Executive Summary

Overview

This Regulatory Impact Analysis (RIA) provides EPA's estimates of the range of the monetized human health benefits, control costs, and net benefits associated with meeting the revised suite of standards for fine particles ($PM_{2.5}$) that were promulgated by EPA on September 21, 2006, as well as for meeting a one alternative. The final rule established a 24-hour standard of 35 µg/m^3 and retained the annual standard of 15 µg/m^3. EPA also promulgated a final decision to retain the current 24-hour PM_{10} standards and to revoke the current annual PM_{10} standards, in order to maintain protection against the health and welfare effects of thoracic coarse particles ($PM_{10\text{-}2.5}$). As was the case for the interim RIA accompanying the proposed rulemaking, due to data and modeling limitations preclude EPA from assessing the costs and benefits of retaining the existing PM_{10} standards. This summary outlines the basis for and approach used in the RIA, presents the key results and insights derived from the analyses, and highlights key uncertainties and limitations.

In setting primary ambient air quality standards, EPA's responsibility under the law is to establish standards that protect public health. The Clean Air Act ("Act") requires EPA, for each criteria pollutant, to set a standard that protects public health with "an adequate margin of safety." As interpreted by the Agency and the courts, the Act requires EPA to base this decision on health considerations; economic factors cannot be considered.

This prohibition against the consideration of cost in the setting of the primary air quality standards, however, does not mean that costs, benefits or other economic considerations are unimportant or should be ignored. 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 cost, benefits, and efficiency are considered by the states during this process, when states are making decisions regarding what timelines, strategies, and policies make the most sense.

This $PM_{2.5}$ NAAQS RIA is focused on development and analyses of illustrative control strategies to meet alternative suites of standards in 2020, the latest year by which the Clean Air Act generally requires full attainment of the new standards. Because the states are ultimately responsible for implementing strategies to meet the revised standards, the RIA provides insights and analysis of a limited number of illustrative control strategies that states might adopt to meet the revised standards. These strategies are subject to a number of important assumptions, uncertainties and limitations, which we document in the relevant portions of the analysis.

EPA presents this analysis pursuant to Executive Order 12866 and the guidelines of OMB Circular A-4.[1] These documents present guidelines for EPA to assess the incremental benefits and costs of the selected regulatory approach as well as one less stringent, and one more stringent, option. In this RIA, the 1997 standards represent the less stringent option, and the

[1] For a copy of these requirements, see: http://www.whitehouse.gov/OMB/inforeg/eo12866.pdf and http://www.whitehouse.gov/omb/circulars/a004/a-4.html.

alternative suite of standards including a tighter annual standard of 14 µg/m^3 together with the revised 24-hour standard of 35 µg/m^3 represents the more stringent option.

ES.1 Approach to the Analysis

The RIA consists of multiple analyses including an assessment of the nature and sources of ambient $PM_{2.5}$; estimates of current and future emissions of relevant gases and particles that contribute to the problem; air quality analyses of baseline and alternative strategies; development of illustrative control strategies to attain the standards alternatives in future years; analyses of the incremental costs and benefits of attaining the alternative standards, together with an examination of key uncertainties and limitations; and a series of conclusions and insights gained from the analysis.

Nature of $PM_{2.5}$

Particulate matter (PM) is a highly complex mixture of solid particles and liquid droplets that occur in the atmosphere together with numerous pollutant gases that interact with them. Atmospheric particles can be grouped according to various characteristics. For regulatory purposes, fine PM are measured as $PM_{2.5}$. Particles are emitted directly from sources (referred to as primary PM) and are also formed through atmospheric chemical reactions (referred to as secondary PM). Primary $PM_{2.5}$ consists of carbonaceous material (e.g. soot, and accompanying organics)—emitted from cars, trucks, heavy equipment, forest fires, and burning waste, as well as from coke ovens, metals from combustion and industrial processes, with some small contribution from crustal materials. Secondary $PM_{2.5}$ forms in the atmosphere from precursor gases including sulfur and nitrogen oxides from power, industrial and other combustion and process sources, certain reactive organic gases from diesel and other mobile sources, solvents, fires, and biogenic sources such as trees, and ammonia from agricultural operations, natural, and other sources. Fine particles can be transported hundreds to thousands of miles from emissions sources. For this reason, fine particle concentrations in a particular area may have a substantial contribution from regional transport as well as local sources. As discussed more fully in Chapter 2, there are important regional differences in fine particle concentrations and composition that are important to recognize in developing control strategies.

