the national analysis, percent reductions get larger as alternative standard levels decrease. In addition to trends observed at the national level (Section 6.2.3.1), there are notable proportional reductions of $PM_{2.5}$ concentrations for Hispanic populations in CA, the SE, and the W, as well as for Asian populations in the SE and CA for all alternative standard levels and in the W for 12/35-8/35.



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)	0.1	0.3	0.0	3.8	0.2	0.3	0.4	4.0	1.2	1.3	0.8	4.9	3.3	3.0	3.6	6.6
Race	White (0-99)	0.1	0.3	0.0	3.8	0.2	0.3	0.4	4.0	1.1	1.2	0.8	4.7	3.0	2.9	3.5	6.2
	American Indian (0-99)	0.1	0.2	0.0	3.4	0.1	0.2	0.3	3.6	0.8	1.0	0.8	4.3	2.5	2.4	3.1	5.6
	Asian (0-99)	0.1	0.6	0.0	4.0	0.1	0.6	0.4	4.1	1.2	2.4	0.8	5.8	3.3	5.1	4.7	8.5
	Black (0-99)	0.2	0.2	0.0	4.3	0.2	0.2	0.2	4.5	1.7	1.2	1.1	5.5	4.3	3.0	5.5	7.2
Ethnicity	Non-Hispanic (0-99)	0.2	0.2	0.0	3.4	0.2	0.2	0.5	3.6	1.2	1.0	0.7	4.8	3.2	2.5	3.2	7.0
	Hispanic (0-99)	0.0	0.6	0.0	4.3	0.0	0.6	0.3	4.4	1.0	2.3	1.1	5.1	3.3	4.6	4.9	6.3
Poverty Status	Above the poverty line (0-99)	0.1	0.3	0.0	3.8	0.2	0.3	0.4	4.0	1.1	1.3	0.8	4.9	3.2	3.1	3.6	6.7
	Below poverty line (0-99)	0.1	0.3	0.0	4.1	0.2	0.3	0.4	4.3	1.2	1.3	0.9	5.0	3.4	3.0	3.9	6.2
Educational Attainment	More educated (HS or more) (25-99)	0.2	0.3	0.0	3.8	0.2	0.3	0.4	4.0	1.2	1.2	0.8	5.0	3.3	2.9	3.6	6.8
	Less educated (no HS) (25-99)	0.1	0.4	0.0	4.5	0.1	0.4	0.3	4.7	1.1	1.5	1.0	5.3	3.2	3.3	4.5	6.6
Age	Children (0-17)	0.1	0.3	0.0	3.7	0.2	0.3	0.4	3.9	1.1	1.5	0.8	4.7	3.3	3.3	3.5	6.4
	Adults (18-64)	0.1	0.3	0.0	3.9	0.2	0.3	0.4	4.1	1.2	1.3	0.8	5.0	3.3	3.2	3.7	6.7
	Older Adults (64-99)	0.2	0.2	0.0	3.9	0.2	0.2	0.4	4.1	1.2	1.0	0.7	5.0	3.2	2.4	3.5	6.7
Sex	Females (0-99)	0.1	0.3	0.0	3.9	0.2	0.3	0.4	4.1	1.2	1.3	0.8	5.0	3.3	3.0	3.6	6.7
	Males (0-99)	0.1	0.3	0.0	3.8	0.2	0.3	0.4	4.0	1.1	1.3	0.8	4.9	3.2	3.1	3.6	6.6

Figure 6-10 Heat Map of Regional Percent Reductions in Average Annual $PM_{2.5}$ Concentrations (µg/m^3) for Demographic Groups When Moving from Current (12/35) to Alternative PM NAAQS Level (10/35, 10/30, 9/35, and 8/35 After Application of Controls

6.3 EJ Analysis of Health Effects under Current Standards and Alternative Standard Levels

In addition to comparing $PM_{2.5}$ concentrations for potential demographic populations of concern in the EJ exposure analysis (Section 6.2.1), 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 $PM_{2.5}$ 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 disproportionate $PM_{2.5}$ health effects (e.g., mortality) under baseline/current PM NAAQS standard levels (question 1)?

2) Are there disproportionate $PM_{2.5}$ 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.[14] 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.

Therefore, due to the limited availability of both new scientific evidence in this NAAQS review and input information (U.S. EPA, 2019, U.S. EPA, 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 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, U.S. EPA, 2022a).

As such, this EJ health analysis assesses long-term $PM_{2.5}$-attributable mortality rates stratified by racial and ethnic demographic populations.[15,16] Mortality is presented as a rate

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[14] 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).

[15] 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, U.S. EPA, 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).

[16] The epidemiologic study and concentration-response functions used here to estimate $PM_{2.5}$-attributable mortality rates were identified using criteria that consider factors such as study design, geographic coverage, demographic populations, and health endpoints. Of the studies available from the 2019 PM ISA and 2022 Supplement , Di et al., 2017 was identified as best characterizing potentially at-risk racial- and ethnicity-stratified populations across the U.S. (U.S. EPA, 2019, U.S. EPA, 2022a). The overall response function was applied to non-Hispanics, as a non-Hispanic-specific concentration-response function was not provided by Di et al., 2017.

per 100,000 (100k) individuals to permit direct comparisons between population demographics with different total population counts.[17] 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 6.6.1.2 and Appendix C of the draft PM Policy Assessment (U.S. EPA, 2021).

6.3.1 Total Mortality Rates

National and regional relative disparities between the demographic-specific mortality rates under air quality scenarios associated with control strategies for the current and potential alternative lower standard levels are provided in Sections 6.3.1.1 and 6.3.1.2, respectively.

6.3.1.1 National

Figure 6-11 and Figure 6-12 show the national averages and distributions of estimated mortality rates per 100k individuals for each demographic population over the age of 64. These estimates are calculated using various inputs, including air quality changes, concentration-response functions, and baseline incidence. The greater magnitude concentration-response relationship between exposure and mortality for the Black population of older adults found by Di et al., 2017 results in estimated higher mortality rates in Blacks. Higher estimated average $PM_{2.5}$ concentrations among Hispanics, as discussed in the previous sections, leads to larger mortality rates in Hispanics than in non-Hispanics even though the baseline incidence rate in Hispanics is slightly lower than the overall rate (U.S. EPA, 2021, Appendix C).

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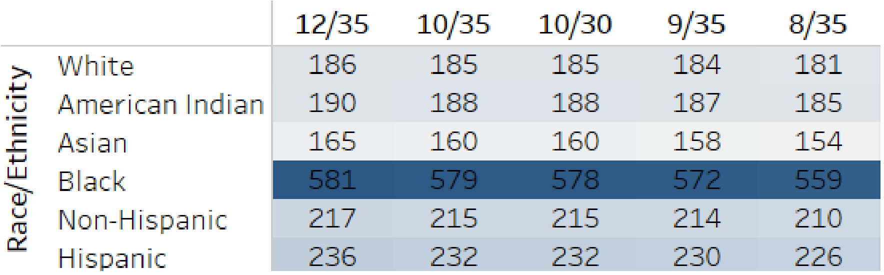
[17] Current Agency VSL practices do not differentiate based on race or ethnicity, so the health analysis did not include monetization. Separately, although the valuation of morbidity outcomes may differ by race or ethnicity (e.g., someone without insurance may delay seeing seen by a medical professional until the situation requires more expensive treatment), available scientific evidence for race/ethnicity-stratified valuation estimates is lacking.



Race/Ethnicity	12/35	10/35	10/30	9/35	8/35
White	186	185	185	184	181
American Indian	190	188	188	187	185
Asian	165	160	160	158	154
Black	581	579	578	572	559
Non-Hispanic	217	215	215	214	210
Hispanic	236	232	232	230	226

Figure 6-11 Heat Map of National Average Annual Total Mortality Rates (per 100K) for Demographic Groups for Current and Alternative PM NAAQS Levels After Application of Controls

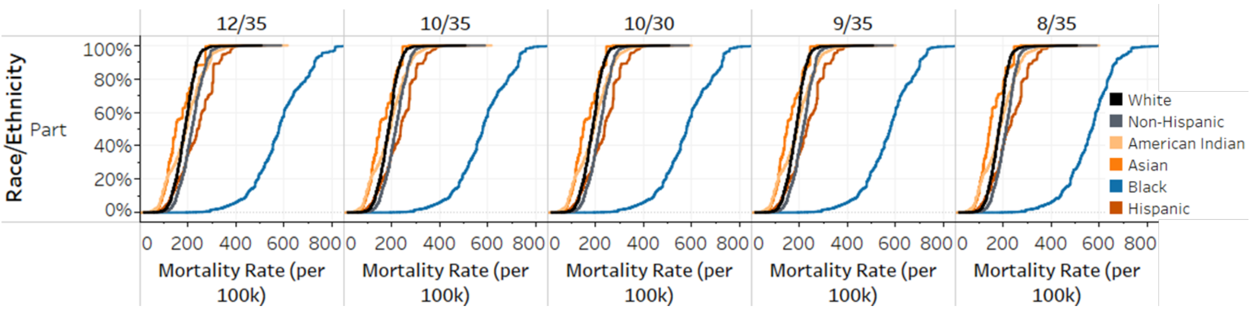
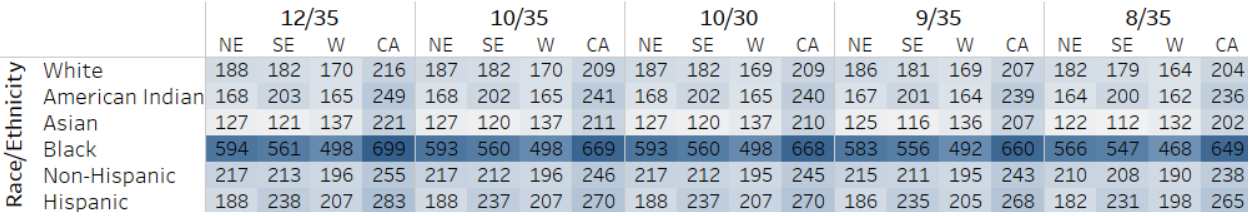


Figure 6-12 National Distributions of Total Annual Mortality Rates for Demographic Groups for Current and Alternative PM NAAQS Levels After Application of Controls

6.3.1.2 Regional

Regionally, the highest mortality rates for reference populations are in CA under air quality scenarios associated with control strategies for both current and alternative PM standard levels, followed by the NE, SE, and then the W (Figure 6-13 and Figure 6-14). Total mortality rates in the reference populations decrease slightly under alternative standard levels in all regions, and the most in CA. Within each of the four regions, average and distributional mortality rates are highest among Blacks and lowest among Asians, 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 6-4).



Race/Ethnicity	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
White	188	182	170	216	187	182	170	209	187	182	169	209	186	181	169	207	182	179	164	204
American Indian	168	203	165	249	168	202	165	241	168	202	165	240	167	201	164	239	164	200	162	236
Asian	127	121	137	221	127	120	137	211	127	120	137	210	125	116	136	207	122	112	132	202
Black	594	561	498	699	593	560	498	669	593	560	498	668	583	556	492	660	566	547	468	649
Non-Hispanic	217	213	196	255	217	212	196	246	217	212	195	245	215	211	195	243	210	208	190	238
Hispanic	188	238	207	283	188	237	207	270	188	237	207	270	186	235	205	268	182	231	198	265

Figure 6-13 **Heat Map of Regional Average Annual Total Mortality Rates (per 100K) for Demographic Groups for Current and Alternative PM NAAQS Levels After Application of Controls**

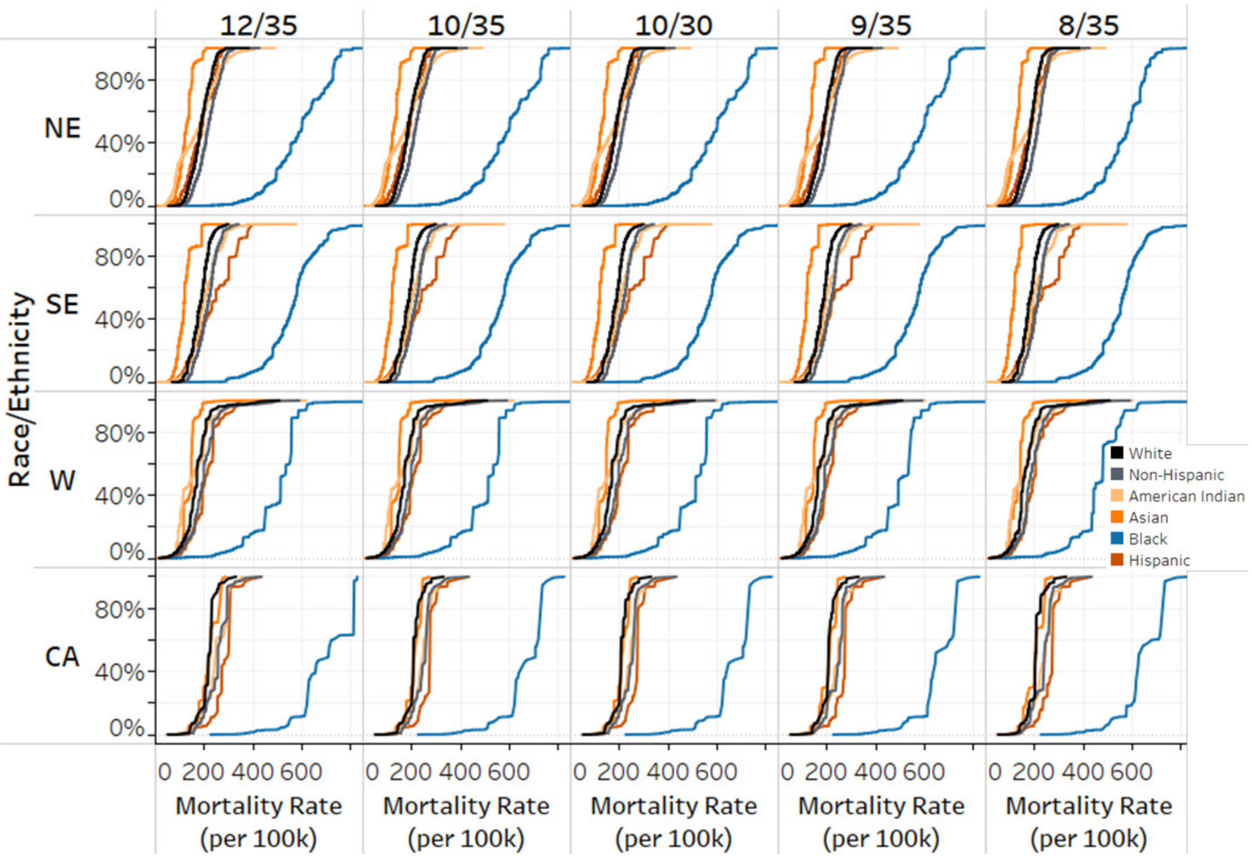


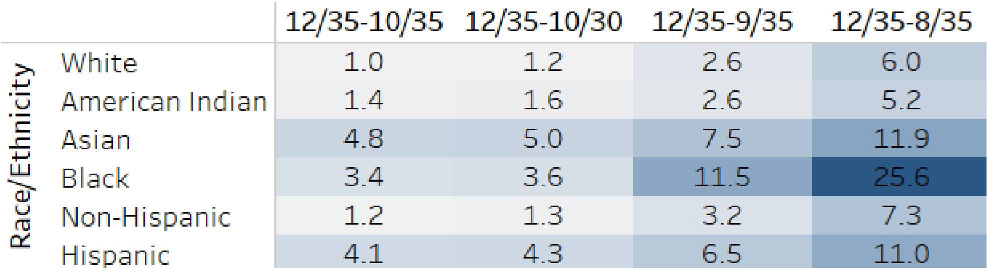
Figure 6-14 **Regional Distributions of Total Annual Mortality Rates for Demographic Groups for Current and Alternative PM NAAQS Levels After Application of Controls**

6.3.2 Mortality Rate Changes

National and regional relative changes in disparities between the demographic-specific mortality rates when moving from air quality associated with control strategies for the current to alternative standard levels are provided in Sections 6.3.2.1 and 6.3.2.2, respectively.

6.3.2.1 National

Nationally, the rate of $PM_{2.5}$-attributable mortality is estimated to decrease for all races and ethnicities when moving from current alternative standard levels, and more so under lower alternate standard levels (Figure 6-15 and Figure 6-16). In addition, reductions in mortality rates are larger for all other races as compared to Whites, and for Hispanics as compared to non-Hispanics.



Race/Ethnicity	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
White	1.0	1.2	2.6	6.0
American Indian	1.4	1.6	2.6	5.2
Asian	4.8	5.0	7.5	11.9
Black	3.4	3.6	11.5	25.6
Non-Hispanic	1.2	1.3	3.2	7.3
Hispanic	4.1	4.3	6.5	11.0

Figure 6-15 Heat Map of National Average Annual Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

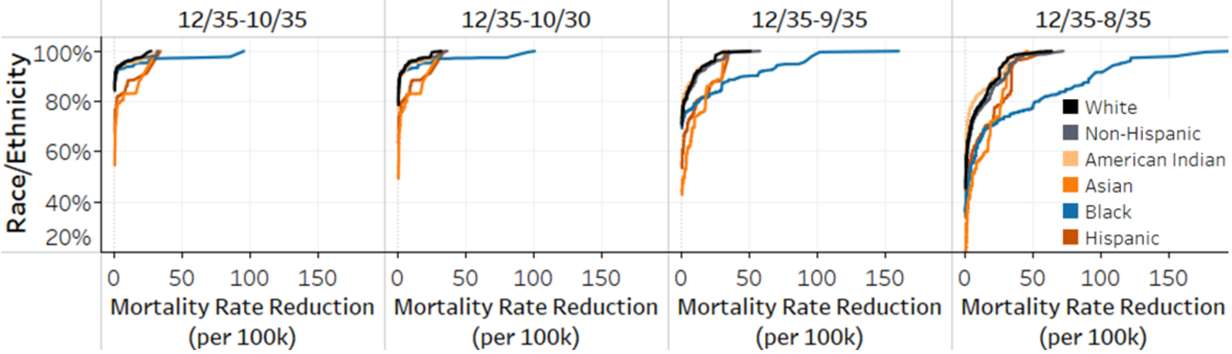
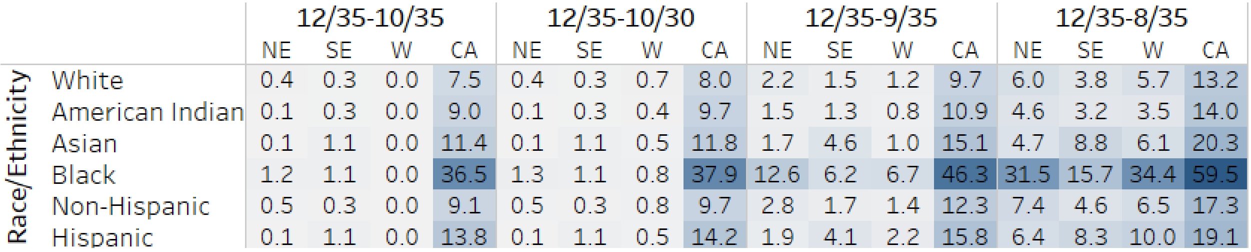


Figure 6-16 National Distributions of Annual Mortality Rate Reductions for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

6.3.2.2 Regional

Of the four regions, the largest mortality rate reductions for the greatest percent of each population are estimated in CA when moving from the current to alternative standard levels (Figure 6-17 and Figure 6-18). Reductions are smaller in the other three regions, although reductions become more substantial in the other three regions for 12/35-9/35 or 12/35-8/35. When comparing across race and ethnicities, Blacks are predicted to see the largest mortality rate reductions and Whites are predicted to see the smallest rate reductions.



Race/Ethnicity	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
White	0.4	0.3	0.0	7.5	0.4	0.3	0.7	8.0	2.2	1.5	1.2	9.7	6.0	3.8	5.7	13.2
American Indian	0.1	0.3	0.0	9.0	0.1	0.3	0.4	9.7	1.5	1.3	0.8	10.9	4.6	3.2	3.5	14.0
Asian	0.1	1.1	0.0	11.4	0.1	1.1	0.5	11.8	1.7	4.6	1.0	15.1	4.7	8.8	6.1	20.3
Black	1.2	1.1	0.0	36.5	1.3	1.1	0.8	37.9	12.6	6.2	6.7	46.3	31.5	15.7	34.4	59.5
Non-Hispanic	0.5	0.3	0.0	9.1	0.5	0.3	0.8	9.7	2.8	1.7	1.4	12.3	7.4	4.6	6.5	17.3
Hispanic	0.1	1.1	0.0	13.8	0.1	1.1	0.5	14.2	1.9	4.1	2.2	15.8	6.4	8.3	10.0	19.1

Figure 6-17 Heat Map of Regional Average Annual Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current and Alternative PM NAAQS Levels After Application of Controls

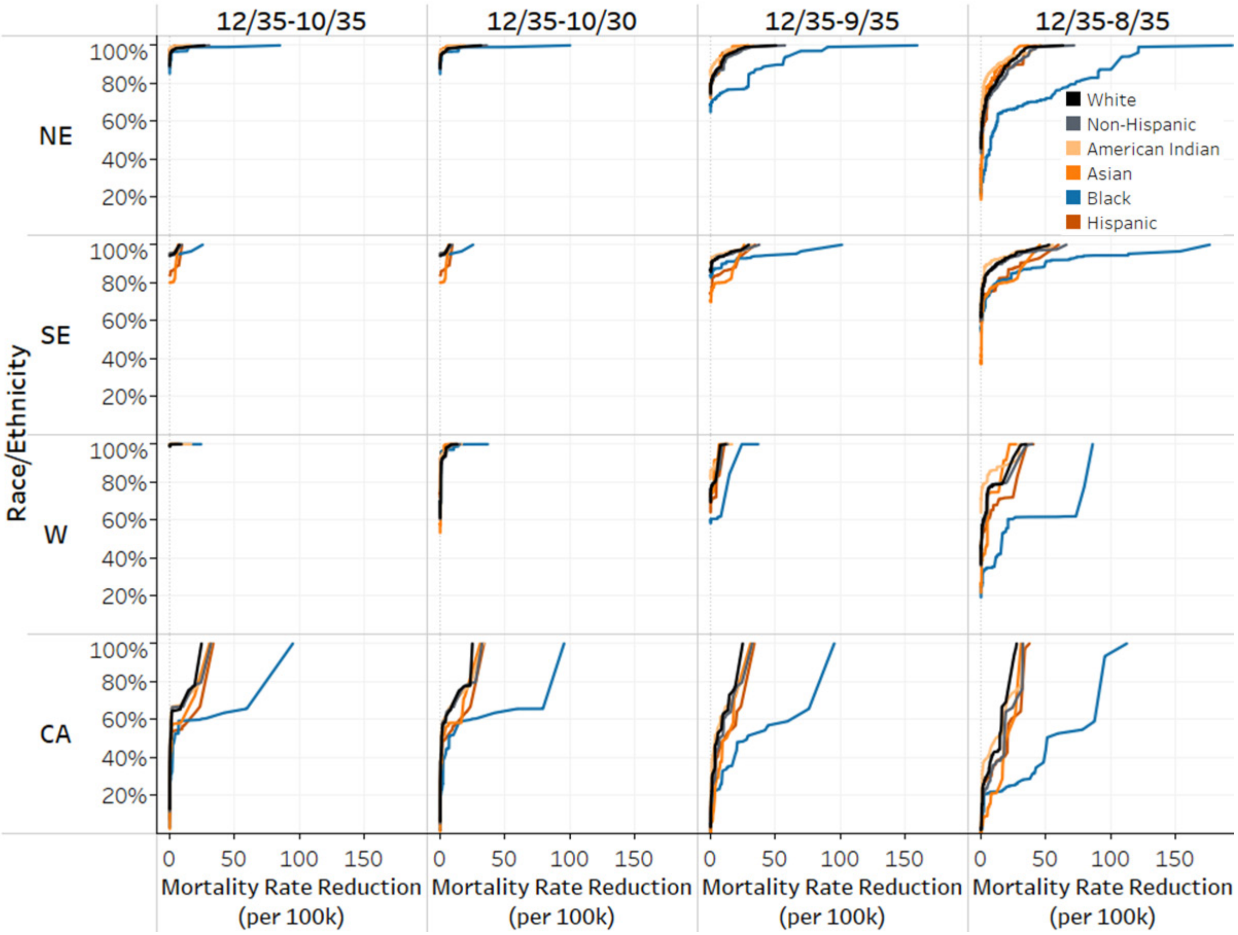


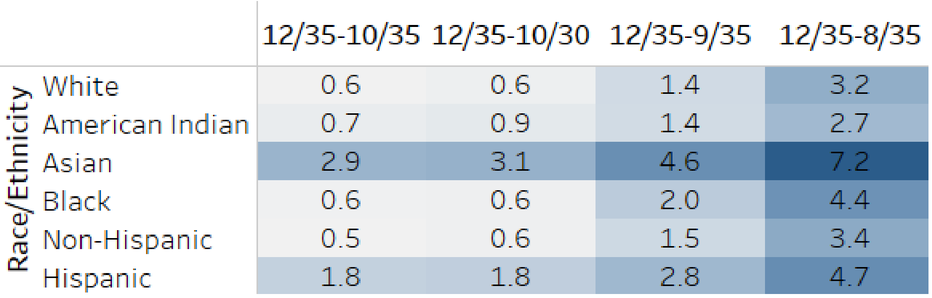
Figure 6-18 **Regional Distributions of Annual Mortality Rate Reductions for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls**

6.3.3 Proportional Changes in Mortality Rates

The proportional change in mortality rate for different demographic groups when moving from current to alternative $PM_{2.5}$ standard levels associated with the illustrate control strategies is calculated in the same way we estimated proportional changes in $PM_{2.5}$ concentrations in Section 6.2.3. Briefly, the mortality rate under the alternative standard level is divided by the mortality rate under the current standard, then subtracted from 1, and multiplied by 100 to get a percent. As the average mortality rates have been representative of the distributions, for simplicity we again only present the average proportional change for each population and scenario, at the national and regional levels (6.3.3.1 and 6.3.3.2).

6.3.3.1 National

Hispanics and Asians are estimated to experience proportionally larger reductions in mortality rates when moving from the current to alternative standard levels associated with control strategies, with the percent relative improvement increasing as standards are lowered (Figure 6-19).

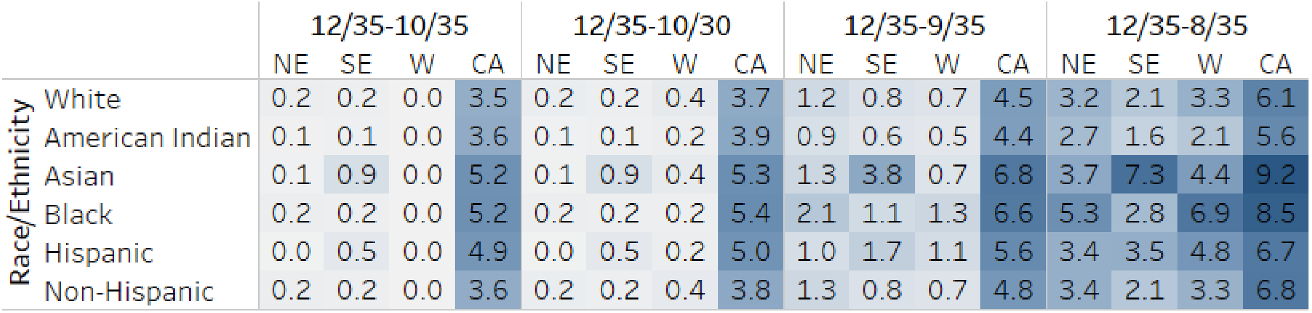


Race/Ethnicity	12/35-10/35	12/35-10/30	12/35-9/35	12/35-8/35
White	0.6	0.6	1.4	3.2
American Indian	0.7	0.9	1.4	2.7
Asian	2.9	3.1	4.6	7.2
Black	0.6	0.6	2.0	4.4
Non-Hispanic	0.5	0.6	1.5	3.4
Hispanic	1.8	1.8	2.8	4.7

Figure 6-19 Heat Map of National Average Percent Mortality Rate Reductions (per 100k People) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

6.3.3.2 Regional

Hispanics and Asians are estimated to experience proportionally larger reductions in mortality rates when moving from current standard to alternative standard levels associated with control strategies in the SE and CA. Blacks experience proportionally larger reductions in mortality rates for 12/35-9/35 and 12/35-8/35.



Race/Ethnicity	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
White	0.2	0.2	0.0	3.5	0.2	0.2	0.4	3.7	1.2	0.8	0.7	4.5	3.2	2.1	3.3	6.1
American Indian	0.1	0.1	0.0	3.6	0.1	0.1	0.2	3.9	0.9	0.6	0.5	4.4	2.7	1.6	2.1	5.6
Asian	0.1	0.9	0.0	5.2	0.1	0.9	0.4	5.3	1.3	3.8	0.7	6.8	3.7	7.3	4.4	9.2
Black	0.2	0.2	0.0	5.2	0.2	0.2	0.2	5.4	2.1	1.1	1.3	6.6	5.3	2.8	6.9	8.5
Hispanic	0.0	0.5	0.0	4.9	0.0	0.5	0.2	5.0	1.0	1.7	1.1	5.6	3.4	3.5	4.8	6.7
Non-Hispanic	0.2	0.2	0.0	3.6	0.2	0.2	0.4	3.8	1.3	0.8	0.7	4.8	3.4	2.1	3.3	6.8

Figure 6-20 Heat Map of Regional Average Percent Mortality Rate Reductions (per 100k) for Demographic Groups When Moving from Current to Alternative PM NAAQS Levels After Application of Controls

6.4 EJ Case Study of Exposure and Health Effects in Impacted Areas

The analyses presented above in sections 6.2 and 6.3 encompass the entire contiguous U.S., including areas that already meet potential alternative standards. Such areas would not be required to reduce emissions to meet the proposed more stringent standards, and therefore $PM_{2.5}$ concentrations in these areas would not be expected to change as a result of EPA adopting more stringent $PM_{2.5}$ standard level(s). Including such areas in the analysis reduces the resulting average exposure and mortality rate change estimates and potentially masks proportionally greater changes (i.e., reductions) in exposure and health impacts in areas that are projected to exceed the proposed alternative standards in the baseline. Areas that exceed the proposed alternative standards can be expected to experience the greatest $PM_{2.5}$ concentration changes following the application of control strategies. Therefore, in addition to analyses of the whole contiguous U.S. (Sections 6.2 and 6.3), here we perform an EJ case study focusing on areas that are predicted to experience $PM_{2.5}$ concentration changes when moving from the current standard of 12/35 to the alternative standard 9/35 under the emission control scenario described in Chapter 3.

This case study is intended to illustrate how changes in higher concentration areas compare to changes at the national scale; for purposes of this illustration, we focus on the single lower alternative standard of 9/35. The specific areas in which $PM_{2.5}$ concentrations change when moving to a lower standard differ with each alternative lower standard, with the number of areas increasing as the standard lowers. As such, fewer areas would be included if we analyzed 10/35 or 10/30, and additional areas would be included if we analyzed 8/35. Also, the case study analysis is limited to the assessment of average $PM_{2.5}$ exposures and risks and does not include all of the distributional information presented in the national analysis above. It is important to note that some of the limitations and caveats that affect the national scale analysis become even more relevant to this case study analysis. For example, 12 km grid scale air quality information may not be sufficiently resolved to detect hyperlocal differences in population exposures; this limitation becomes more important as we try to dial in on changes in exposure and risk in the considerably smaller areas included in the case study. Finally, the illustrative nature of the emission control strategy leading to emissions reductions in this NAAQS RIA may lead to increased uncertainties when looking only at areas in which $PM_{2.5}$ concentrations are predicted to change, as $PM_{2.5}$ concentrations in this analysis may not reflect state-level implementation decisions.

The subset of areas in which $PM_{2.5}$ concentrations are predicted to change when moving from 12/35 to 9/35 are colored blue in Figure 6-21. The subset of areas constitutes approximately 5% of the area across the contiguous U.S. and just over a quarter of the population. Information regarding the other ~95% of areas, which are projected to already meet a standard of 9/35 and therefore are not projected to experience a change in $PM_{2.5}$ concentrations under this more stringent standard, is also provided in certain figures for context.

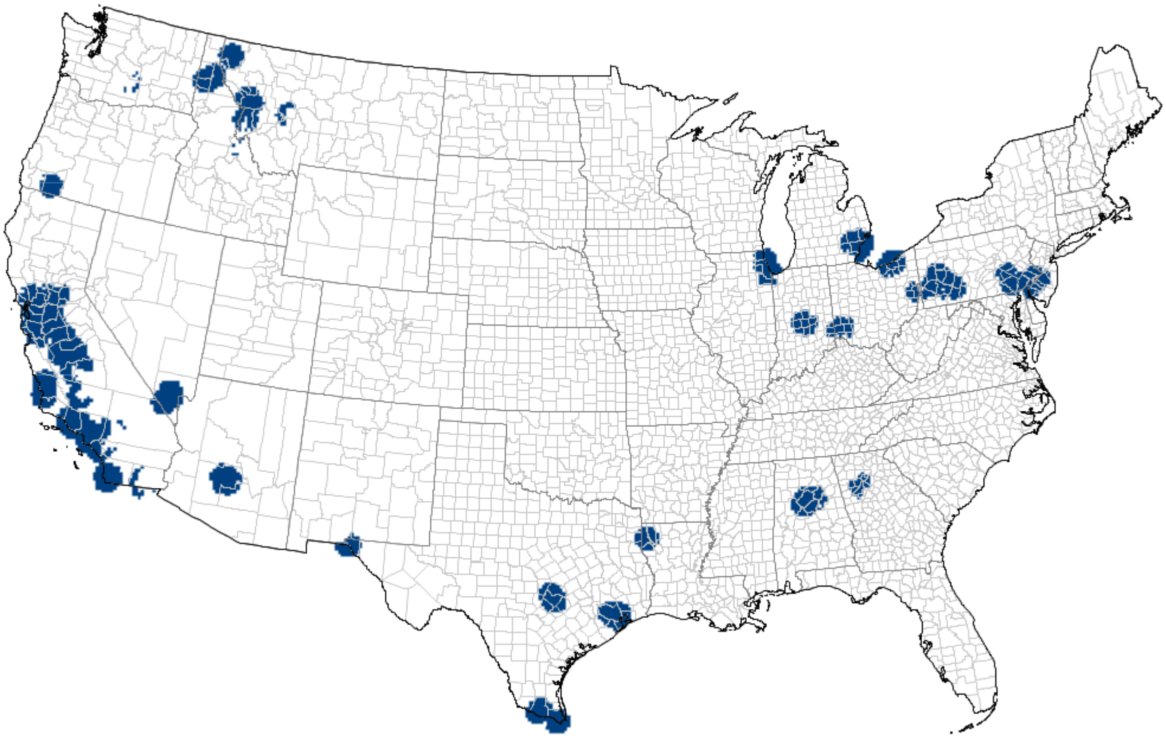
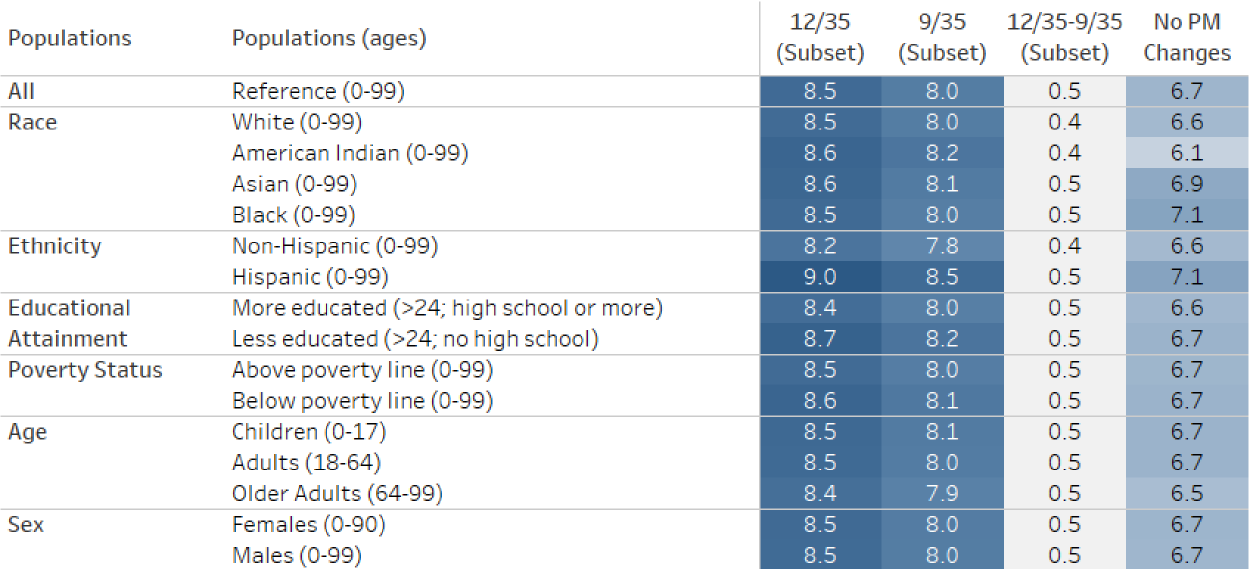


Figure 6-21 Map of Areas in which $PM_{2.5}$ Concentrations Change when Moving from 12/35 to 9/35 After Application of Controls

6.4.1 Exposures

Average annual $PM_{2.5}$ concentrations and concentration changes for the various demographic populations analyzed are presented for the subset of areas in Figure 6-22. Columns labelled '12/35 (Subset)' and '9/35 (Subset)' provide average $PM_{2.5}$ concentrations experienced by populations residing in the subset of ~5% of areas (~25% of people) where $PM_{2.5}$ concentration changes when moving from 12/35 to 9/35. The far-right column labeled 'No PM Changes' provides the average $PM_{2.5}$ concentrations experienced by populations residing in the other ~95% of areas (~75% of people) that do not experience a change in $PM_{2.5}$ concentration under the more stringent standard of 9/35. The column labelled '12/35-9/35 (Subset)' also shows the average $PM_{2.5}$ concentration reduction afforded to each population residing in the subset of areas where concentrations change, when moving from 12/35 to 9/35.

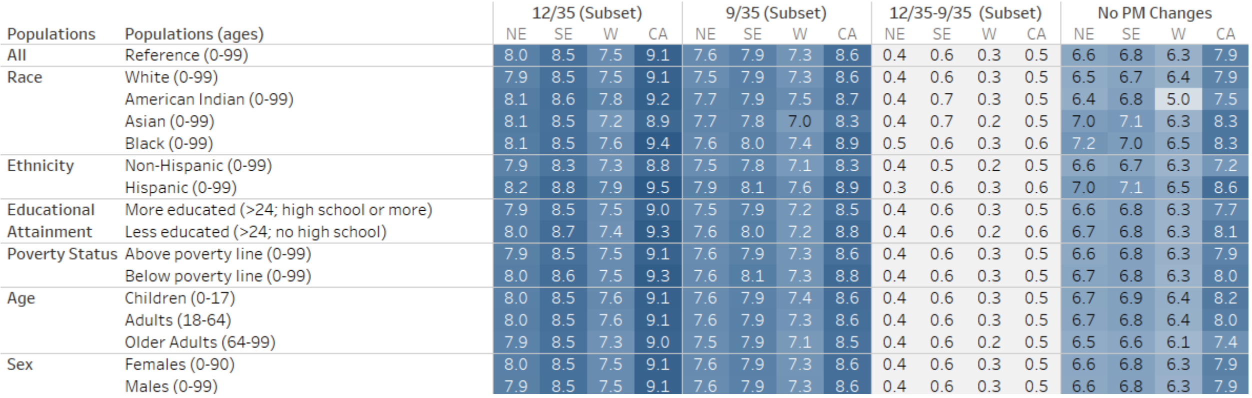
Comparing these averages to national-level estimates (Figure 6-1), we note that as expected, we observe higher average baseline exposures in areas where air quality changes, but the overall pattern of exposure across groups is fairly similar to the national pattern. Like Figure 6-1, Figure 6-22 shows that the most substantial disparity in average annual $PM_{2.5}$ exposures occurs between Hispanic populations and non-Hispanic populations. Further, in comparing the subset of areas where air quality changes to areas where it does not change, we note that average exposures in the subset of areas where air quality does change are at least 1 $\mu g/m^3$ higher than averages in the areas where air quality does not change under both the baseline and 9/35 scenarios. In addition, disparities are pronounced among certain demographics (e.g., the average baseline exposure among Hispanics living in areas where air quality does change is almost 2 $\mu g/m^3$ higher than exposures among Hispanics in areas that already meet 9/35). Similarly, the average air quality improvements experienced by populations living in areas where air quality does change are 2-4 times larger than when such changes are averaged over the entire contiguous U.S. (Figure 6-5).