Overview of Air Quality Modeling Methodology/Baseline emissions forecasts

As a first step in the national assessment of alternatives, the analysis forecasts emissions and air quality in 2015 and 2020 under a *regulatory base case* that incorporates national, regional, state and local regulations that are already promulgated and/or adopted. This base case does not forecast actions states may take to implement the existing $PM_{2.5}$ standards. The regulatory base case includes recent rules that will significantly reduce $PM_{2.5}$ concentrations in future years by addressing emissions from the power generation sector - the Clean Air Interstate Rule (CAIR), the Clean Air Mercury Rule (CAMR), and the Clean Air Visibility Rule (CAVR, which also affects some industrial boiler emissions), and mobile sources through national rules for light and heavy-duty vehicles and non-road mobile sources. Current state programs that address these and other source categories that were on the books as of early 2005 are also modeled for future years. Based on the emissions forecasts, EPA developed annual and daily $PM_{2.5}$ design value projections using the CMAQ model.[2]

Development and Application of Illustrative Control Strategies

The air quality modeling results for the *regulatory base case* (Figure ES-1, ES-2) provided the starting point for developing illustrative control strategies to attain the 1997 as well as the revised and alternative suites of standards that are the focus of this RIA. The figures show that by 2020, while $PM_{2.5}$ air quality would be significantly better than today under current requirements, several eastern and western States will need to develop and adopt additional controls to attain the revised standards. The modeling shown in Figure ES-2 suggests that under the revised suite of standards, greater reductions will be needed in some Western areas, particularly in California.

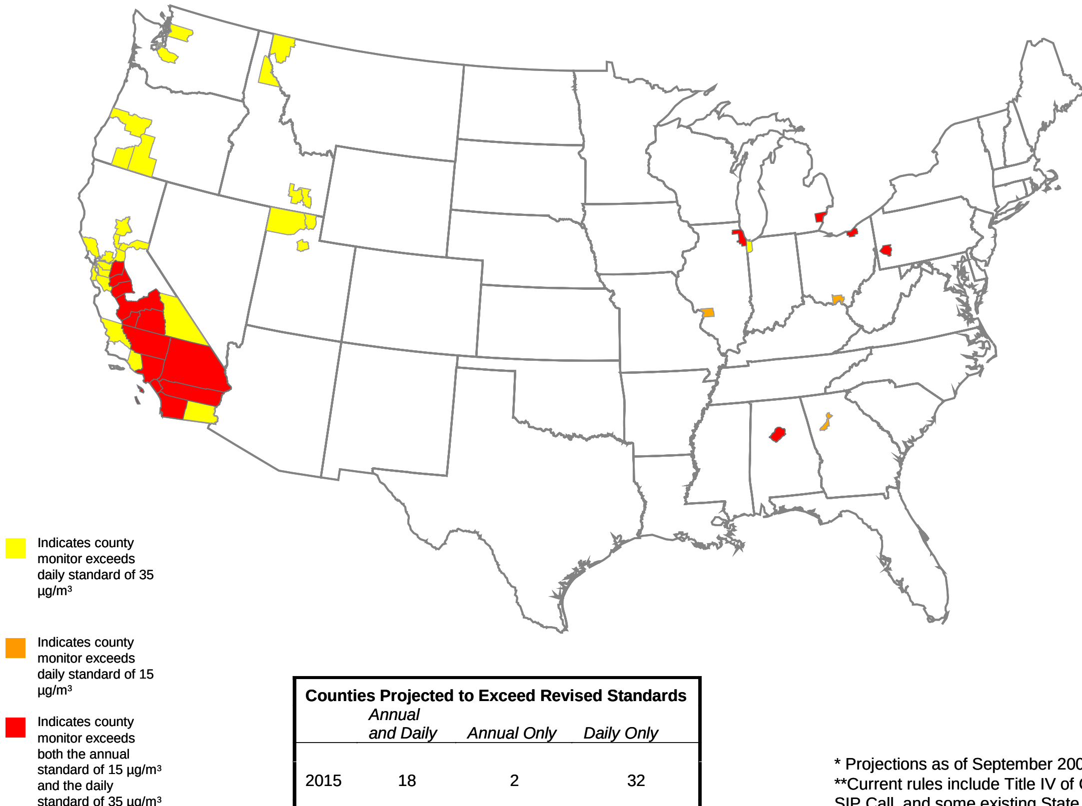
We followed a three-step process to simulate attainment in each of the areas forecast to need additional controls to meet the revised and alternative standards: 1) We identified cost-effective controls to apply in each projected nonattainment area and then simulated the resulting air quality change in an air quality model; 2) For those areas that did not attain under 1) we developed and simulated the results of applying additional known emission controls that were not applied in the initial strategy, and then evaluated attainment status considering the uncertainty in the analyses; 3) For areas that we determined would still not attain under the more readily identifiable control strategies in 1) and 2), we used a combination of qualitative and quantitative analysis to estimate the costs and benefits of fully attaining the standards. This included identification of potential trends in pollution control measures (such as greater adoption of hydrogen fuel cell vehicles), extrapolation of costs based on existing technologies, and estimation of benefits by "rolling back" monitor values to just attain the standards.