Populations	Populations (ages)	12/35 (Subset)	9/35 (Subset)	12/35-9/35 (Subset)	No PM Changes
All	Reference (0-99)	8.5	8.0	0.5	6.7
Race	White (0-99)	8.5	8.0	0.4	6.6
	American Indian (0-99)	8.6	8.2	0.4	6.1
	Asian (0-99)	8.6	8.1	0.5	6.9
	Black (0-99)	8.5	8.0	0.5	7.1
Ethnicity	Non-Hispanic (0-99)	8.2	7.8	0.4	6.6
	Hispanic (0-99)	9.0	8.5	0.5	7.1
Educational Attainment	More educated (>24; high school or more)	8.4	8.0	0.5	6.6
	Less educated (>24; no high school)	8.7	8.2	0.5	6.7
Poverty Status	Above poverty line (0-99)	8.5	8.0	0.5	6.7
	Below poverty line (0-99)	8.6	8.1	0.5	6.7
Age	Children (0-17)	8.5	8.1	0.5	6.7
	Adults (18-64)	8.5	8.0	0.5	6.7
	Older Adults (64-99)	8.4	7.9	0.5	6.5
Sex	Females (0-90)	8.5	8.0	0.5	6.7
	Males (0-99)	8.5	8.0	0.5	6.7

Figure 6-22 Heat Map of National Average Annual $PM_{2.5}$ Concentrations and Concentration Changes ($\mu g/m^3$) by Demographic for 12/35, 9/35, and 12/35-9/35 in the Subset of Areas that Do and Do Not Experience Changes in Air Quality When Moving from 12/35 to 9/35

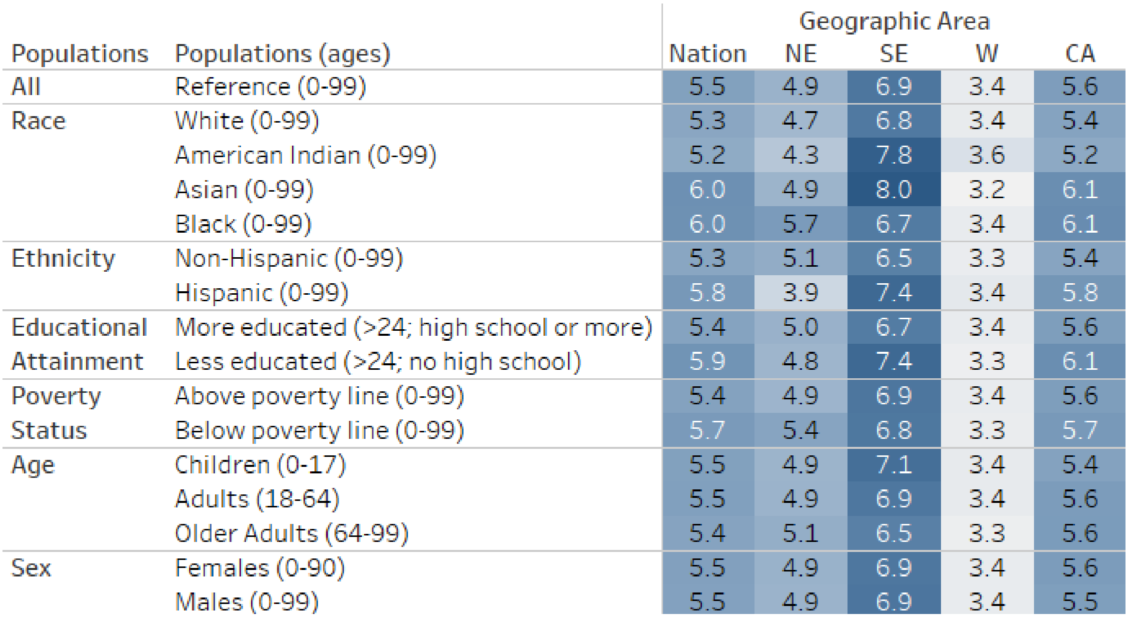
Average exposures of the subset of areas where air quality changes in each of the four regions analyzed show similar results, with larger average annual $PM_{2.5}$ concentrations and concentration reductions for this subset of areas in all regions (Figure 6-23). In the subset of areas where air quality does change moving from 12/35 to 9/35, absolute concentration reductions are more similar across the regions than when all areas are included as in Sections 6.2 and 6.3, with the largest reductions predicted in the SE, followed by CA, the NE, and the W. We note that this is tied to the control strategy, which identified different available measures in each region.



		12/35 (Subset)				9/35 (Subset)				12/35-9/35 (Subset)				No PM Changes			
Populations	Populations (ages)	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
All	Reference (0-99)	8.0	8.5	7.5	9.1	7.6	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.6	6.8	6.3	7.9
Race	White (0-99)	7.9	8.5	7.5	9.1	7.5	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.5	6.7	6.4	7.9
	American Indian (0-99)	8.1	8.6	7.8	9.2	7.7	7.9	7.5	8.7	0.4	0.7	0.3	0.5	6.4	6.8	5.0	7.5
	Asian (0-99)	8.1	8.5	7.2	8.9	7.7	7.8	7.0	8.3	0.4	0.7	0.2	0.5	7.0	7.1	6.3	8.3
	Black (0-99)	8.1	8.5	7.6	9.4	7.6	8.0	7.4	8.9	0.5	0.6	0.3	0.6	7.2	7.0	6.5	8.3
Ethnicity	Non-Hispanic (0-99)	7.9	8.3	7.3	8.8	7.5	7.8	7.1	8.3	0.4	0.5	0.2	0.5	6.6	6.7	6.3	7.2
	Hispanic (0-99)	8.2	8.8	7.9	9.5	7.9	8.1	7.6	8.9	0.3	0.6	0.3	0.6	7.0	7.1	6.5	8.6
Educational Attainment	More educated (>24; high school or more)	7.9	8.5	7.5	9.0	7.5	7.9	7.2	8.5	0.4	0.6	0.3	0.5	6.6	6.8	6.3	7.7
	Less educated (>24; no high school)	8.0	8.7	7.4	9.3	7.6	8.0	7.2	8.8	0.4	0.6	0.2	0.6	6.7	6.8	6.3	8.1
Poverty Status	Above poverty line (0-99)	7.9	8.5	7.5	9.1	7.6	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.6	6.8	6.3	7.9
	Below poverty line (0-99)	8.0	8.6	7.5	9.3	7.6	8.1	7.3	8.8	0.4	0.6	0.3	0.5	6.7	6.8	6.3	8.0
Age	Children (0-17)	8.0	8.5	7.6	9.1	7.6	7.9	7.4	8.6	0.4	0.6	0.3	0.5	6.7	6.9	6.4	8.2
	Adults (18-64)	8.0	8.5	7.6	9.1	7.6	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.7	6.8	6.4	8.0
	Older Adults (64-99)	7.9	8.5	7.3	9.0	7.5	7.9	7.1	8.5	0.4	0.6	0.2	0.5	6.5	6.6	6.1	7.4
Sex	Females (0-90)	8.0	8.5	7.5	9.1	7.6	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.6	6.8	6.3	7.9
	Males (0-99)	7.9	8.5	7.5	9.1	7.6	7.9	7.3	8.6	0.4	0.6	0.3	0.5	6.6	6.8	6.3	7.9

Figure 6-23 Heat Map of Regional Average Annual $PM_{2.5}$ Concentrations and Concentration Changes (μg/m^3) by Demographic for 12/35, 9/35, and 12/35-9/35 in the Subset of Areas that Do and Do Not Experience Changes in Air Quality When Moving from 12/35 to 9/35

While absolute exposure and exposure reduction estimates are necessary foundational information, the proportionality of the reductions more clearly answers question 3 of the EJ Technical Guidance (U.S. EPA, 2015). Proportional exposure reductions (i.e., the percent change in $PM_{2.5}$ concentrations when moving from 12/35 to 9/35 divided by the total exposure under 12/35) for the national and regional subset of areas in which $PM_{2.5}$ concentrations changed when moving from 12/35 to 9/35 are shown in Figure 6-24. As expected, proportional reductions are also greater than the national proportions (Figure 6-9 and Figure 6-10). Nationally, all populations with exposures higher than the overall reference (i.e., Hispanic, Asian, Black, and those less educated) are predicted to have larger proportional exposure decreases than the reference population. CA reflects the national trend, although there are variations in the NE, SE, and W. For example, ethnic exposure disparities in the NE, Black exposure disparities in the SE, and educational attainment disparities in the W are not proportionally mitigated in the subset of areas with air quality improvements when moving from the current standard to 9/35. However, it is also important to note that Hispanics are underrepresented in the NE, and population counts are lowest in the W.



Populations	Populations (ages)	Nation	Geographic Area NE	SE	W	CA
All	Reference (0-99)	5.5	4.9	6.9	3.4	5.6
Race	White (0-99)	5.3	4.7	6.8	3.4	5.4
	American Indian (0-99)	5.2	4.3	7.8	3.6	5.2
	Asian (0-99)	6.0	4.9	8.0	3.2	6.1
	Black (0-99)	6.0	5.7	6.7	3.4	6.1
Ethnicity	Non-Hispanic (0-99)	5.3	5.1	6.5	3.3	5.4
	Hispanic (0-99)	5.8	3.9	7.4	3.4	5.8
Educational Attainment	More educated (>24; high school or more)	5.4	5.0	6.7	3.4	5.6
	Less educated (>24; no high school)	5.9	4.8	7.4	3.3	6.1
Poverty Status	Above poverty line (0-99)	5.4	4.9	6.9	3.4	5.6
	Below poverty line (0-99)	5.7	5.4	6.8	3.3	5.7
Age	Children (0-17)	5.5	4.9	7.1	3.4	5.4
	Adults (18-64)	5.5	4.9	6.9	3.4	5.6
	Older Adults (64-99)	5.4	5.1	6.5	3.3	5.6
Sex	Females (0-90)	5.5	4.9	6.9	3.4	5.6
	Males (0-99)	5.5	4.9	6.9	3.4	5.5

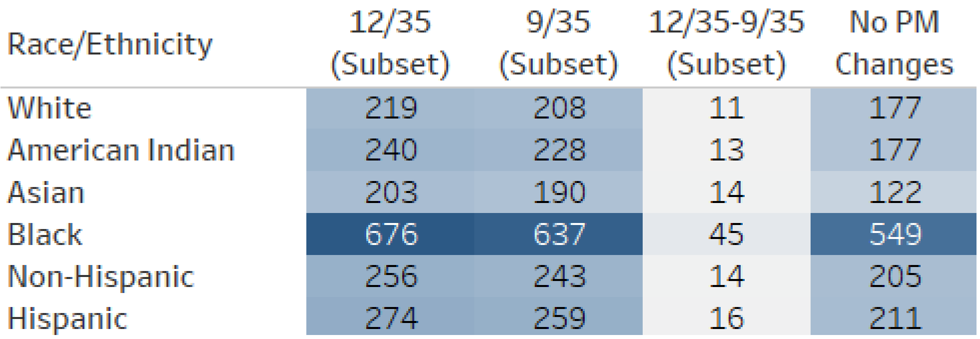
Figure 6-24 Heat Map of National Percent Reductions in Average Annual $PM_{2.5}$ Concentrations for Demographic Groups in the Subset of Areas in which $PM_{2.5}$ Concentrations Change When Moving from 12/35 to 9/35

6.4.2 Mortality Rates

Although the mitigation of exposure disparities is predicted for all demographic groups at the national level and most demographic groups at the regional scale in areas in which $PM_{2.5}$ concentrations are expected to change in moving from 12/35 to 9/35, it is also important to translate exposure disparities into health disparities when feasible, acknowledging that additional uncertainties are associated with estimating population-stratified health effects. To exemplify the potential importance of stratifying health impacts within various demographic of potential EJ concern, when employing the Di et al., 2017 population-stratified mortality hazard ratios (Table 6-2), the same $PM_{2.5}$ exposure reduction will reduce the hazard of mortality ~3-fold more in Black populations than in White populations. Therefore, we also separate mortality rate impacts in the subset of areas where $PM_{2.5}$ concentrations are expected to change when moving from 12/35 to 9/35 from areas that are not associated with $PM_{2.5}$ concentration changes.

Average national annual mortality rates and mortality rate changes for the various demographic populations analyzed are presented in Figure 6-25. Similar to average $PM_{2.5}$

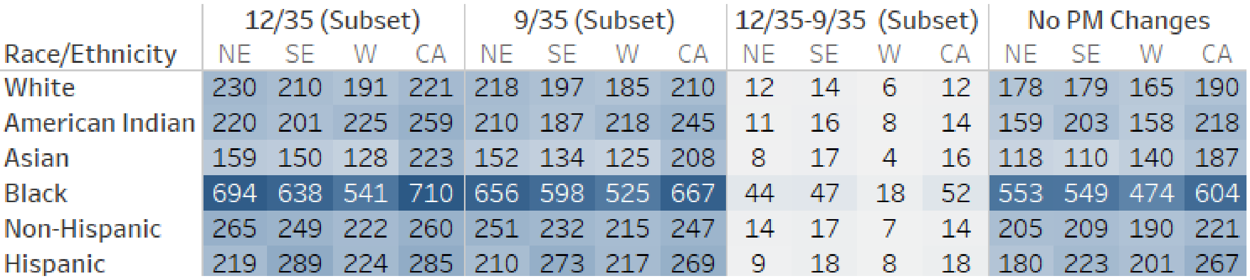
concentrations (Figure 6-22), average mortality rates in the subset of areas where air quality changes are higher, and averages in the areas where air quality does not change are lower than in the analysis of all areas (Figure 6-11 and Figure 6-13). The mortality rate reductions are also 2-5 times larger (Figure 6-15 and Figure 6-17).



Race/Ethnicity	12/35 (Subset)	9/35 (Subset)	12/35-9/35 (Subset)	No PM Changes
White	219	208	11	177
American Indian	240	228	13	177
Asian	203	190	14	122
Black	676	637	45	549
Non-Hispanic	256	243	14	205
Hispanic	274	259	16	211

Figure 6-25 **Heat Map of National Average Annual Total Mortality Rates and Mortality Rate Reductions (per 100K) by Demographic for 12/35, 9/35, and 12/35-9/35 in the Subset of Areas that Do and Do Not Experience Changes in Air Quality when Moving from 12/35 to 9/35**

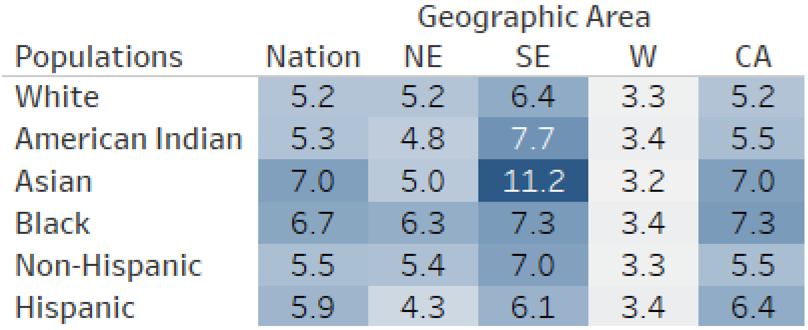
In the subset of areas in which $PM_{2.5}$ air quality changes in moving from 12/35 to 9/35, absolute mortality rate reductions are larger and also more similar across the regions than when all areas are included as in Sections 6.2 and 6.3 (Figure 6-26).



	12/35 (Subset)				9/35 (Subset)				12/35-9/35 (Subset)				No PM Changes			
Race/Ethnicity	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA	NE	SE	W	CA
White	230	210	191	221	218	197	185	210	12	14	6	12	178	179	165	190
American Indian	220	201	225	259	210	187	218	245	11	16	8	14	159	203	158	218
Asian	159	150	128	223	152	134	125	208	8	17	4	16	118	110	140	187
Black	694	638	541	710	656	598	525	667	44	47	18	52	553	549	474	604
Non-Hispanic	265	249	222	260	251	232	215	247	14	17	7	14	205	209	190	221
Hispanic	219	289	224	285	210	273	217	269	9	18	8	18	180	223	201	267

Figure 6-26 **Heat Map of Regional Average Annual Total Mortality Rates and Mortality Rate Reductions (per 100K) by Demographic for 12/35 9/35, and 12/35-9/35, in the Subset of Areas that Do and Do Not Change When Moving from 12/35-9/35**

Proportionally, mortality rate reductions associated with the change between the 12/35 and 9/35 scenarios are greatest for Black and Hispanic populations, helping to alleviate some of the disparities in the baseline (Figure 6-27). While mortality rate disparities for Blacks are predicted to be reduced in each region, impacts on disparities for Hispanics vary by region, with the greatest percent reduction in CA and the W. In comparing these reductions to the overall reductions in mortality rates nationally (Figure 6-19 and Figure 6-20), we note that the percent reductions are larger in the areas in which air quality changes when moving from 12/35 to 9/35, and that the pattern of results also varies somewhat by region (e.g., the greatest proportional rate reductions are seen among Asians in the SE, as compared to Blacks and Asians in CA in the analysis of all areas).



	Geographic Area				
Populations	Nation	NE	SE	W	CA
White	5.2	5.2	6.4	3.3	5.2
American Indian	5.3	4.8	7.7	3.4	5.5
Asian	7.0	5.0	11.2	3.2	7.0
Black	6.7	6.3	7.3	3.4	7.3
Non-Hispanic	5.5	5.4	7.0	3.3	5.5
Hispanic	5.9	4.3	6.1	3.4	6.4

Figure 6-27 Heat Map of National and Regional Percent Reductions in Average Annual Total Mortality Rates (per 100K) by Demographic in the Subset of Areas in which $PM_{2.5}$ Concentrations Change When Moving from 12/35-9/35

6.5 Summary

For this proposal, we quantitatively evaluate the potential for disparities in $PM_{2.5}$ concentrations and mortality effects across different demographic populations for the current (12/35; 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 emission 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. 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 a case study to examine the subset of areas in which air quality is projected to change after the application of controls outlined in Chapter 3 to illustrate how air quality improvements in the areas with the highest starting concentrations might be distributed demographically. 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 by 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 proposed 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 disproportionate $PM_{2.5}$ exposures/health effects under baseline/current PM NAAQS standard levels?
2) Are there disproportionate $PM_{2.5}$ exposures/health effects under illustrative alternative PM NAAQS standard levels?

3) Are $PM_{2.5}$ exposure/health effect 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 6.2) and the EJ health effects analysis (Section 6.3), responses to the above three questions can be summarized as:

1) **Disparities in the baseline**: 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 and Figure 6-2). Specifically, Hispanics, Asians, Blacks, and those less educated (no high school) 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, the Hispanic population is 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, though to different extents, as Asian concentrations in the W and CA are similar to the reference group, and those less educated are exposed to higher $PM_{2.5}$ concentrations only in CA (Figure 6-3 and Figure 6-4). Similar, but magnified, trends are observed when evaluating only the areas in which air quality improvements are predicted.

   In terms of health effects, some demographic populations are also predicted to experience disproportionately higher rates of premature mortality than reference populations (Figure 6-11 through Figure 6-14). Black populations are estimated to have the highest national and regional mortality rates, 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 which may increase susceptibility to adverse outcomes among Black populations. Hispanic mortality rates are disproportionately higher in the SE, W, and CA. Higher mortality rates are predicted for Asians and American Indians in CA and for American Indians in the SE. Similar, but larger, trends are also observed when evaluating only the areas in which air quality improvements are predicted.

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 are also reflected in the policy options under consideration. Specifically, disproportionately higher $PM_{2.5}$ concentrations and health effects remain for some populations estimated under air quality scenarios associated with the illustrative control strategies (10/35, 10/30, 9/35, and 8/35) (Figure 6-1 through Figure 6-4 and Figure 6-11 through Figure 6-14). Nationally and regionally, these patterns and the populations affected are similar to those seen in the baseline. and larger when considering only the subset of areas in which air quality improvements are expected.

3) **Relative impact of alternative policy options on disparities in the baseline**: For most populations assessed, $PM_{2.5}$ concentration 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 6-1 through Figure 6-10). This conclusion is strengthened when restricting analyses to areas in which $PM_{2.5}$ concentrations are predicted to decrease (Figure 6-29 through Figure 6-34). More specifically, increasing portions of certain populations of potential EJ concern are expected to experience greater $PM_{2.5}$ concentration reductions as the control strategies become more stringent (Figure 6-6). At the national scale, Hispanics, Asians, and those less educated 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. However, concentrations in the Black population are estimated to proportionally decrease on par with reference concentrations. Average concentration reductions

were also similar across Black and White populations when the spatial scale of the analysis was limited to those areas affected by the illustrative control strategies. Considering the four geographic regions, proportionally greater reductions in $PM_{2.5}$ concentrations experienced by Asian, Hispanic, and less educated populations are most notable in the SE and CA, whereas $PM_{2.5}$ concentration reductions among Black populations tend to be proportionally larger than among the reference population in CA, W, and the NE, especially under lower standard levels. Due to the higher prevalence of Black populations in the SE, the lack of proportional concentration reductions in that region may mask increased concentration reductions in other regions at the national level.

In general, more stringent control strategies are also associated with reductions in mortality rate disparities. Specifically, the analysis shows that as the $PM_{2.5}$ 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). Similar to the estimated changes in $PM_{2.5}$ concentrations following reductions in $PM_{2.5}$ concentrations under alternative standards, disparities in $PM_{2.5}$ mortality rates across demographic groups are mitigated nationally for Hispanics in all the alternative PM standard levels (10/35, 10/30, 9/35, and 8/35) as compared to the baseline (Figure 6-19). Nationally, Black populations are predicted to experience proportionally similar mortality rate reductions to White populations under control strategies associated with 12/35-10/35 or 12/35-10/30, but greater reductions in mortality rates than White populations under control strategies associated with 12/35-9/35 or 12/35-8/35. While Asians are estimated to experience the greatest proportional mortality rate reductions of the races/ethnicities analyzed, they are predicted to initially experience disproportionally lower mortality rates under the baseline scenario. When the spatial scale of the analysis was limited to those areas affected by the illustrative control strategies for 9/35, Asian, Black and Hispanics experienced the greatest reduction in mortality rates nationally and in most regions.

6.6 Environmental Justice Appendix

6.6.1 Input Information

6.6.1.1 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 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).

6.6.1.2 EJ Health Effects Analysis Input Data

The health assessment requires input data in addition to the information used in the exposure assessment (Section 6.6.1.1). As such, there are additional uncertainties, albeit similar to the benefits assessment results (Chapter 5). We 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. Of the available studies, Di et al., 2017 was a nationwide study, evaluated the largest study size over one of the most recent time spans, used a sophisticated exposure estimation technique, and provided sufficient information to apply risk models quantifying increased risks to the following nonwhite groups: Black, Asian, Native American, and Hispanic populations. Although Di et al., 2017 effect estimates were derived from a cohort aged 65 and older and the study did not provide a non-Hispanic concentration-response function, it was identified as best characterizing populations potentially at increased risk of long-term exposure and all-cause mortality. Health impact functions, including beta parameters and standard errors (SE), were developed for each at-risk population demographic described by Di et al., 2017 and are provided in Table 6-2.

Table 6-2 Hazard Ratios, Beta Coefficients, and Standard Errors (SE) from Di et al., 2017

Demographic Population	Risk of Death Associated with a 10 μg/m^3 Increase in PM$_{2.5}$	Beta Coefficient (SE)
White	1.063 (1.060, 1.065)	0.0061 (0.0001)
All	1.073 (1.071, 1.075)	0.0070 (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)

Concentration-response functions stratified by race and ethnicity were only available for ages greater than 64. While BenMAP-CE includes population information for 5-year age spans up to 84 and Di et al., 2017 provides stratified concentration-response functions for 10-year age spans (65-74, 75-84, and 85-99), the stratified concentration-response functions for 10-year age spans were not also stratified by race or ethnicity. Therefore, this analysis only evaluated a single age range group of 65-99 years.

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 and respiratory mortality data from 2007 to 2016 from the CDC WONDER mortality database.[18] Race-stratified incidence rates were calculated for the

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[18] https://wonder.cdc.gov/

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 non-White incidence rates by race (Black, Asian, Native American) 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 User Manual with one notable difference in methodology; we included an intermediate spatial scale between county and state for imputation purposes.[19] 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.[20] Ethnicity-stratified incidence rates were calculated for the

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[19] https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf

[20] https://wonder.cdc.gov/

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 for imputation purposes, described in detail in Section D.1.3 of the BenMAP User Manual.[21]

6.6.2 EJ Analysis of Total Exposures Associated with Meeting the Standards

In addition to air quality surfaces associated with the illustrative emission control strategies evaluated in the main EJ chapter, $PM_{2.5}$ air quality surfaces associated with meeting the current and alternative standard levels were also developed. Air quality associated with meeting the standards was based on assumptions that emission controls could be identified to meet the required emission amounts (Appendix 2A). Results for both air quality scenarios 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 standards reduce disparities more so than air quality scenarios associated with the control strategies, especially for Hispanics populations in CA.

National and regional $PM_{2.5}$ concentrations by demographic populations for air quality scenarios associated with both the control strategies and meeting the standards are provided in Sections 6.6.2.1 and 6.6.2.2, respectively.

6.6.2.1 National

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 and lower alternative standard levels than air quality scenarios associated with control strategies (Figure 6-28 and Figure 6-29). This may narrow disproportionate $PM_{2.5}$ concentrations for certain populations, such as Hispanics, under air quality associated with more stringent alternative standard levels.

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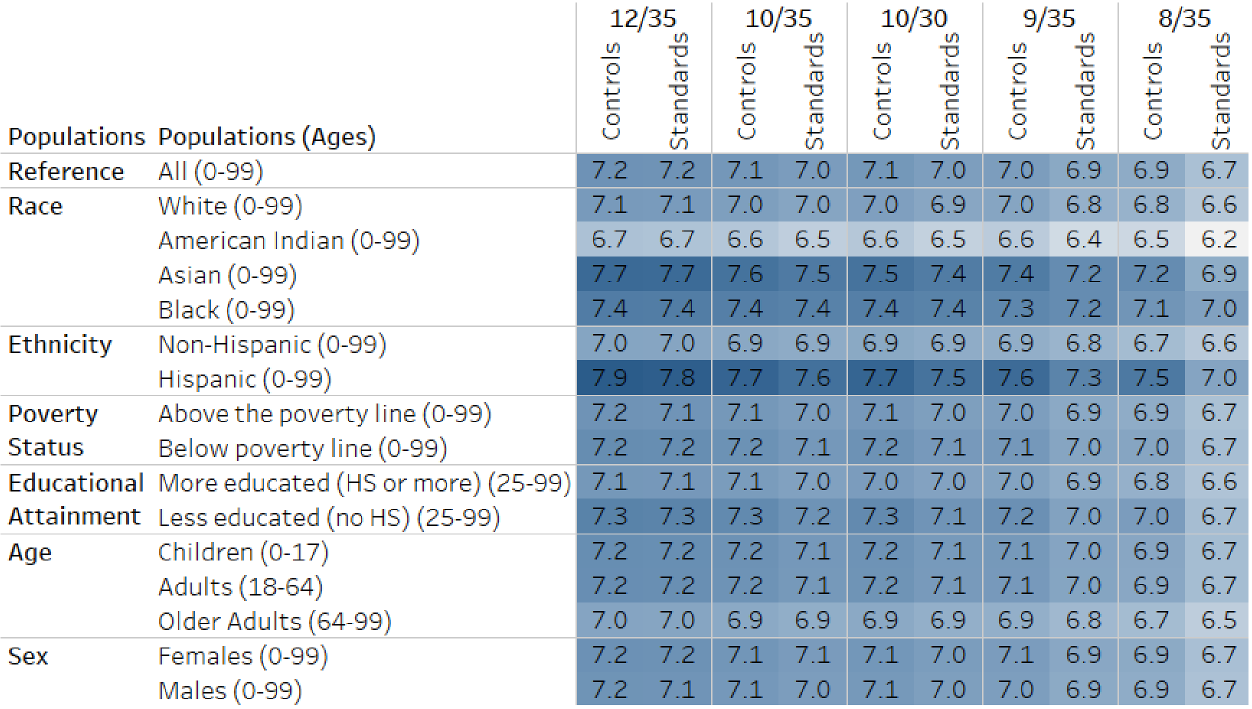
[21] https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf



Populations	Populations (Ages)	12/35		10/35		10/30		9/35		8/35	
		Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	7.2	7.2	7.1	7.0	7.1	7.0	7.0	6.9	6.9	6.7
Race	White (0-99)	7.1	7.1	7.0	7.0	7.0	6.9	7.0	6.8	6.8	6.6
	American Indian (0-99)	6.7	6.7	6.6	6.5	6.6	6.5	6.6	6.4	6.5	6.2
	Asian (0-99)	7.7	7.7	7.6	7.5	7.5	7.4	7.4	7.2	7.2	6.9
	Black (0-99)	7.4	7.4	7.4	7.4	7.4	7.4	7.3	7.2	7.1	7.0
Ethnicity	Non-Hispanic (0-99)	7.0	7.0	6.9	6.9	6.9	6.9	6.9	6.8	6.7	6.6
	Hispanic (0-99)	7.9	7.8	7.7	7.6	7.7	7.5	7.6	7.3	7.5	7.0
Poverty Status	Above the poverty line (0-99)	7.2	7.1	7.1	7.0	7.1	7.0	7.0	6.9	6.9	6.7
	Below poverty line (0-99)	7.2	7.2	7.2	7.1	7.2	7.1	7.1	7.0	7.0	6.7
Educational Attainment	More educated (HS or more) (25-99)	7.1	7.1	7.1	7.0	7.0	7.0	7.0	6.9	6.8	6.6
	Less educated (no HS) (25-99)	7.3	7.3	7.3	7.2	7.3	7.1	7.2	7.0	7.0	6.7
Age	Children (0-17)	7.2	7.2	7.2	7.1	7.2	7.1	7.1	7.0	6.9	6.7
	Adults (18-64)	7.2	7.2	7.2	7.1	7.2	7.1	7.1	7.0	6.9	6.7
	Older Adults (64-99)	7.0	7.0	6.9	6.9	6.9	6.9	6.9	6.8	6.7	6.5
Sex	Females (0-99)	7.2	7.2	7.1	7.1	7.1	7.0	7.1	6.9	6.9	6.7
	Males (0-99)	7.2	7.1	7.1	7.0	7.1	7.0	7.0	6.9	6.9	6.7

Figure 6-28 Heat Map of National Average Annual $PM_{2.5}$ Concentrations (µg/m^3) Associated Either with Control Strategies (Controls) or with Meeting the Standards (Standards) by Demographic for Current (12/35) and Alternative PM NAAQS Levels (10/35, 10/30, 9/35, and 8/35)

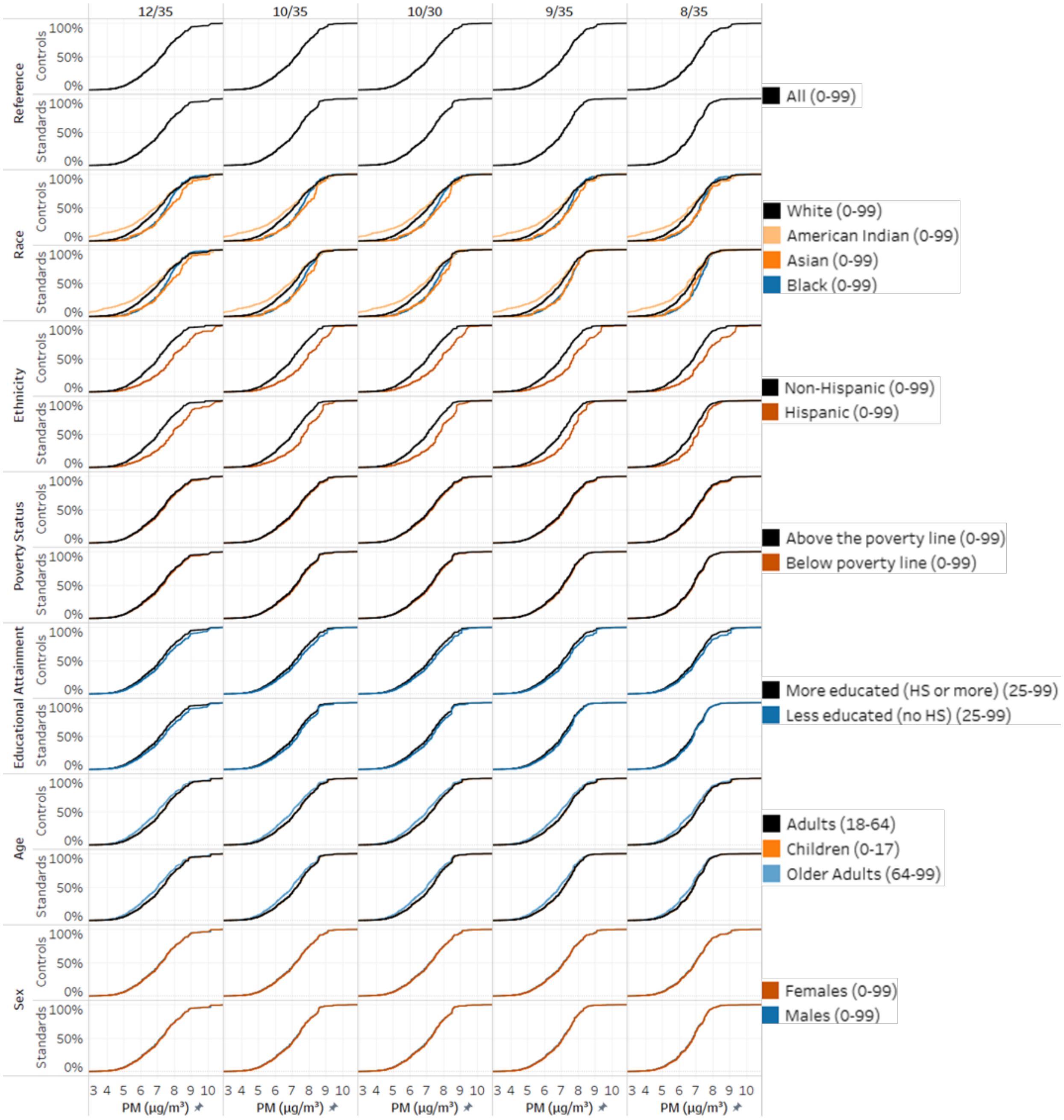


Figure 6-29 National Distributions of Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current and Alternative PM NAAQS Levels

6.6.2.2 Regional

Regionally, air quality scenarios associated with meeting the standards also led to similar or slightly lower $PM_{2.5}$ concentrations as air quality scenarios associated with the current standards for more stringent standard levels, except for in CA, where air quality associated with the standards resulted in substantially lower $PM_{2.5}$ concentrations (Figure 6-30 and Figure 6-31).[22]

Comparing 'Controls' and 'Standards' in CA associated with the lower alternative standard levels allows for some insight into areas without known emission control strategies. For example, for the alternative standard level of 9/35 in CA, more than 90% of non-Hispanics and Hispanics are projected to experience annual $PM_{2.5}$ concentrations <9 $\mu g/m^3$ when meeting an alternative standard level of 9/35 and a similar percentage of non-Hispanics are expected to experience annual $PM_{2.5}$ concentrations <9 $\mu g/m^3$ associated with emission control strategies for 9/35. In contrast, only about 60% of Hispanics are expected to experience annual $PM_{2.5}$ concentrations <9 $\mu g/m^3$ with controls associated with 9/35. Therefore, disparities between Hispanics and non-Hispanics predicted with controls at 9/35 are mitigated if CA were to meet the alternative standard level of 9/35.

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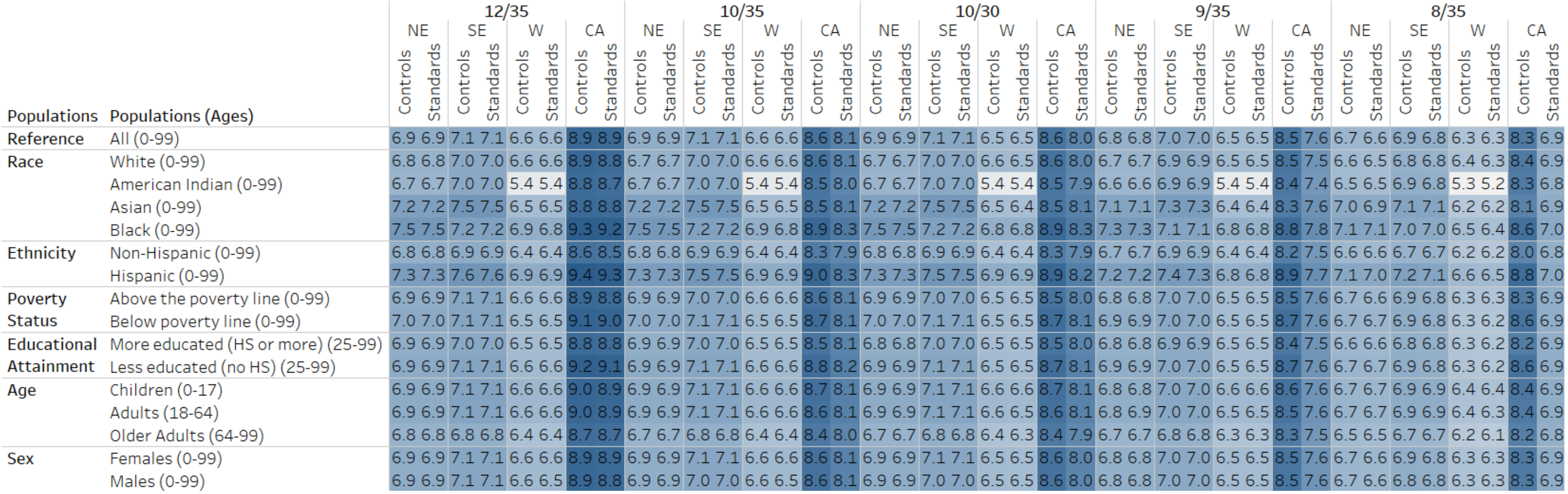
[22] The overall reference, ages, and sex population groups were excluded from Figure 6-30 to so that the figure could fit on a single page.



		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	
Populations	Populations (Ages)	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	6.9	6.9	7.1	7.1	6.6	6.6	8.9	8.9	6.9	6.9	7.1	7.1	6.6	6.6	8.6	8.1	6.9	6.9	7.1	7.1	6.5	6.5	8.6	8.0	6.8	6.8	7.0	7.0	6.5	6.5	8.5	7.6	6.7	6.6	6.9	6.8	6.3	6.3	8.3	6.9
Race	White (0-99)	6.8	6.8	7.0	7.0	6.6	6.6	8.9	8.8	6.7	6.7	7.0	7.0	6.6	6.6	8.6	8.1	6.7	6.7	7.0	7.0	6.6	6.5	8.6	8.0	6.7	6.7	6.9	6.9	6.5	6.5	8.5	7.5	6.6	6.5	6.8	6.8	6.4	6.3	8.4	6.9
	American Indian (0-99)	6.7	6.7	7.0	7.0	5.4	5.4	8.8	8.7	6.7	6.7	7.0	7.0	5.4	5.4	8.5	8.0	6.7	6.7	7.0	7.0	5.4	5.4	8.5	7.9	6.6	6.6	6.9	6.9	5.4	5.4	8.4	7.4	6.5	6.5	6.9	6.8	5.3	5.2	8.3	6.8
	Asian (0-99)	7.2	7.2	7.5	7.5	6.5	6.5	8.8	8.8	7.2	7.2	7.5	7.5	6.5	6.5	8.5	8.1	7.2	7.2	7.5	7.5	6.5	6.4	8.5	8.1	7.1	7.1	7.3	7.3	6.4	6.4	8.3	7.6	7.0	6.9	7.1	7.1	6.2	6.2	8.1	6.9
	Black (0-99)	7.5	7.5	7.2	7.2	6.9	6.8	9.3	9.2	7.5	7.5	7.2	7.2	6.9	6.8	8.9	8.3	7.5	7.5	7.2	7.2	6.8	6.8	8.9	8.3	7.3	7.3	7.1	7.1	6.8	6.8	8.8	7.8	7.1	7.1	7.0	7.0	6.5	6.4	8.6	7.0
Ethnicity	Non-Hispanic (0-99)	6.8	6.8	6.9	6.9	6.4	6.4	8.6	8.5	6.8	6.8	6.9	6.9	6.4	6.4	8.3	7.9	6.8	6.8	6.9	6.9	6.4	6.4	8.3	7.9	6.7	6.7	6.9	6.9	6.4	6.4	8.2	7.5	6.6	6.6	6.7	6.7	6.2	6.2	8.0	6.8
	Hispanic (0-99)	7.3	7.3	7.6	7.6	6.9	6.9	9.4	9.3	7.3	7.3	7.5	7.5	6.9	6.9	9.0	8.3	7.3	7.3	7.5	7.5	6.9	6.9	8.9	8.2	7.2	7.2	7.4	7.3	6.8	6.8	8.9	7.7	7.1	7.0	7.2	7.1	6.6	6.5	8.8	7.0
Poverty Status	Above the poverty line (0-99)	6.9	6.9	7.1	7.1	6.6	6.6	8.9	8.8	6.9	6.9	7.0	7.0	6.6	6.6	8.6	8.1	6.9	6.9	7.0	7.0	6.5	6.5	8.5	8.0	6.8	6.8	7.0	7.0	6.5	6.5	8.5	7.6	6.7	6.6	6.9	6.8	6.3	6.3	8.3	6.9
	Below poverty line (0-99)	7.0	7.0	7.1	7.1	6.5	6.5	9.1	9.0	7.0	7.0	7.1	7.1	6.5	6.5	8.7	8.1	7.0	7.0	7.1	7.1	6.5	6.5	8.7	8.1	6.9	6.9	7.0	7.0	6.5	6.5	8.7	7.6	6.7	6.7	6.9	6.8	6.3	6.2	8.6	6.9
Educational Attainment	More educated (HS or more) (25-99)	6.9	6.9	7.0	7.0	6.5	6.5	8.8	8.8	6.9	6.9	7.0	7.0	6.5	6.5	8.5	8.1	6.8	6.8	7.0	7.0	6.5	6.5	8.5	8.0	6.8	6.8	6.9	6.9	6.5	6.5	8.4	7.5	6.6	6.6	6.8	6.8	6.3	6.2	8.2	6.9
	Less educated (no HS) (25-99)	6.9	6.9	7.1	7.1	6.6	6.6	9.2	9.1	6.9	6.9	7.1	7.1	6.6	6.6	8.8	8.2	6.9	6.9	7.1	7.1	6.5	6.5	8.7	8.1	6.9	6.9	7.0	7.0	6.5	6.5	8.7	7.6	6.7	6.7	6.9	6.8	6.3	6.2	8.6	6.9
Age	Children (0-17)	6.9	6.9	7.1	7.1	6.6	6.6	9.0	8.9	6.9	6.9	7.1	7.1	6.6	6.6	8.7	8.1	6.9	6.9	7.1	7.1	6.6	6.6	8.7	8.1	6.8	6.8	7.0	7.0	6.6	6.6	8.6	7.6	6.7	6.7	6.9	6.9	6.4	6.4	8.4	6.9
	Adults (18-64)	6.9	6.9	7.1	7.1	6.6	6.6	9.0	8.9	6.9	6.9	7.1	7.1	6.6	6.6	8.6	8.1	6.9	6.9	7.1	7.1	6.6	6.5	8.6	8.1	6.8	6.9	7.0	7.0	6.5	6.5	8.5	7.6	6.7	6.7	6.9	6.9	6.4	6.3	8.4	6.9
	Older Adults (64-99)	6.8	6.8	6.8	6.8	6.4	6.4	8.7	8.7	6.7	6.7	6.8	6.8	6.4	6.4	8.4	8.0	6.7	6.7	6.8	6.8	6.4	6.3	8.4	7.9	6.7	6.7	6.8	6.8	6.3	6.3	8.3	7.5	6.5	6.5	6.7	6.7	6.2	6.1	8.2	6.8
Sex	Females (0-99)	6.9	6.9	7.1	7.1	6.6	6.6	8.9	8.9	6.9	6.9	7.1	7.1	6.6	6.6	8.6	8.1	6.9	6.9	7.1	7.1	6.5	6.5	8.6	8.0	6.8	6.8	7.0	7.0	6.5	6.5	8.5	7.6	6.7	6.6	6.9	6.8	6.3	6.3	8.3	6.9
	Males (0-99)	6.9	6.9	7.1	7.1	6.6	6.5	8.9	8.8	6.9	6.9	7.0	7.0	6.6	6.5	8.6	8.1	6.9	6.9	7.0	7.0	6.5	6.5	8.6	8.0	6.8	6.8	7.0	7.0	6.5	6.5	8.5	7.6	6.7	6.6	6.8	6.8	6.3	6.3	8.3	6.9