In developing strategies tailored to specific problem areas, we combined information from our air quality models and our emission control database. These combined data enabled us to selectively apply emission control measures on those industrial sources where it was most cost effective to do so—effectively generating the greatest estimated air quality improvement at the lowest cost. Because the national and regional programs summarized above (e.g. CAIR, mobile rules) will address a good portion of the regional transport contribution of $PM_{2.5}$, the first set of controls to meet the 1997 and revised standards focus on reductions in local emissions. These local emissions are defined as those occurring in the projected nonattainment county and immediate surrounding counties in the MSA. In some cases, the local control strategy did not provide enough emission reductions to attain the standards. In that case, we explored emission controls among a broader set of counties within the state containing the projected nonattainment area. The exception to this approach is California, where, due to the extreme and widespread nature of the nonattainment problem, we considered controls throughout Southern California in the attainment strategies.

[2] The methodologies for forecasting emissions and air quality and associated uncertainties are detailed in the Technical Support Document – "Air Quality Modeling Technique used for Multi-Pollutant Analysis?" (http://www.epa.gov/airmarkets/mp/aqsupport/airquality.pdf). The methodology used to derive the 98^{th} percentile 24-hour values is summarized in Chapter 4 of this RIA.

Figure ES-1. Counties Projected to Violate the Revised PM2.5 NAAQS in 2020

With CAIR/CAMR/CAVR and Some Current Rules** Absent Additional Local Controls



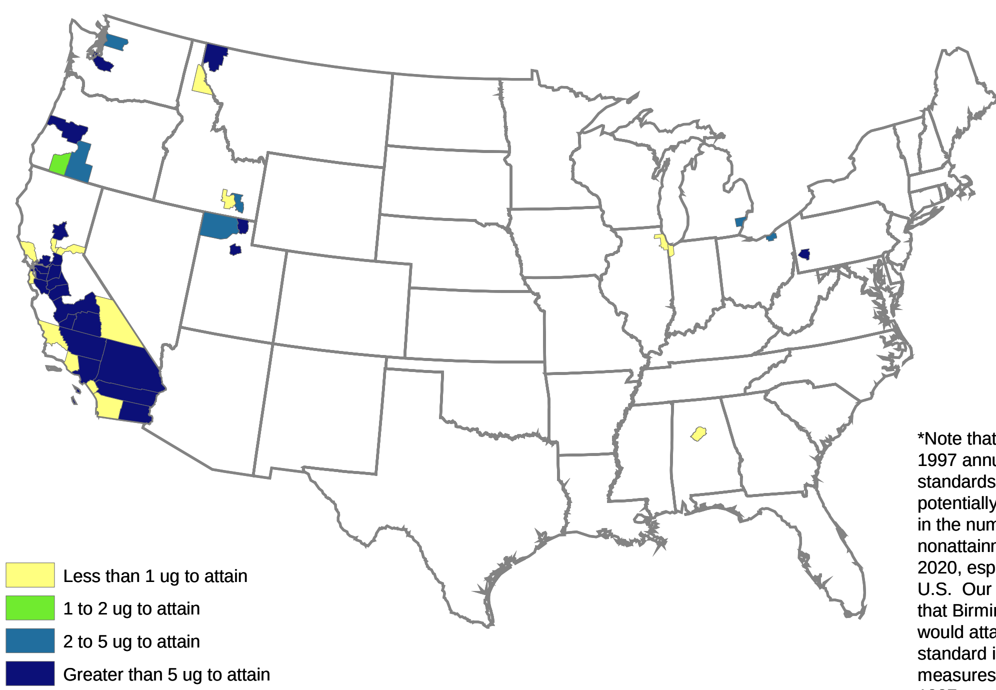
Counties Projected to Exceed Revised Standards

	Annual and Daily	*Annual Only*	*Daily Only*
2015	18	2	32
2020	17	3	28

* Projections as of September 2006.
**Current rules include Title IV of CAA, NOx SIP Call, and some existing State rules

Figure ES-2. Projected Reduction in Daily Design Value Needed to Attain the Revised Daily Standard of 35 $\mu g/m^3$ in 2020

*Incremental to baseline with CAIR/CAMR/CAVR and Mobile Source Rules without additional local controls for attainment of the current standards**



*Note that attainment with the 1997 annual and daily standards by 2020 would potentially result in reductions in the number of nonattainment counties in 2020, especially in the Eastern U.S. Our modeling suggests that Birmingham and Chicago would attain the revised daily standard in 2020 with measures needed to attain the 1997 standards.