Figure 6-30 **Heat Map of Regional Average Annual $PM_{2.5}$ Concentrations (µg/m^3) Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current and Alternative PM NAAQS Levels**

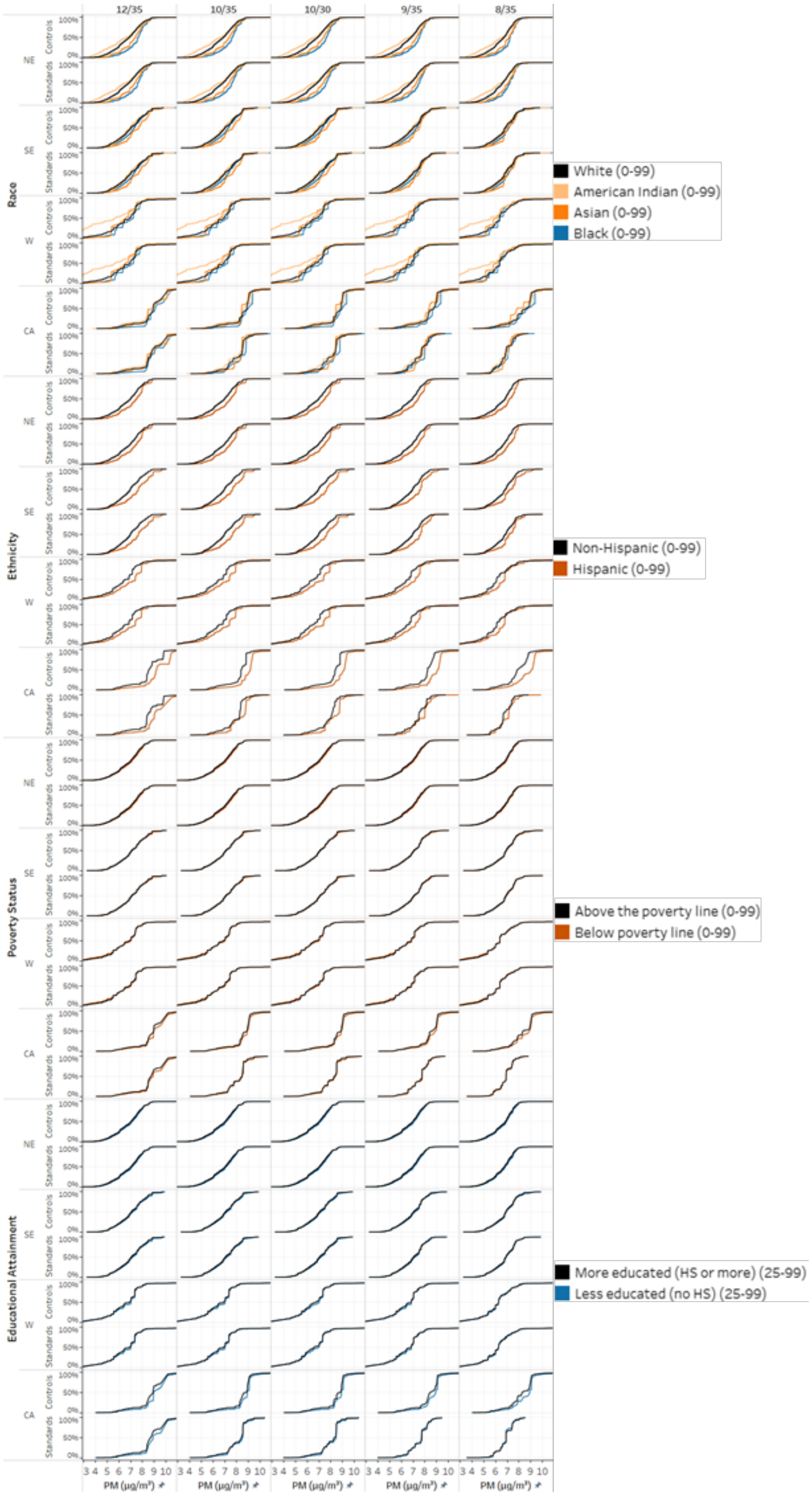


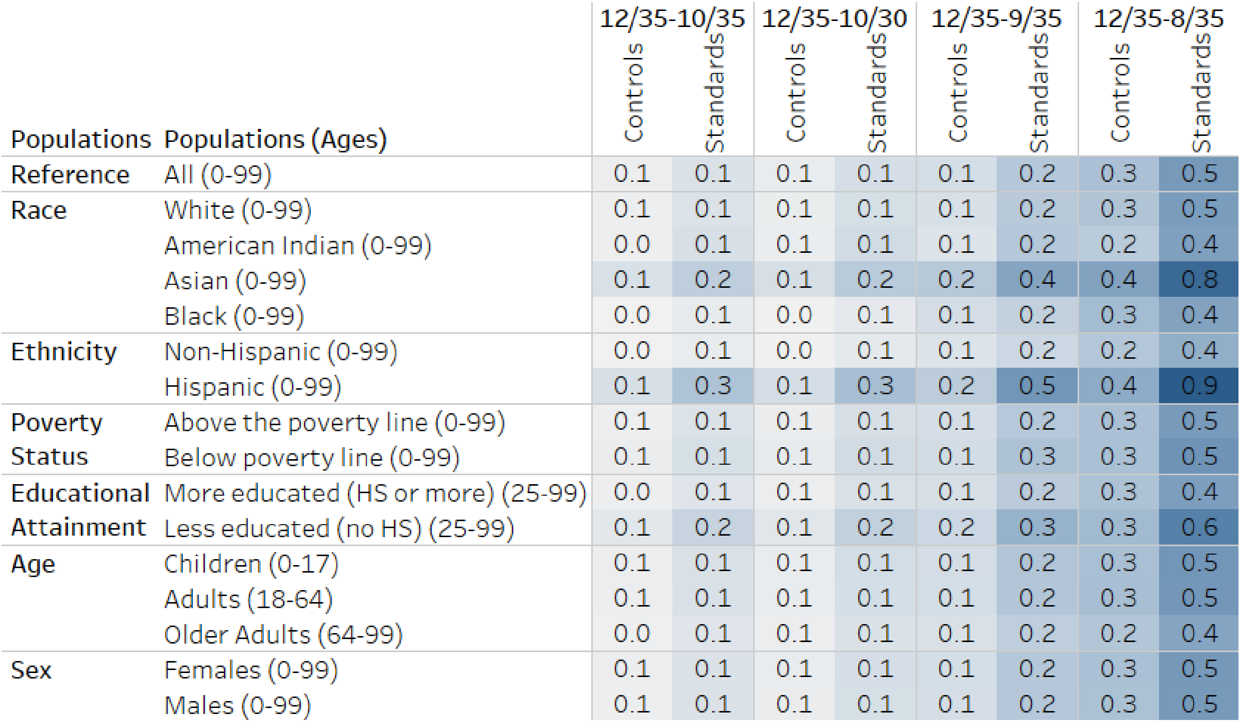
Figure 6-31 Regional Distributions of Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current and Alternative PM NAAQS Levels

6.6.3 EJ Analysis of Exposure Changes Associated with Meeting the Standards

National and regional changes in $PM_{2.5}$ concentrations for demographic populations when moving from current to more stringent alternative standard levels for air quality scenarios associated with meeting the standards, and the ability to compare them with air quality scenarios associated with the illustrative emission control strategies, are provided in Sections 6.2.3.1 and 6.2.3.2, respectively.

6.6.3.1 National

Nationally, $PM_{2.5}$ concentration reductions for air quality scenarios associated with the illustrative emission control strategies are estimated to be similar or slightly greater than $PM_{2.5}$ concentration reductions for air quality scenarios associated with meeting the standards when moving from current to more stringent standard levels (Figure 6-32 and Figure 6-33).



		12/35-10/35		12/35-10/30		12/35-9/35		12/35-8/35	
Populations	Populations (Ages)	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
Race	White (0-99)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
	American Indian (0-99)	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.4
	Asian (0-99)	0.1	0.2	0.1	0.2	0.2	0.4	0.4	0.8
	Black (0-99)	0.0	0.1	0.0	0.1	0.1	0.2	0.3	0.4
Ethnicity	Non-Hispanic (0-99)	0.0	0.1	0.0	0.1	0.1	0.2	0.2	0.4
	Hispanic (0-99)	0.1	0.3	0.1	0.3	0.2	0.5	0.4	0.9
Poverty Status	Above the poverty line (0-99)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
	Below poverty line (0-99)	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.5
Educational Attainment	More educated (HS or more) (25-99)	0.0	0.1	0.1	0.1	0.1	0.2	0.3	0.4
	Less educated (no HS) (25-99)	0.1	0.2	0.1	0.2	0.2	0.3	0.3	0.6
Age	Children (0-17)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
	Adults (18-64)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
	Older Adults (64-99)	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.4
Sex	Females (0-99)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
	Males (0-99)	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5

Figure 6-32 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 Alternative PM NAAQS Levels

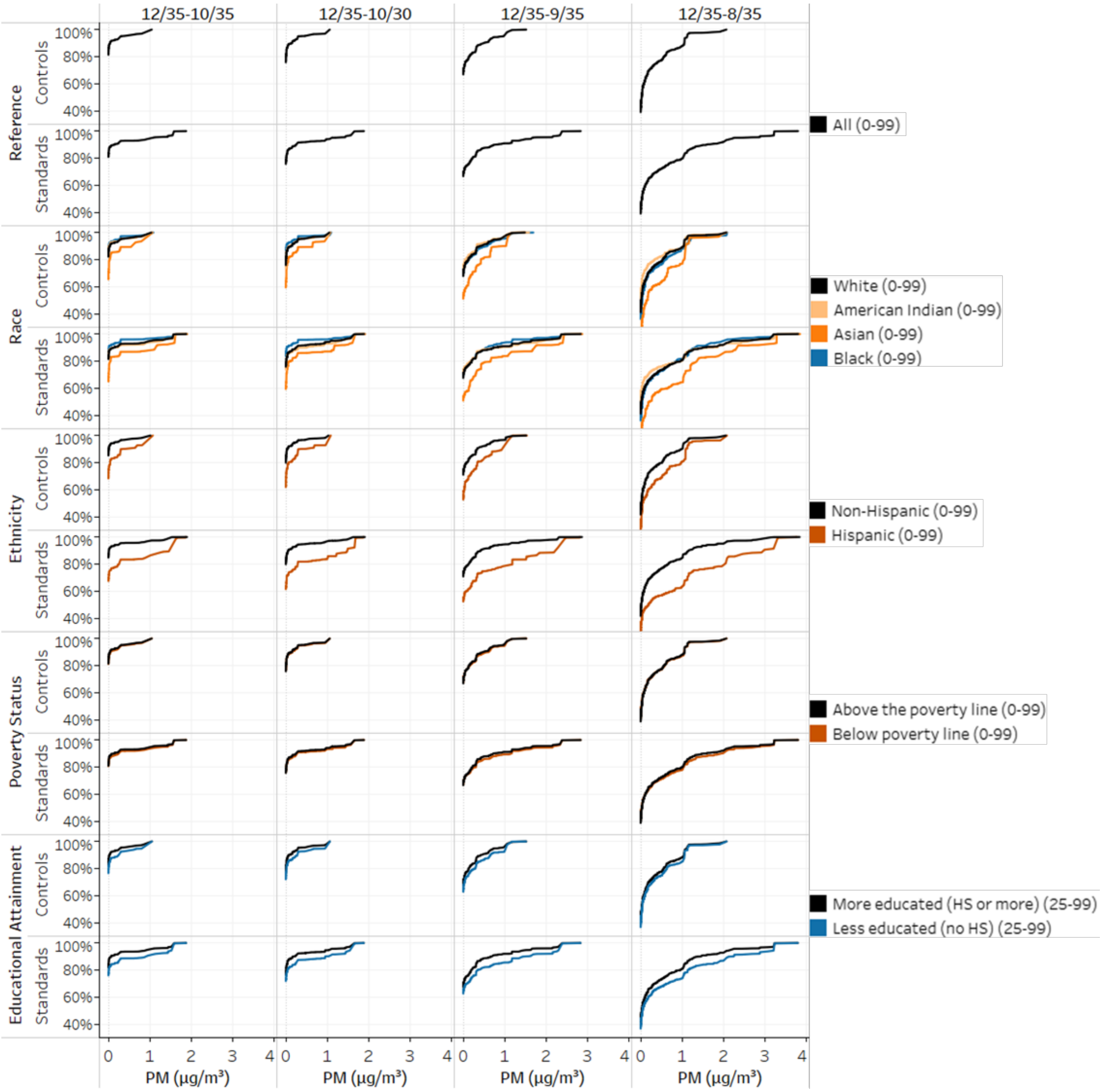


Figure 6-33 National Distributions of Annual Reductions in $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Alternative PM NAAQS Levels

6.6.3.2 Regional

Regionally, air quality scenarios associated with meeting the standards led to similar $PM_{2.5}$ concentration changes as air quality scenarios associated with control strategies under more stringent alternative standard levels in the NE, SE, and W (Figure 6-34 and Figure 6-35).[23] In CA, $PM_{2.5}$ concentration reductions were substantially greater under air quality scenarios associated with meeting the standards.

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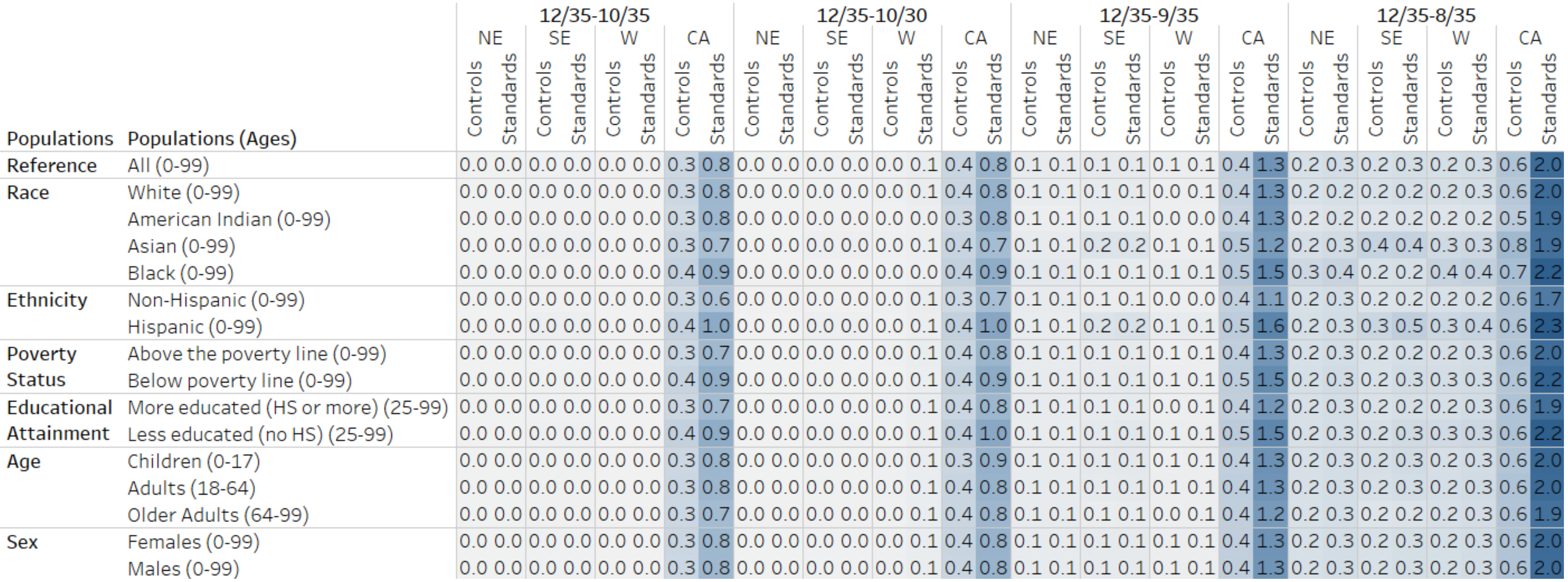
[23] Overall reference, ages, and sex population groups were excluded from Figure 6-34 to restrict the figure to a single page.



Populations	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	
		Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.3	0.2	0.3	0.6	2.0
Race	White (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.0	0.1	0.4	1.3	0.2	0.2	0.2	0.2	0.2	0.3	0.6	2.0
	American Indian (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.1	0.1	0.1	0.1	0.0	0.0	0.4	1.3	0.2	0.2	0.2	0.2	0.2	0.2	0.5	1.9
	Asian (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.1	0.1	0.2	0.2	0.1	0.1	0.5	1.2	0.2	0.3	0.4	0.4	0.3	0.3	0.8	1.9
	Black (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.5	1.5	0.3	0.4	0.2	0.2	0.4	0.4	0.7	2.2
Ethnicity	Non-Hispanic (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.1	0.1	0.1	0.1	0.0	0.0	0.4	1.1	0.2	0.3	0.2	0.2	0.2	0.2	0.6	1.7
	Hispanic (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.0	0.1	0.1	0.2	0.2	0.1	0.1	0.5	1.6	0.2	0.3	0.3	0.5	0.3	0.4	0.6	2.3
Poverty Status	Above the poverty line (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.2	0.2	0.3	0.6	2.0
	Below poverty line (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.5	1.5	0.2	0.3	0.2	0.3	0.3	0.3	0.6	2.2
Educational Attainment	More educated (HS or more) (25-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.0	0.1	0.4	1.2	0.2	0.3	0.2	0.2	0.2	0.3	0.6	1.9
	Less educated (no HS) (25-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.0	0.1	0.1	0.1	0.1	0.1	0.1	0.5	1.5	0.2	0.3	0.2	0.3	0.3	0.3	0.6	2.2
Age	Children (0-17)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.3	0.2	0.3	0.6	2.0
	Adults (18-64)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.3	0.2	0.3	0.6	2.0
	Older Adults (64-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.0	0.1	0.4	1.2	0.2	0.3	0.2	0.2	0.2	0.3	0.6	1.9
Sex	Females (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.3	0.2	0.3	0.6	2.0
	Males (0-99)	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.3	0.2	0.3	0.2	0.3	0.2	0.3	0.6	2.0

Figure 6-34 **Heat Map of National Reductions in Average Annual $PM_{2.5}$ Concentrations (µg/m³) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Alternative PM NAAQS Levels**

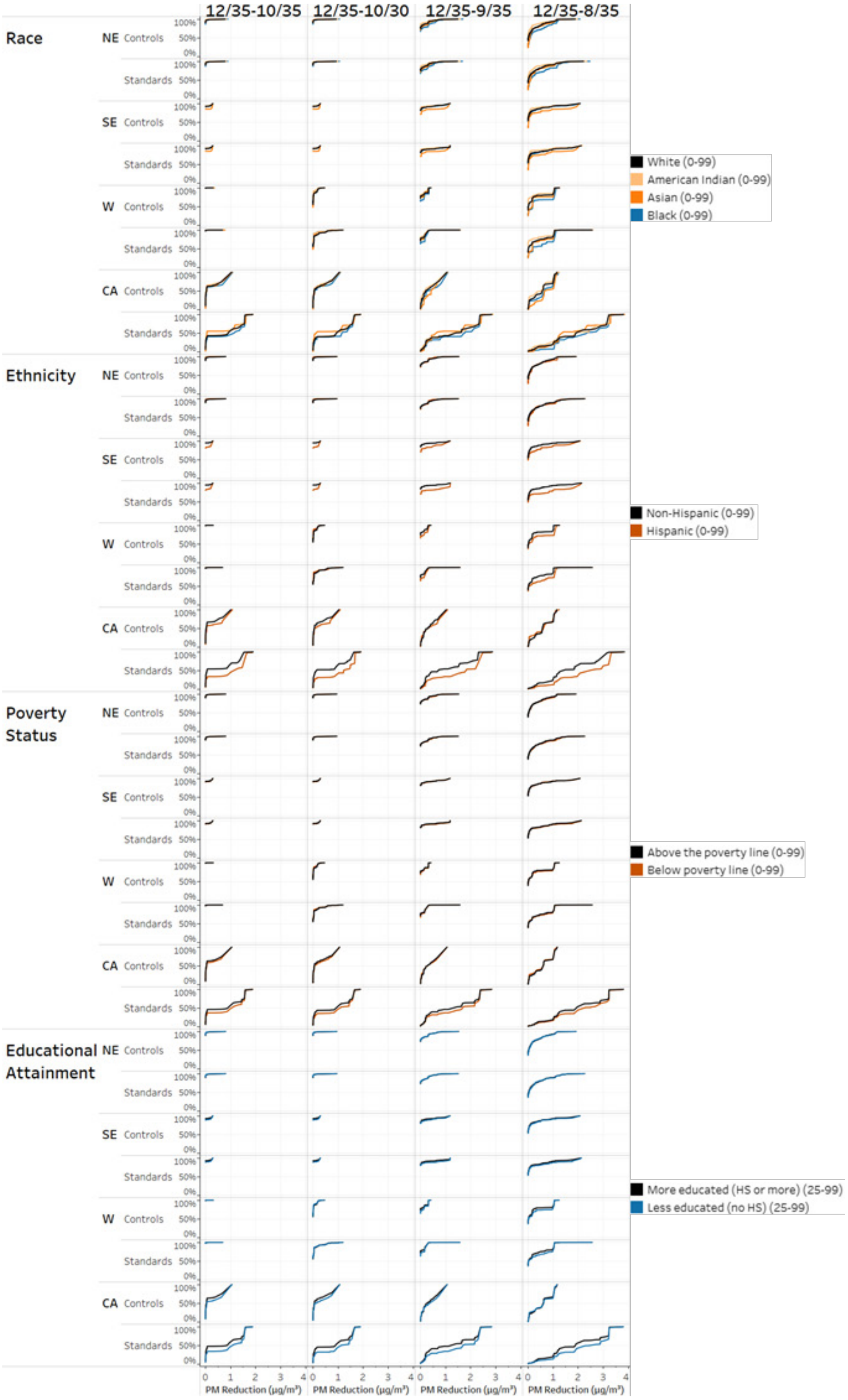


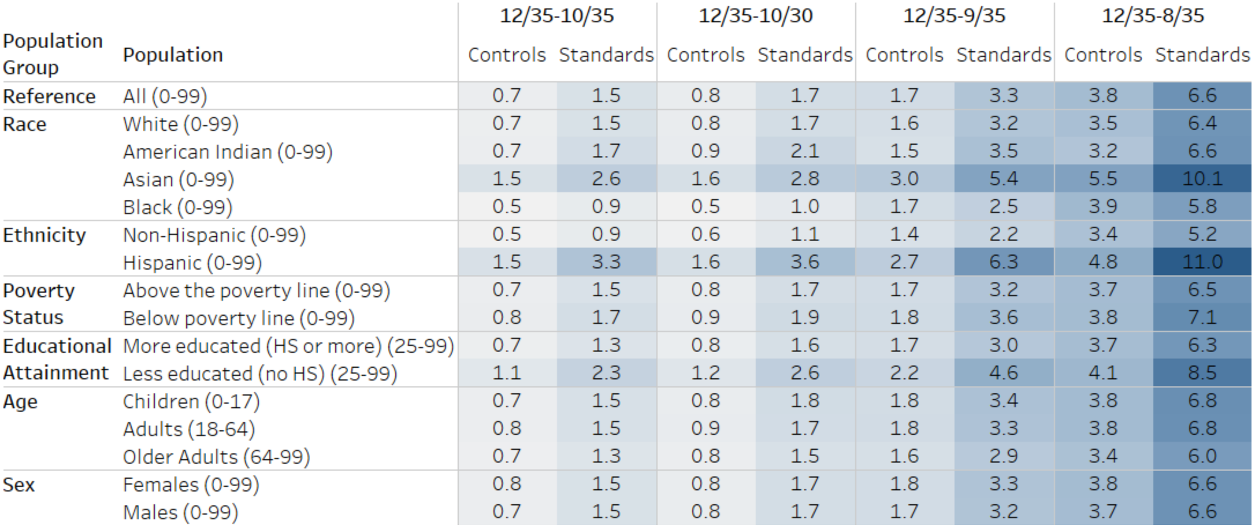
Figure 6-35 National Distributions of Reductions in Annual $PM_{2.5}$ Concentrations Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Alternative PM NAAQS Levels

6.6.4 Proportionality of Exposure Changes Associated with Meeting the Standards

The proportionality of national and 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 to more stringent alternative standard levels are provided in Sections 6.6.4.1 and 6.6.4.2, respectively.

6.6.4.1 National

Nationally, air quality scenarios associated with meeting the standards proportionally 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 6-36).

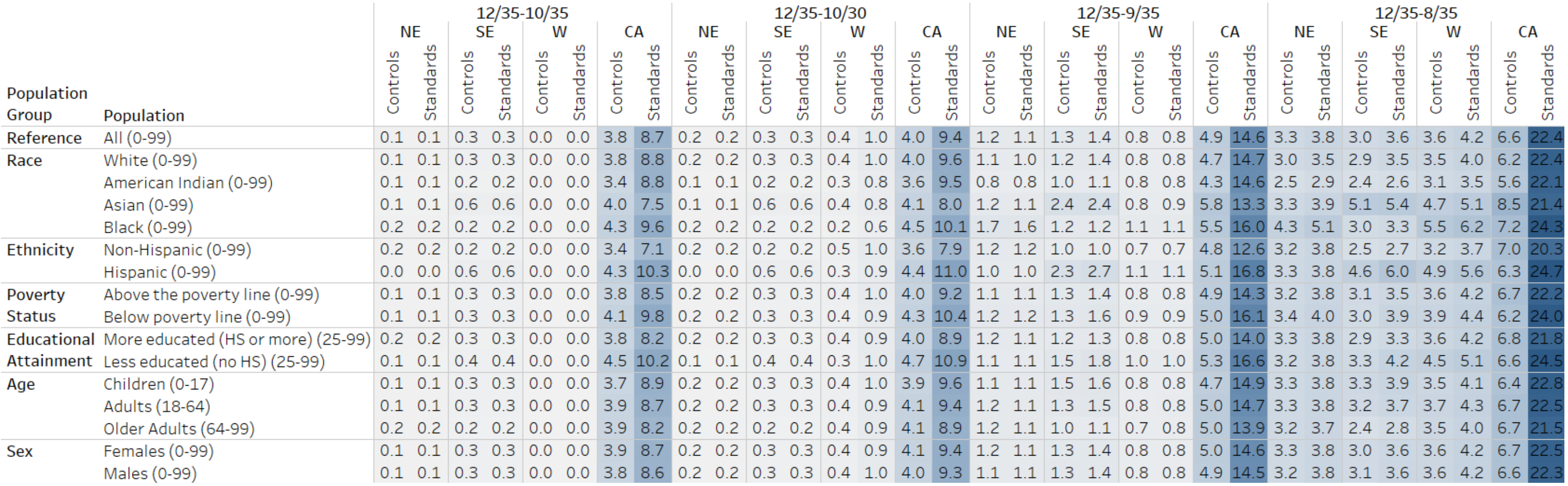


Population Group	Population	12/35-10/35		12/35-10/30		12/35-9/35		12/35-8/35	
		Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	0.7	1.5	0.8	1.7	1.7	3.3	3.8	6.6
Race	White (0-99)	0.7	1.5	0.8	1.7	1.6	3.2	3.5	6.4
	American Indian (0-99)	0.7	1.7	0.9	2.1	1.5	3.5	3.2	6.6
	Asian (0-99)	1.5	2.6	1.6	2.8	3.0	5.4	5.5	10.1
	Black (0-99)	0.5	0.9	0.5	1.0	1.7	2.5	3.9	5.8
Ethnicity	Non-Hispanic (0-99)	0.5	0.9	0.6	1.1	1.4	2.2	3.4	5.2
	Hispanic (0-99)	1.5	3.3	1.6	3.6	2.7	6.3	4.8	11.0
Poverty Status	Above the poverty line (0-99)	0.7	1.5	0.8	1.7	1.7	3.2	3.7	6.5
	Below poverty line (0-99)	0.8	1.7	0.9	1.9	1.8	3.6	3.8	7.1
Educational Attainment	More educated (HS or more) (25-99)	0.7	1.3	0.8	1.6	1.7	3.0	3.7	6.3
	Less educated (no HS) (25-99)	1.1	2.3	1.2	2.6	2.2	4.6	4.1	8.5
Age	Children (0-17)	0.7	1.5	0.8	1.8	1.8	3.4	3.8	6.8
	Adults (18-64)	0.8	1.5	0.9	1.7	1.8	3.3	3.8	6.8
	Older Adults (64-99)	0.7	1.3	0.8	1.5	1.6	2.9	3.4	6.0
Sex	Females (0-99)	0.8	1.5	0.8	1.7	1.8	3.3	3.8	6.6
	Males (0-99)	0.7	1.5	0.8	1.7	1.7	3.2	3.7	6.6

Figure 6-36 Heat Map of National Percent Reductions in Average Annual $PM_{2.5}$ Concentrations (μg/m^3) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving From Current to Alternative PM NAAQS Levels

6.6.4.2 Regional

Dividing the country into the four regions shows that air quality associated with meeting the standards in CA would lead to substantially greater proportional $PM_{2.5}$ concentration reductions under all scenarios evaluated (Figure 6-37). Also, differences between air quality scenarios associated control strategies versus meeting the standards are greater when moving to lower alternative standard levels.



Population Group	Population	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	
		Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
Reference	All (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	3.8	8.7	0.2	0.2	0.3	0.3	0.4	1.0	4.0	9.4	1.2	1.1	1.3	1.4	0.8	0.8	4.9	14.6	3.3	3.8	3.0	3.6	3.6	4.2	6.6	22.4
Race	White (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	3.8	8.8	0.2	0.2	0.3	0.3	0.4	1.0	4.0	9.6	1.1	1.0	1.2	1.4	0.8	0.8	4.7	14.7	3.0	3.5	2.9	3.5	3.5	4.0	6.2	22.4
	American Indian (0-99)	0.1	0.1	0.2	0.2	0.0	0.0	3.4	8.8	0.1	0.1	0.2	0.2	0.3	0.8	3.6	9.5	0.8	0.8	1.0	1.1	0.8	0.8	4.3	14.6	2.5	2.9	2.4	2.6	3.1	3.5	5.6	22.1
	Asian (0-99)	0.1	0.1	0.6	0.6	0.0	0.0	4.0	7.5	0.1	0.1	0.6	0.6	0.4	0.8	4.1	8.0	1.2	1.1	2.4	2.4	0.8	0.9	5.8	13.3	3.3	3.9	5.1	5.4	4.7	5.1	8.5	21.4
	Black (0-99)	0.2	0.2	0.2	0.2	0.0	0.0	4.3	9.6	0.2	0.2	0.2	0.2	0.2	0.6	4.5	10.1	1.7	1.6	1.2	1.2	1.1	1.1	5.5	16.0	4.3	5.1	3.0	3.3	5.5	6.2	7.2	24.3
Ethnicity	Non-Hispanic (0-99)	0.2	0.2	0.2	0.2	0.0	0.0	3.4	7.1	0.2	0.2	0.2	0.2	0.5	1.0	3.6	7.9	1.2	1.2	1.0	1.0	0.7	0.7	4.8	12.6	3.2	3.8	2.5	2.7	3.2	3.7	7.0	20.3
	Hispanic (0-99)	0.0	0.0	0.6	0.6	0.0	0.0	4.3	10.3	0.0	0.0	0.6	0.6	0.3	0.9	4.4	11.0	1.0	1.0	2.3	2.7	1.1	1.1	5.1	16.8	3.3	3.8	4.6	6.0	4.9	5.6	6.3	24.7
Poverty Status	Above the poverty line (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	3.8	8.5	0.2	0.2	0.3	0.3	0.4	1.0	4.0	9.2	1.1	1.1	1.3	1.4	0.8	0.8	4.9	14.3	3.2	3.8	3.1	3.5	3.6	4.2	6.7	22.2
	Below poverty line (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	4.1	9.8	0.2	0.2	0.3	0.3	0.4	0.9	4.3	10.4	1.2	1.2	1.3	1.6	0.9	0.9	5.0	16.1	3.4	4.0	3.0	3.9	3.9	4.4	6.2	24.0
Educational Attainment	More educated (HS or more) (25-99)	0.2	0.2	0.3	0.3	0.0	0.0	3.8	8.2	0.2	0.2	0.3	0.3	0.4	0.9	4.0	8.9	1.2	1.1	1.2	1.3	0.8	0.8	5.0	14.0	3.3	3.8	2.9	3.3	3.6	4.2	6.8	21.8
	Less educated (no HS) (25-99)	0.1	0.1	0.4	0.4	0.0	0.0	4.5	10.2	0.1	0.1	0.4	0.4	0.3	1.0	4.7	10.9	1.1	1.1	1.5	1.8	1.0	1.0	5.3	16.6	3.2	3.8	3.3	4.2	4.5	5.1	6.6	24.5
Age	Children (0-17)	0.1	0.1	0.3	0.3	0.0	0.0	3.7	8.9	0.2	0.2	0.3	0.3	0.4	1.0	3.9	9.6	1.1	1.1	1.5	1.6	0.8	0.8	4.7	14.9	3.3	3.8	3.3	3.9	3.5	4.1	6.4	22.8
	Adults (18-64)	0.1	0.1	0.3	0.3	0.0	0.0	3.9	8.7	0.2	0.2	0.3	0.3	0.4	0.9	4.1	9.4	1.2	1.1	1.3	1.5	0.8	0.8	5.0	14.7	3.3	3.8	3.2	3.7	3.7	4.3	6.7	22.5
	Older Adults (64-99)	0.2	0.2	0.2	0.2	0.0	0.0	3.9	8.2	0.2	0.2	0.2	0.2	0.4	0.9	4.1	8.9	1.2	1.1	1.0	1.1	0.7	0.8	5.0	13.9	3.2	3.7	2.4	2.8	3.5	4.0	6.7	21.5
Sex	Females (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	3.9	8.7	0.2	0.2	0.3	0.3	0.4	0.9	4.1	9.4	1.2	1.1	1.3	1.4	0.8	0.8	5.0	14.6	3.3	3.8	3.0	3.6	3.6	4.2	6.7	22.5
	Males (0-99)	0.1	0.1	0.3	0.3	0.0	0.0	3.8	8.6	0.2	0.2	0.3	0.3	0.4	1.0	4.0	9.3	1.1	1.1	1.3	1.4	0.8	0.8	4.9	14.5	3.2	3.8	3.1	3.6	3.6	4.2	6.6	22.3

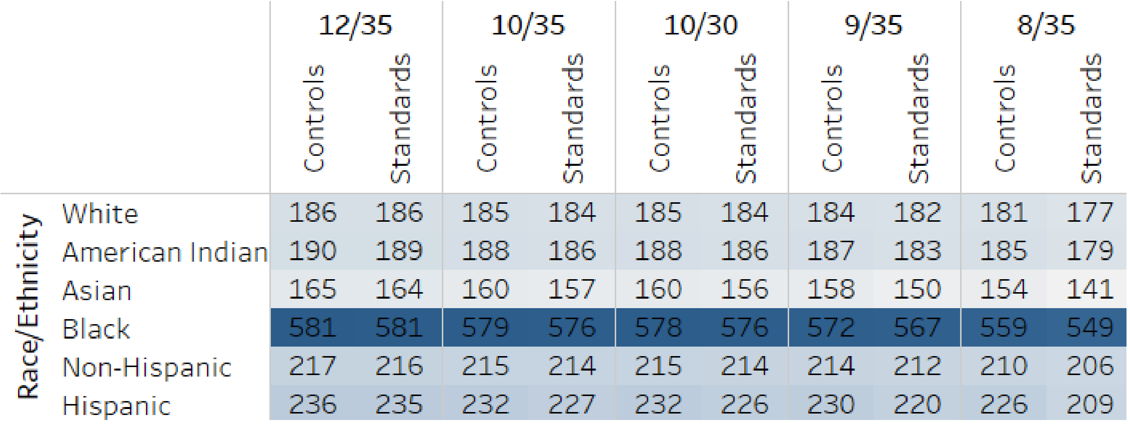
Figure 6-37 Heat Map of Regional Percent Reductions in Average Annual PM2.5 Concentrations (µg/m³) Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving From Current to Alternative PM NAAQS Levels

6.6.5 EJ Analysis of Total Mortality Rates Associated with Meeting the Standards

National and regional total demographic-specific mortality rates for both air quality scenarios associated with control strategies and meeting the standards are provided in Sections 6.6.5.1 and 6.6.5.2, respectively.

6.6.5.1 National

Using concentration-response relationships derived from Di et al., 2017, the older (>64 years) Black population is estimated to have the highest mortality rates per 100k of all races and ethnicities evaluated. This is the case under air quality scenarios associated with either the illustrative emission control scenarios or under air quality scenarios associated with meeting the standards for current and alternative standard levels (Figure 6-38 and Figure 6-39). Older Hispanics and older American Indians are also predicted to have a higher rate of mortality than older non-Hispanics and older Whites, respectively, under all air quality scenarios evaluated.



Race/Ethnicity	12/35		10/35		10/30		9/35		8/35	
	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
White	186	186	185	184	185	184	184	182	181	177
American Indian	190	189	188	186	188	186	187	183	185	179
Asian	165	164	160	157	160	156	158	150	154	141
Black	581	581	579	576	578	576	572	567	559	549
Non-Hispanic	217	216	215	214	215	214	214	212	210	206
Hispanic	236	235	232	227	232	226	230	220	226	209

Figure 6-38 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 and Alternative PM NAAQS Levels

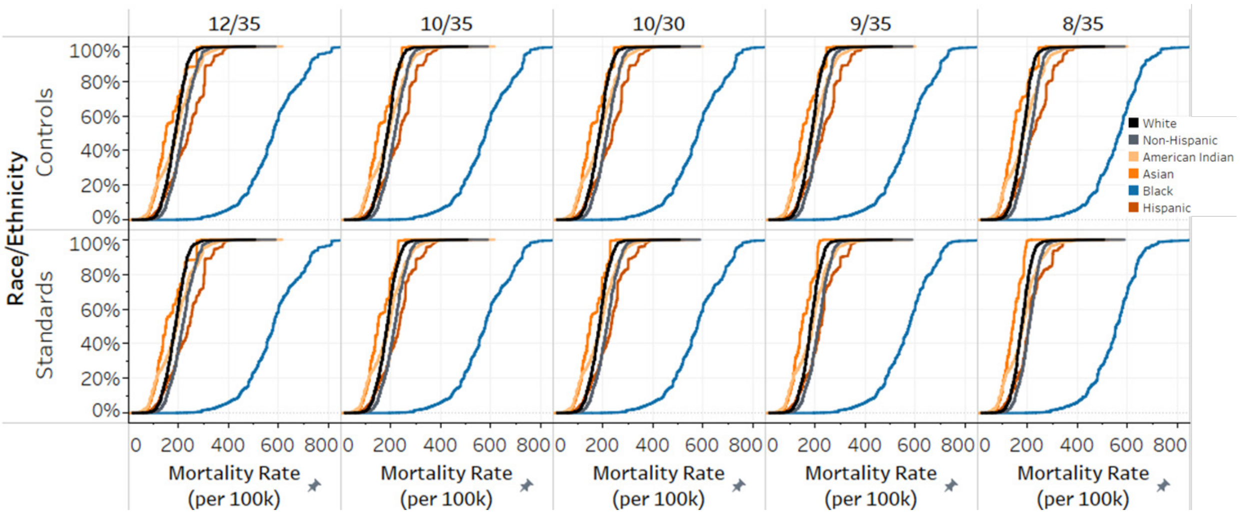
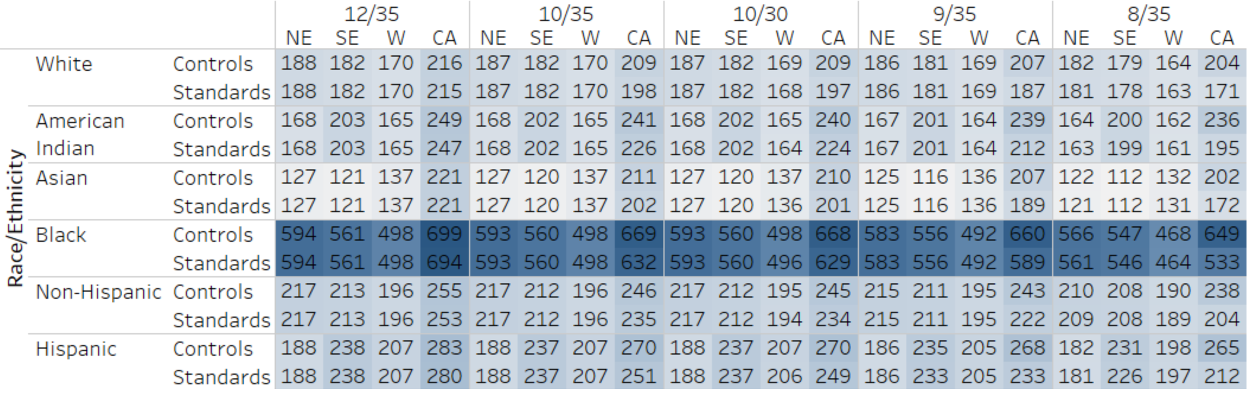


Figure 6-39 National Distributions of Total Mortality Rates Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current and Alternative PM NAAQS Levels

6.6.5.2 Regional

Similar to $PM_{2.5}$ concentrations, regional average mortality rates are lowest in the W and highest in CA (Figure 6-40). Black populations are estimated to have the highest mortality rates in all regions. Hispanic mortality rates are lower in the NE and higher in the other three regions.