Given the baseline air quality forecast under the alternative standard (14, 35), we added a regional control program covering both utility and industrial sources of SO_2 in portions of the Eastern US due to the number of projected nonattainment areas under the alternative standard, and prevalence of sulfate in the Eastern U.S.

In general, we were able to model attainment with the alternative standard in most regions of the country with a mix of local or regional control strategies. The major exceptions are in California and Utah, where modeling of such strategies indicated that several counties would not attain the revised or alternative standards.

ES-2. Results of Benefit-Cost Analysis

Table ES-1 summarizes the net benefits of attaining a revised and alternative $PM_{2.5}$ NAAQS. The table summarizes the full attainment benefits, economic costs and net benefits at 3 and 7 percent discount rates.

A new component of our benefits analysis is the expanded characterization of uncertainty about the impacts of PM on the risk of premature death. Since the publication of the RIA for the Clean Air Interstate Rule, we have completed a full-scale expert elicitation designed to more fully characterize the state of our understanding of the concentration-response function for PM-related premature mortality. The elicitation results form a major component of the current effort to use probabilistic assessment techniques to integrate uncertainty into the main benefits analysis.

To reflect our expanded understanding of uncertainty, and to move us towards implementation of the recommendations of the National Research Council's 2002 report "Estimating the Public Health Benefits of Proposed Air Pollution Regulations," our summary benefits estimates are presented as ranges, and include additional information on the quantified uncertainty distributions surrounding the points on those ranges, derived from both the epidemiological studies and the expert elicitation.

Tables ES-2 and ES-3 summarize the estimated benefits associated with attaining the revised and alternative $PM_{2.5}$ standards, incremental to our modeled attainment strategy for the 1997 standards. These tables include both the estimated reductions in the incidence of mortality and morbidity and the monetized value associated with these reductions in incidence. In addition to these health benefits, we estimate that, incremental to our modeled attainment strategy for the 1997 standards, the monetary benefits associated with improvements in visibility in selected national parks and wilderness areas in 2020 will be $530 million for the revised standards, and $1,200 million for the alternative standards.

Table ES-2 and ES-3 summarize the range of incidence and the range of total monetized benefits (health plus visibility) across several sources of mortality effect estimates that we used in our analysis. The ranges reflect two different sources of information about the impact of reductions in PM on reductions in the risk of premature death, including both the published epidemiology literature and an expert elicitation study conducted by EPA in 2006. Estimates based on the American Cancer Society study show benefits of meeting the revised 24-hour PM2.5 standard at $17 billion a year in 2020. In order to provide an indication of the sensitivity of the benefits estimates to alternative assumptions, in Chapter 5 we present a variety of benefits estimates based on both epidemiological studies (including the American Cancer Society Study and the Six

Cities Study) and the expert elicitation. EPA intends to ask the Science Advisory Board to provide additional advice as to which scientific studies should be used in future RIAs to estimate the benefits of reductions in PM.

Table ES-1: Comparison of Full Attainment Benefits with Social Costs[f], Incremental to Attainment of 1997 Standards (Billion 1999$)

	Revised standard of 15/35 (μg/m^3)					Alternative standards of 14/35 (μg/m^3)				
	Benefits[a]		*Costs[b]*	*Net benefits[c]*		*Benefits[a]*		*Costs[b]*	*Net benefits[c]*	
Benefits Based on Mortality Function from the American Cancer Society Study and Morbidity Functions from the Published Scientific Literature[d]										
3%	$17		$5.4	$12		$30		$7.9	$22	
7%	$15		$5.4	$9		$26		$7.9	$18	
Benefits Range Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from the Published Scientific Literature[e]										
	Low Mean	High Mean		Low Mean	High Mean	Low Mean	High Mean		Low Mean	High Mean
3%	$9	$76	$5.4	$3.5	$70	$17	$140	$7.9	$8.7	$130
7%	$8	$64	$5.4	$2.4	$59	$15	$120	$7.9	$6.7	$110

[a] Results reflect the use of two different discount rates: 3% and 7%, as recommended in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b) and OMB Circular A-4 (OMB, 2003). Results are rounded to two significant digits

[b] Includes roughly $180 Million in supplemental engineering costs.