Race/Ethnicity		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
White	Controls	188	182	170	216	187	182	170	209	187	182	169	209	186	181	169	207	182	179	164	204
	Standards	188	182	170	215	187	182	170	198	187	182	168	197	186	181	169	187	181	178	163	171
American Indian	Controls	168	203	165	249	168	202	165	241	168	202	165	240	167	201	164	239	164	200	162	236
	Standards	168	203	165	247	168	202	165	226	168	202	164	224	167	201	164	212	163	199	161	195
Asian	Controls	127	121	137	221	127	120	137	211	127	120	137	210	125	116	136	207	122	112	132	202
	Standards	127	121	137	221	127	120	137	202	127	120	136	201	125	116	136	189	121	112	131	172
Black	Controls	594	561	498	699	593	560	498	669	593	560	498	668	583	556	492	660	566	547	468	649
	Standards	594	561	498	694	593	560	498	632	593	560	496	629	583	556	492	589	561	546	464	533
Non-Hispanic	Controls	217	213	196	255	217	212	196	246	217	212	195	245	215	211	195	243	210	208	190	238
	Standards	217	213	196	253	217	212	196	235	217	212	194	234	215	211	195	222	209	208	189	204
Hispanic	Controls	188	238	207	283	188	237	207	270	188	237	207	270	186	235	205	268	182	231	198	265
	Standards	188	238	207	280	188	237	207	251	188	237	206	249	186	233	205	233	181	226	197	212

Figure 6-40 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 and Alternative PM NAAQS Levels

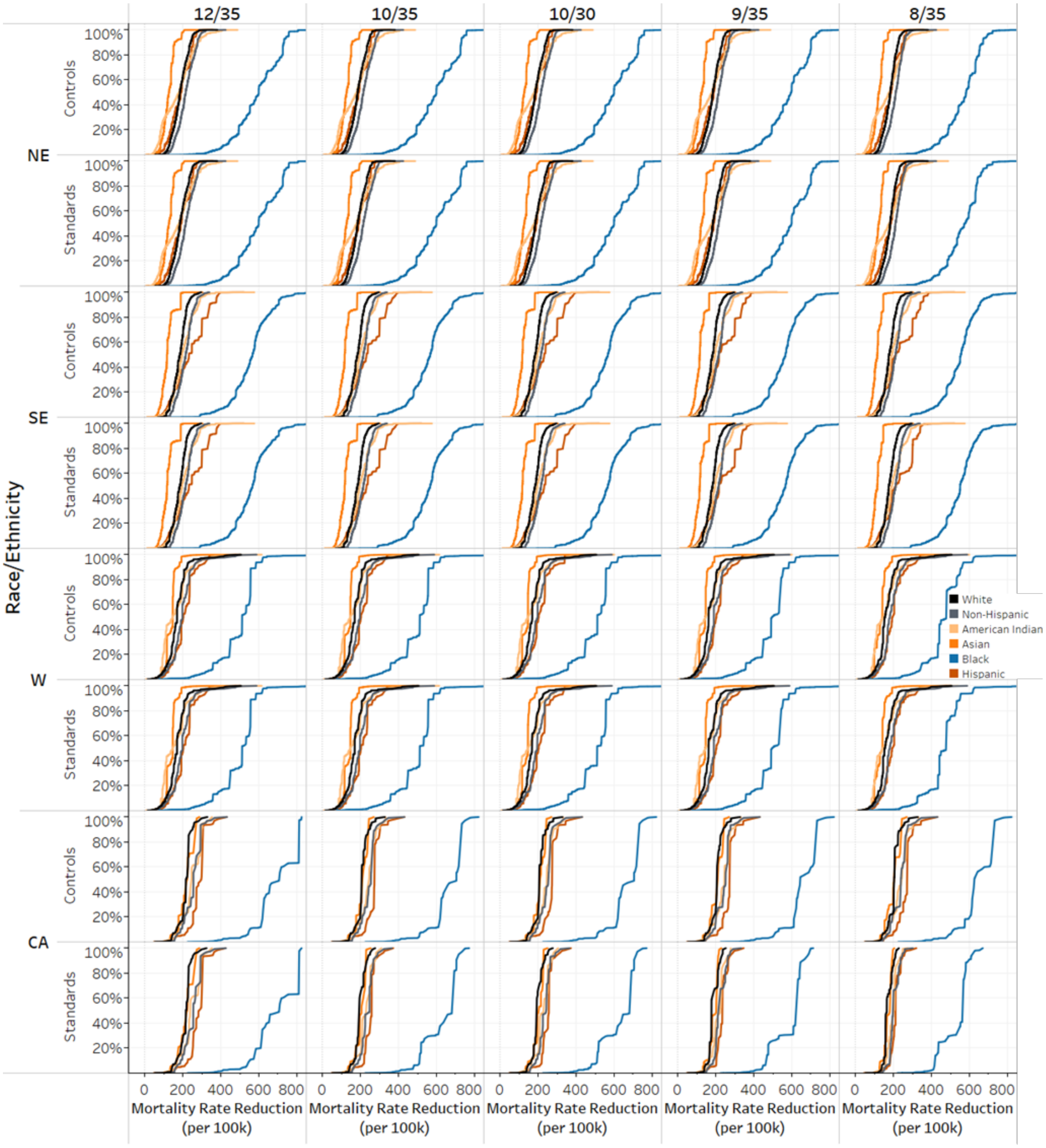


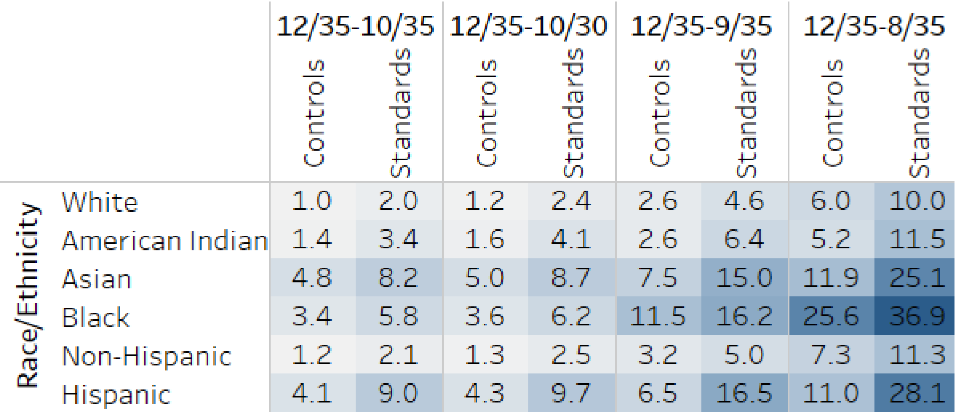
Figure 6-41 **Regional Distributions of Total Mortality Rates Associated Either with Control Strategies or with Meeting the Standards by Demographic for Current and Alternative PM NAAQS Levels**

6.6.6 EJ Analysis of Mortality Rate Change Associated with Meeting the Standards

National and regional changes in demographic-specific mortality rates when moving from current to alternate standard levels under air quality surfaces associated with either control strategies or meeting the standards levels are provided in Sections 6.6.6.1 and 6.6.6.2, respectively.

6.6.6.1 National

Nationally, mortality rate reductions are larger for Asians and Hispanics under air quality associated with the standards, as compared to air quality associated with the illustrative emission control strategies (Figure 6-42 and Figure 6-43). Mortality rate reductions increase in absolute terms for Black as alternative standard levels become more stringent.



Race/Ethnicity	12/35-10/35		12/35-10/30		12/35-9/35		12/35-8/35	
	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
White	1.0	2.0	1.2	2.4	2.6	4.6	6.0	10.0
American Indian	1.4	3.4	1.6	4.1	2.6	6.4	5.2	11.5
Asian	4.8	8.2	5.0	8.7	7.5	15.0	11.9	25.1
Black	3.4	5.8	3.6	6.2	11.5	16.2	25.6	36.9
Non-Hispanic	1.2	2.1	1.3	2.5	3.2	5.0	7.3	11.3
Hispanic	4.1	9.0	4.3	9.7	6.5	16.5	11.0	28.1

Figure 6-42 Heat Map of National 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 Alternative PM NAAQS Levels

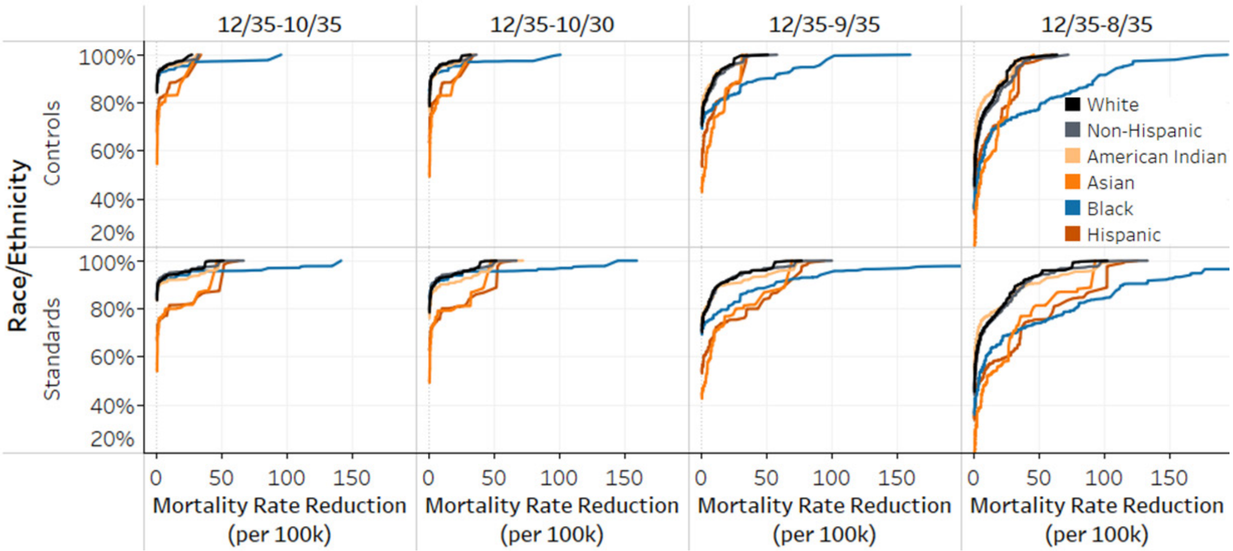
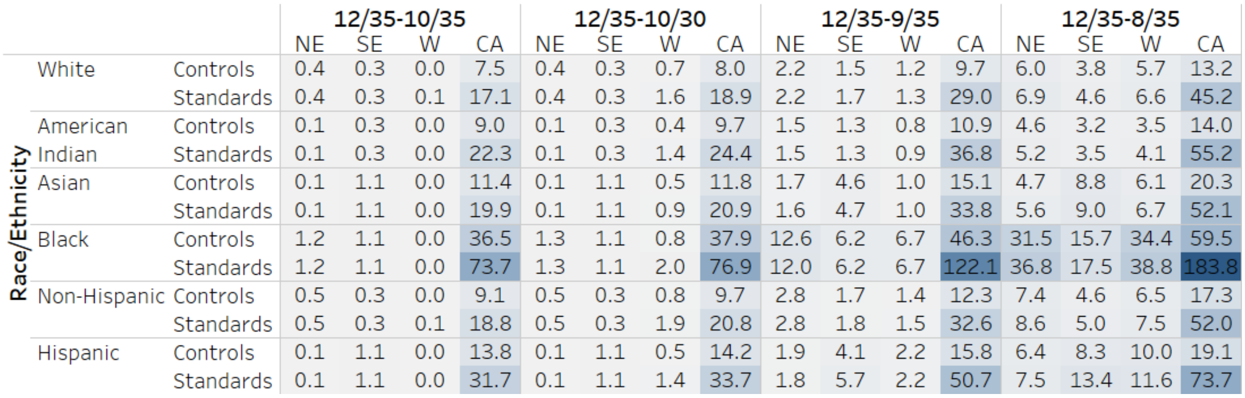


Figure 6-43 **National Distributions of Annual Total Mortality Rate Reductions Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Alternative PM NAAQS Levels**

6.6.6.2 Regional

Absolute mortality rate reductions per 100k individuals are most notable in CA and for Hispanic, Asian, and Black populations under full attainment scenarios at lower alternative standard levels (Figure 6-44 and Figure 6-45). Note that we did not specifically evaluate the areas that would not meet the alternative standard levels through application of existing controls.



Race/Ethnicity		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
White	Controls	0.4	0.3	0.0	7.5	0.4	0.3	0.7	8.0	2.2	1.5	1.2	9.7	6.0	3.8	5.7	13.2
	Standards	0.4	0.3	0.1	17.1	0.4	0.3	1.6	18.9	2.2	1.7	1.3	29.0	6.9	4.6	6.6	45.2
American Indian	Controls	0.1	0.3	0.0	9.0	0.1	0.3	0.4	9.7	1.5	1.3	0.8	10.9	4.6	3.2	3.5	14.0
	Standards	0.1	0.3	0.0	22.3	0.1	0.3	1.4	24.4	1.5	1.3	0.9	36.8	5.2	3.5	4.1	55.2
Asian	Controls	0.1	1.1	0.0	11.4	0.1	1.1	0.5	11.8	1.7	4.6	1.0	15.1	4.7	8.8	6.1	20.3
	Standards	0.1	1.1	0.0	19.9	0.1	1.1	0.9	20.9	1.6	4.7	1.0	33.8	5.6	9.0	6.7	52.1
Black	Controls	1.2	1.1	0.0	36.5	1.3	1.1	0.8	37.9	12.6	6.2	6.7	46.3	31.5	15.7	34.4	59.5
	Standards	1.2	1.1	0.0	73.7	1.3	1.1	2.0	76.9	12.0	6.2	6.7	122.1	36.8	17.5	38.8	183.8
Non-Hispanic	Controls	0.5	0.3	0.0	9.1	0.5	0.3	0.8	9.7	2.8	1.7	1.4	12.3	7.4	4.6	6.5	17.3
	Standards	0.5	0.3	0.1	18.8	0.5	0.3	1.9	20.8	2.8	1.8	1.5	32.6	8.6	5.0	7.5	52.0
Hispanic	Controls	0.1	1.1	0.0	13.8	0.1	1.1	0.5	14.2	1.9	4.1	2.2	15.8	6.4	8.3	10.0	19.1
	Standards	0.1	1.1	0.0	31.7	0.1	1.1	1.4	33.7	1.8	5.7	2.2	50.7	7.5	13.4	11.6	73.7

Figure 6-44 **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 Alternative PM NAAQS Levels**

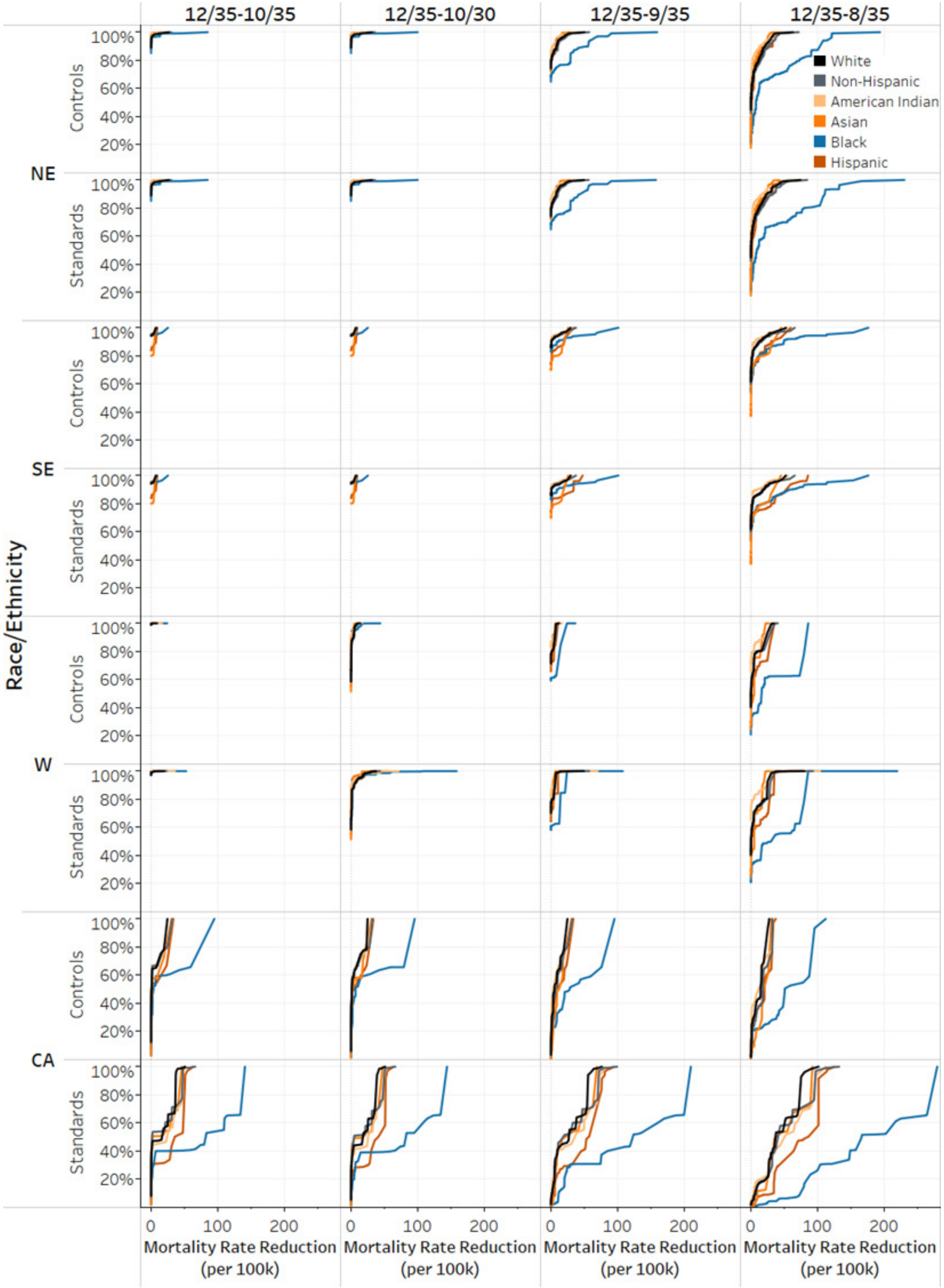


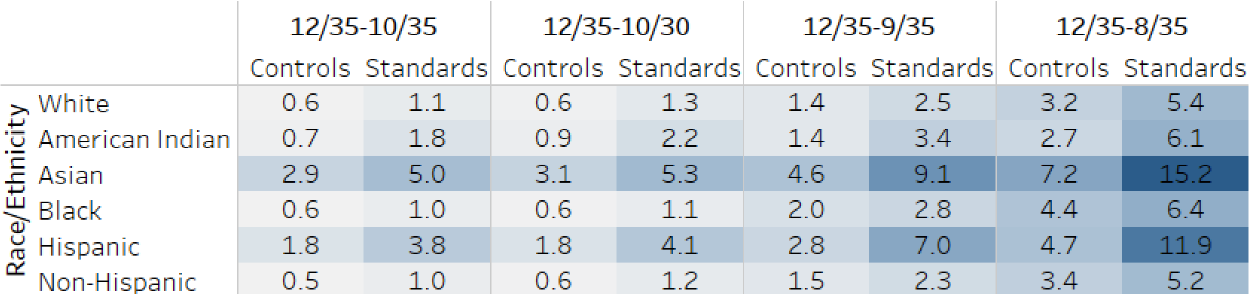
Figure 6-45 **Regional Distributions of Average Annual Total Mortality Rate Reductions Associated Either with Control Strategies or with Meeting the Standards by Demographic for When Moving from Current to Alternative PM NAAQS Levels**

6.6.7 Proportionality of Mortality Rate Changes Associated with Meeting the Standards

The proportionality of national and regional changes in demographic-specific mortality rates when moving from current to more stringent alternative standard levels under air quality scenarios associated with control strategies and with meeting the standards are provided in Sections 6.6.7.1 and 6.6.7.2, respectively.

6.6.7.1 National

Proportional reductions when moving to more stringent alternative PM NAAQS reduce mortality rate disparities for Hispanics under all air quality scenarios evaluated at the national scale. Proportional reductions when moving to more stringent alternative standards reduce mortality rate disparities at the national level for Blacks are similar to Whites for 12/35-10/35 and 10/30, but larger than Whites for 12/35-9/35 and 12/35-8/35 (Figure 6-46).

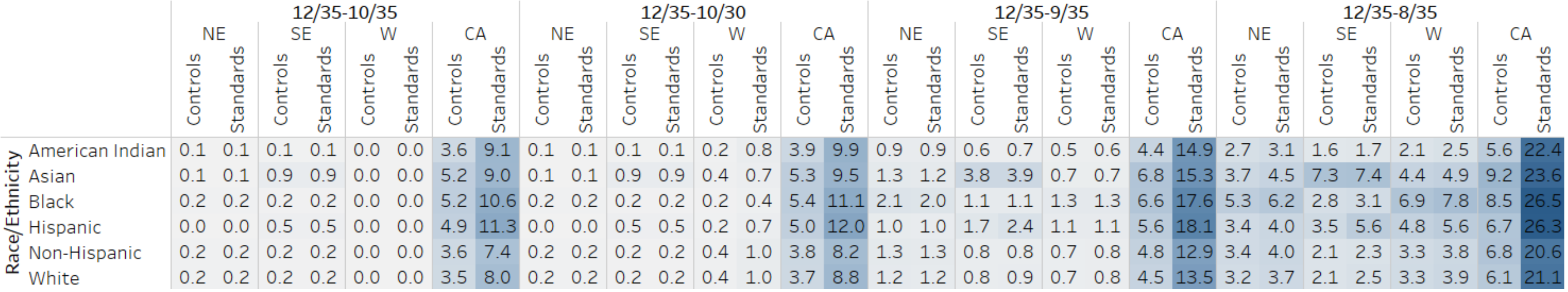


	12/35-10/35		12/35-10/30		12/35-9/35		12/35-8/35	
Race/Ethnicity	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
White	0.6	1.1	0.6	1.3	1.4	2.5	3.2	5.4
American Indian	0.7	1.8	0.9	2.2	1.4	3.4	2.7	6.1
Asian	2.9	5.0	3.1	5.3	4.6	9.1	7.2	15.2
Black	0.6	1.0	0.6	1.1	2.0	2.8	4.4	6.4
Hispanic	1.8	3.8	1.8	4.1	2.8	7.0	4.7	11.9
Non-Hispanic	0.5	1.0	0.6	1.2	1.5	2.3	3.4	5.2

Figure 6-46 Heat Map of National Percent Changes in Average Mortality Rate Reductions Associated Either with Control Strategies or with Meeting the Standards by Demographic When Moving from Current to Alternative PM NAAQS Levels

6.6.7.2 Regional

Proportional changes also demonstrate that mortality rates disparities are expected to be reduced for Hispanics and Blacks in CA, especially under more stringent alternative standard levels and under air quality scenarios associated with meeting the standards (Figure 6-47). Note that we did not specifically evaluate the areas that would not meet the alternative standard levels through application of existing controls.



Race/Ethnicity	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	
	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards	Controls	Standards
American Indian	0.1	0.1	0.1	0.1	0.0	0.0	3.6	9.1	0.1	0.1	0.1	0.1	0.2	0.8	3.9	9.9	0.9	0.9	0.6	0.7	0.5	0.6	4.4	14.9	2.7	3.1	1.6	1.7	2.1	2.5	5.6	22.4
Asian	0.1	0.1	0.9	0.9	0.0	0.0	5.2	9.0	0.1	0.1	0.9	0.9	0.4	0.7	5.3	9.5	1.3	1.2	3.8	3.9	0.7	0.7	6.8	15.3	3.7	4.5	7.3	7.4	4.4	4.9	9.2	23.6
Black	0.2	0.2	0.2	0.2	0.0	0.0	5.2	10.6	0.2	0.2	0.2	0.2	0.2	0.4	5.4	11.1	2.1	2.0	1.1	1.1	1.3	1.3	6.6	17.6	5.3	6.2	2.8	3.1	6.9	7.8	8.5	26.5
Hispanic	0.0	0.0	0.5	0.5	0.0	0.0	4.9	11.3	0.0	0.0	0.5	0.5	0.2	0.7	5.0	12.0	1.0	1.0	1.7	2.4	1.1	1.1	5.6	18.1	3.4	4.0	3.5	5.6	4.8	5.6	6.7	26.3
Non-Hispanic	0.2	0.2	0.2	0.2	0.0	0.0	3.6	7.4	0.2	0.2	0.2	0.2	0.4	1.0	3.8	8.2	1.3	1.3	0.8	0.8	0.7	0.8	4.8	12.9	3.4	4.0	2.1	2.3	3.3	3.8	6.8	20.6
White	0.2	0.2	0.2	0.2	0.0	0.0	3.5	8.0	0.2	0.2	0.2	0.2	0.4	1.0	3.7	8.8	1.2	1.2	0.8	0.9	0.7	0.8	4.5	13.5	3.2	3.7	2.1	2.5	3.3	3.9	6.1	21.1

Figure 6-47 **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 Alternative PM NAAQS Levels**

6.7 References

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CHAPTER 7: LABOR IMPACTS

Overview

This chapter discusses baseline employment in some of the industries potentially affected by this proposal. 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 control technologies, 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 2020 and the percent change in employment over the ten years from 2011 to 2020 for the industries and 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 control measures that could reduce fugitive road dust are to apply asphalt or concrete to roadbeds or roadsides, we included 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 2020 (thousands)	Percent Change in Employment 2011-2020
Non-EGU Point			
Cement and Concrete Product Manufacturing	3273	194.5	18
Basic Chemical Manufacturing	3251	150.1	5
Pulp, Paper, and Paperboard Mills	3221	92.6	-15
Iron and Steel Mills and Ferroalloy Manufacturing	3311	83.2	-10
Non-ferrous Metal (except Aluminum) Production and Processing	3314	58.2	-6
Petroleum and Coal Products Manufacturing	3241	106.5	-5
Mining (except Oil and Gas)	212	179.4	-19
Oil and Gas Point			
Oil and Gas Extraction	2111	138.6	-20
Residential Wood Combustion			
Ventilation, Heating, Air Conditioning and Commercial Refrigeration Equipment Manufacturing	3334	134.4	3
Hardware, and Plumbing and Heating Equipment Supplies Merchant Wholesalers	4237	280.2	18
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.
[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 oil and gas extraction 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 control measures that could reduce fugitive road dust are to apply asphalt or concrete to roadbeds or roadsides, i.e., shoulders. Associated with these control measures, the overall employment for paving, surfacing and tamping equipment operators in 2021 was 44,200.[1] The industry with the highest concentration of employment in paving, surfacing and tamping equipment operators is highway, street and bridge construction which employs 16,410 workers. Texas, California, New York, Illinois, and Florida are the states with the highest employment level 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 was most recently conducted in 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 2020. 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.

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[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 (2020)**
Non-EGU Point			
Cement and Concrete Product Manufacturing	3.39	2.92	2.88
Basic Chemical Manufacturing	0.57	0.68	0.85
Pulp, and Paper, and Paperboard Mills	1.18	1.24	1.41
Iron and Steel Mills and Ferroalloy Manufacturing	0.97	0.97	1.14
Non-ferrous Metals (except Aluminum) Production and Processing	1.33	1.21	1.25
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	2.84	3.04	3.38
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	1.28

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 trying to evaluate the employment effects due to an environmental regulation. Employment effects must be evaluated in light of 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 proposal. Thus, the EPA did not estimate potential employment impacts associated with this proposal. 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 proposing to revise the current annual $PM_{2.5}$ standard to a level within the range of 9-10 μg/m^3 and is soliciting comment on an alternative annual standard level down to 8 μg/m^3 and a level up to 11 μg/m^3. The Agency is also proposing to retain the current 24-hour standard of 35 μg/m^3 and is soliciting comment on an alternative 24-hour standard level of 25 μg/m^3. OMB Circular A-4 requires analysis of one potential alternative standard level more stringent than the proposed standard and one less stringent than the proposed standard. In this Regulatory Impact Analysis (RIA), we are analyzing the proposed annual and current 24-hour alternative standard levels of 10/35 μg/m^3 and 9/35 μg/m^3, as well as the following two more stringent alternative standard levels: (1) an 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) an alternative 24-hour standard level of 30 μg/m^3 in combination with the proposed annual standard level of 10 μg/m^3 (i.e., 10/30 μg/m^3). Because the EPA is proposing that the current secondary PM standards be retained, we did not evaluate alternative secondary standard levels in this RIA. The docket for the proposed 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] 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 μg/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 proposed 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 proposed standard levels. States, not the EPA, will implement the proposed NAAQS and will ultimately determine appropriate emissions control strategies and measures. This section summarizes the results of the analyses.

As shown in Chapter 4, the estimated costs associated with the control strategies for the proposed alternative standard levels are approximately $95 million for the proposed alternative standard level of 10/35 μg/m^3 and $390 million for the proposed alternative standard level of 9/35 μg/m^3 in 2032 (2017$, 7 percent interest rate).[2] As shown in Chapter 5, the estimated monetized benefits associated with these control strategies for the proposed alternative standard levels are approximately $7.6 billion and $16 billion for the proposed alternative standard level of 10/35 μg/m^3 and $19 billion and $39 billion for the proposed alternative standard level of 9/35 μg/m^3 in 2032 (2017$, based on a real discount rate of 7 percent).[3] The benefits are associated with two point estimates from two

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

[2] When calculating the annualized costs, we would like to use the interest rates faced by firms; however, we do not know what those rates are. As such we use 7 percent as a conservative estimate.

[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.

different epidemiologic studies discussed in more detail in Chapter 5, Section 5.3.3. It is expected that some costs and benefits will begin occurring before 2032, as states begin implementing control measures to attain earlier or to show progress towards attainment.

As discussed in Chapter 3, Section 3.2.5, the estimated $PM_{2.5}$ emissions reductions from control applications do not fully account for all the emissions reductions needed to reach the proposed 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 3.2.6, we discuss the remaining air quality challenges for areas in the northeast and southeast, as well as in the west and California for the proposed alternative standard levels of 10/35 $\mu g/m^3$ and 9/35 $\mu g/m^3$. The EPA calculates the monetized net benefits of the proposed alternative standard levels by subtracting the estimated monetized compliance costs from the estimated monetized benefits in 2032. These estimates do not fully account for all of the emissions reductions needed to reach the proposed and more stringent alternative standard levels. In 2032, the monetized net benefits of the proposed alternative standard level of 10/35 $\mu g/m^3$ are approximately $8.4 billion and $17 billion using a 3 percent real discount rate for the benefits estimates and the monetized net benefits of the proposed alternative standard level of 9/35 $\mu g/m^3$ are approximately $20 billion and $43 billion using a 3 percent real discount rate for the benefits estimates (in 2017$). The benefits are associated with two point estimates from two different epidemiologic studies discussed in more detail in Chapter 5, Section 5.3.3. Table 8-1 presents a summary of these impacts for the proposed alternative standard levels and the more stringent alternative standard levels for 2032.

Table 8-1 Estimated Monetized Benefits, Costs, and Net Benefits of the Control Strategies Applied Toward Primary Alternative 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 2032 for the U.S. (millions of 2017$)

	10/35	10/30	9/35	8/35
Benefits[a]	$8,500 and $17,000	$9,600 and $20,000	$21,000 and $43,000	$46,000 and $95,000
Costs[b]	$95	$260	$390	$1,800
Net Benefits	$8,400 and $17,000	$9,300 and $19,000	$20,000 and $43,000	$44,000 and $93,000

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.

[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 5.3.4 and 5.3.5).

[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 proposed alternative standard levels, annual benefits and costs are discounted to 2022 at 3 percent and 7 percent discount rates as directed 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 proposed alternative standard level of 10/35 $\mu g/m^3$ the PV of the costs, in 2017$ and discounted to 2022, is $1.1 billion when using a 3 percent discount rate and $540 million when using a 7 percent discount rate. The EAV is $72 million per year when using a 3 percent discount rate and $51 million when using a 7 percent discount rate. For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 9/35 $\mu g/m^3$ the PV of the costs, in 2017$ and discounted to 2022, is $4.5 billion when using a 3 percent discount rate and $2.3 billion when using a 7 percent discount rate. The EAV is $300 million per year when using a 3 percent discount rate and $210 million when using a 7 percent discount rate. The costs in PV and EAV terms for the proposed 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 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 2022, 3 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$70	$190	$290	$1,400
2033	$68	$190	$280	$1,300
2034	$66	$180	$280	$1,300
2035	$64	$180	$270	$1,200
2036	$63	$170	$260	$1,200
2037	$61	$170	$250	$1,200
2038	$59	$160	$250	$1,100
2039	$57	$160	$240	$1,100
2040	$56	$150	$230	$1,100
2041	$54	$150	$220	$1,000
2042	$52	$140	$220	$1,000
2043	$51	$140	$210	$980
2044	$49	$130	$210	$950
2045	$48	$130	$200	$920
2046	$47	$130	$190	$900
2047	$45	$120	$190	$870
2048	$44	$120	$180	$840
2049	$43	$120	$180	$820
2050	$41	$110	$170	$800
2051	$40	$110	$170	$770
Present Value	$1,100	$2,900	$4,500	$21,000
Equivalent Annualized Value	$72	$200	$300	$1,400

Table 8-3 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs of the Control Strategies Applied Toward the Primary 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 2022, 7 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$48	$130	$200	$930
2033	$45	$120	$190	$870
2034	$42	$110	$170	$810
2035	$39	$110	$160	$760
2036	$37	$100	$150	$710
2037	$34	$93	$140	$660
2038	$32	$87	$130	$620
2039	$30	$81	$120	$580
2040	$28	$76	$120	$540
2041	$26	$71	$110	$500
2042	$24	$66	$100	$470
2043	$23	$62	$95	$440
2044	$21	$58	$89	$410
2045	$20	$54	$83	$380
2046	$19	$51	$78	$360
2047	$17	$47	$72	$340
2048	$16	$44	$68	$310
2049	$15	$41	$63	$290
2050	$14	$39	$59	$270
2051	$13	$36	$55	$260
Present Value	$540	$1,500	$2,300	$10,000
Equivalent Annualized Value	$51	$140	$210	$990

For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 10/35 µg/m^3 the PV of the benefits, in 2017$ and discounted to 2022, is $200 billion when using a 3 percent discount rate and $91 billion when using a 7 percent discount rate. The EAV is $13 billion per year when using a 3 percent discount rate and $8.5 billion when using a 7 percent discount rate. For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 9/35 µg/m^3 the PV of the benefits, in 2017$ and discounted to 2022, is $490 billion when using a 3 percent discount rate and $220billion when using a 7 percent discount rate. The EAV is $33 billion per year when using a 3 percent discount rate and $21 billion when using a 7 percent discount rate. The benefits in PV and EAV terms for the proposed 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 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 2022, 3 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$13,000	$15,000	$32,000	$71,000
2033	$13,000	$14,000	$31,000	$69,000
2034	$12,000	$14,000	$30,000	$67,000
2035	$12,000	$13,000	$29,000	$65,000
2036	$12,000	$13,000	$29,000	$63,000
2037	$11,000	$13,000	$28,000	$61,000
2038	$11,000	$12,000	$27,000	$59,000
2039	$11,000	$12,000	$26,000	$58,000
2040	$10,000	$12,000	$25,000	$56,000
2041	$9,900	$11,000	$25,000	$54,000
2042	$9,700	$11,000	$24,000	$53,000
2043	$9,400	$11,000	$23,000	$51,000
2044	$9,100	$10,000	$23,000	$50,000
2045	$8,800	$10,000	$22,000	$48,000
2046	$8,600	$9,700	$21,000	$47,000
2047	$8,300	$9,400	$21,000	$46,000
2048	$8,100	$9,100	$20,000	$44,000
2049	$7,900	$8,900	$19,000	$43,000
2050	$7,600	$8,600	$19,000	$42,000
2051	$7,400	$8,400	$18,000	$40,000
Present Value	$200,000	$220,000	$490,000	$1,100,000
Equivalent Annualized Value	$13,000	$15,000	$33,000	$73,000

Table 8-5 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Benefits of the Control Strategies Applied Toward the Primary 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 2022, 7 percent discount rate)

Year	10/35	10/30	9/35	8/35
2032	$8,000	$9,000	$20,000	$44,000
2033	$7,500	$8,400	$18,000	$41,000
2034	$7,000	$7,900	$17,000	$38,000
2035	$6,500	$7,400	$16,000	$36,000
2036	$6,100	$6,900	$15,000	$33,000
2037	$5,700	$6,400	$14,000	$31,000
2038	$5,300	$6,000	$13,000	$29,000
2039	$5,000	$5,600	$12,000	$27,000
2040	$4,600	$5,200	$11,000	$25,000
2041	$4,300	$4,900	$11,000	$24,000
2042	$4,100	$4,600	$10,000	$22,000
2043	$3,800	$4,300	$9,400	$21,000
2044	$3,500	$4,000	$8,800	$19,000
2045	$3,300	$3,700	$8,200	$18,000
2046	$3,100	$3,500	$7,700	$17,000
2047	$2,900	$3,300	$7,200	$16,000
2048	$2,700	$3,100	$6,700	$15,000
2049	$2,500	$2,900	$6,300	$14,000
2050	$2,400	$2,700	$5,800	$13,000
2051	$2,200	$2,500	$5,500	$12,000
Present Value	$91,000	$100,000	$220,000	$490,000
Equivalent Annualized Value	$8,500	$9,600	$21,000	$47,000

For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 10/35 μg/m^3 the PV of the net benefits, in 2017$ and discounted to 2022, is $200 billion when using a 3 percent discount rate and $90 billion when using a 7 percent discount rate. The EAV is $13 billion per year when using a 3 percent discount rate and $8.5 billion when using a 7 percent discount rate. For the twenty-year period of 2032 to 2051, for the proposed alternative standard level of 9/35 μg/m^3 the PV of the net benefits, in 2017$ and discounted to 2022, is $490 billion when using a 3 percent discount rate and $220 billion when using a 7 percent discount rate. The EAV is $33 billion per year when using a 3 percent discount rate and $21 billion when using a 7 percent discount rate. The comparison of benefits and costs in PV and EAV terms for the proposed alternative standard levels can be found in Table 8-6 and Table 8-7. Estimates in the tables 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 Proposed Primary Alternative Standard Level of 10/35 $\mu g/m^3$ (millions of 2017\$, 2032-2051, discounted to 2022 using 3 and 7 percent discount rates)

	Benefits[a]		**Costs[b]**		**Net Benefits**	
Year	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
2032	$13,000	$8,000	$70	$48	$13,000	$7,900
2033	$13,000	$7,500	$68	$45	$13,000	$7,400
2034	$12,000	$7,000	$66	$42	$12,000	$6,900
2035	$12,000	$6,500	$64	$39	$12,000	$6,500
2036	$12,000	$6,100	$63	$37	$11,000	$6,100
2037	$11,000	$5,700	$61	$34	$11,000	$5,700
2038	$11,000	$5,300	$59	$32	$11,000	$5,300
2039	$11,000	$5,000	$57	$30	$10,000	$4,900
2040	$10,000	$4,600	$56	$28	$10,000	$4,600
2041	$9,900	$4,300	$54	$26	$9,900	$4,300
2042	$9,700	$4,100	$52	$24	$9,600	$4,000
2043	$9,400	$3,800	$51	$23	$9,300	$3,800
2044	$9,100	$3,500	$49	$21	$9,100	$3,500
2045	$8,800	$3,300	$48	$20	$8,800	$3,300
2046	$8,600	$3,100	$47	$19	$8,500	$3,100
2047	$8,300	$2,900	$45	$17	$8,300	$2,900
2048	$8,100	$2,700	$44	$16	$8,000	$2,700
2049	$7,900	$2,500	$43	$15	$7,800	$2,500
2050	$7,600	$2,400	$41	$14	$7,600	$2,300
2051	$7,400	$2,200	$40	$13	$7,400	$2,200
Present Value	**$200,000**	**$91,000**	**$1,100**	**$540**	**$200,000**	**$90,000**
Equivalent Annualized Value	**$13,000**	**$8,500**	**$72**	**$51**	**$13,000**	**$8,500**

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 5-7, 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 5.3.4 and 5.3.5).

[b] The costs are annualized using a 7 percent interest rate.

Table 8-7 Summary of Present Values and Equivalent Annualized Values for Estimated Monetized Compliance Costs, Benefits, and Net Benefits of the Control Strategies Applied Toward the Proposed Primary Alternative Standard Level of 9/35 $\mu g/m^3$ (millions of 2017$, 2032-2051, discounted to 2022 using 3 and 7 percent discount rates)

	Benefits[a]		Costs[b]		Net Benefits	
Year	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
2032	$32,000	$20,000	$290	$200	$32,000	$20,000
2033	$31,000	$18,000	$280	$190	$31,000	$18,000
2034	$30,000	$17,000	$280	$170	$30,000	$17,000
2035	$29,000	$16,000	$270	$160	$29,000	$16,000
2036	$29,000	$15,000	$260	$150	$28,000	$15,000
2037	$28,000	$14,000	$250	$140	$27,000	$14,000
2038	$27,000	$13,000	$250	$130	$27,000	$13,000
2039	$26,000	$12,000	$240	$120	$26,000	$12,000
2040	$25,000	$11,000	$230	$120	$25,000	$11,000
2041	$25,000	$11,000	$220	$110	$24,000	$11,000
2042	$24,000	$10,000	$220	$100	$24,000	$9,900
2043	$23,000	$9,400	$210	$95	$23,000	$9,300
2044	$23,000	$8,800	$210	$89	$22,000	$8,700
2045	$22,000	$8,200	$200	$83	$22,000	$8,100
2046	$21,000	$7,700	$190	$78	$21,000	$7,600
2047	$21,000	$7,200	$190	$72	$20,000	$7,100
2048	$20,000	$6,700	$180	$68	$20,000	$6,600
2049	$19,000	$6,300	$180	$63	$19,000	$6,200
2050	$19,000	$5,800	$170	$59	$19,000	$5,800
2051	$18,000	$5,500	$170	$55	$18,000	$5,400
Present Value	**$490,000**	**$220,000**	**$4,500**	**$2,300**	**$490,000**	**$220,000**
Equivalent Annualized Value	**$33,000**	**$21,000**	**$300**	**$210**	**$33,000**	**$21,000**

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 5-7, 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 5.3.4 and 5.3.5).

[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 3.2.5, 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 control measures 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 measures, 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 measure or change to another measure based on economic or other reasons, the EPA assumes the control equipment and measures 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 control measures 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 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.

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[4] The pulse approach assumes changes in air pollution in a single year and affects mortality estimates over a 20-year period.

8.3 References

Miller BG (2003). Life table methods for quantitative impact assessments in chronic mortality. Journal of Epidemiology & Community Health, 57(3):200–206.

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