[c] Estimates rounded to two significant digits after calculations.

[d] based on Pope et al 2002, used as primary estimate in previous RIAs.

[e]Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. The distribution of benefits estimates associated with each of the twelve expert responses can be found in Chapter 5.

[f] For the purposes of comparison with the benefits, EPA uses the total social cost estimate which is slightly higher than the engineering cost

Table ES-2. Estimated Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the Revised and Alternative Standards, Incremental to Attainment of the 1997 Standards (95 Percent Confidence Intervals Provided in Parentheses)

Estimate	Revised Standards (15/35)	Alternative Revised Standards (14/35)
Mortality		
Estimate based on American Cancer Society study[a]	2,500 (1,000 – 4,100)	4,400 (1,700 – 7,100)
Range based on expert elicitation results[b]		
Low Mean	1,200 (0 – 5,800)	2,200 (0 – 11,000)
High Mean	13,000 (6,400 – 19,000)	24,000 (12,000 – 35,000)
Morbidity		
Chronic bronchitis (age >25 and over)	2,600 (490 – 4,800)	4,600 (850—8,300)
Nonfatal myocardial infarction (age >17)	5,000 (2,700 – 7,200)	8,700 (4,800 – 13,000)
Hospital admissions—respiratory (all ages)[b]	530 (260 – 800)	980 (490 – 1,500)
Hospital admissions—cardiovascular (age >17)[c]	1,100 (690 – 1,500)	2,100 (1,300 – 2,800)
Emergency room visits for asthma (age <19)	1,200 (730 – 1,700)	3,200 (1,900 – 4,500)
Acute bronchitis (age 8–12)	7,300 (–260 – 15,000)	13,000 (–440 – 25,000)
Lower respiratory symptoms (age 7–14)	56,000 (27,000 – 84,000)	88,000 (43,000 – 130,000)
Upper respiratory symptoms (asthmatic children, age 9–18)	41,000 (13,000 – 70,000)	65,000 (20,000 – 110,000)
Asthma exacerbation (asthmatic children, age 6–18)	51,000 (5,600 – 150,000)	79,000 (8,900 – 230,000)
Work loss days (age 18–65)	350,000 (300,000 – 390,000)	550,000 (480,000 – 620,000)
Minor restricted-activity days (age 18–65)	2,000,000 (1,700,000 – 2,300,000)	3,300,000 (2,700,000 – 3,800,000)

[a] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[b] The low mean estimate is based on the C-R function provided Expert K. The high mean estimate is based on the C-R function provided by Expert E. The expert elicitation project is described in greater detail in Chapter 5, and a complete report of the project is available on EPA's website. . Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of mortality estimates associated with each of the twelve expert responses can be found in Chapter 5.

Table ES-3. Estimated Annual Monetized Benefits in 2020 of Illustrative Implementation Strategies for the Selected and Alternative $PM_{2.5}$ NAAQS, Incremental to Attainment of the 1997 Standards

Note: Unquantified benefits are not included in these estimates, thus total benefits are likely to be larger than indicated in this table.

	Total Full Attainment Benefits[a] (billions 1999$)			
	15/35 (μg/m3)		*14/35 (μg/m3)*	
Benefits Based on Mortality Function from the American Cancer Society Study and Morbidity Functions from the Published Scientific Literature [b]				
Using a 3% discount rate	$17 ($4.1 – $36)		$30 ($7.3 - $63)	
Using a 7% discount rate	$15 ($3.5 – $31)		$26 ($6.4 - $54)	
Benefits Range Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from the Published Scientific Literature[c]				
	Low Mean	High Mean	Low Mean	High Mean
Using a 3% discount rate	$9 ($0.8 - $42)	$76 ($19-$150)	$17 ($1.7 - $77)	$140 ($36 - $280)
Using a 7% discount rate	$8 ($0.8 - $36)	$64 ($16 - $130)	$15 ($1.6 - $66)	$120 ($31 - $240)

[a] Results reflect the use of two different discount rates: 3% and 7%, as recommended in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b) and OMB Circular A-4 (OMB, 2003). Results are rounded to two significant digits.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[c] Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of benefits estimates associated with each of the twelve expert responses can be found in Chapter 5.

Table ES-4 summarizes the total annualized engineering and social costs of meeting the current standard and the alternative scenarios using 3 and 7 percent discount rates. Total annualized costs are estimated from a baseline inventory in 2020 that reflects controls for CAIR/CAMR/CAVR and other on-the-books rules. Based on engineering cost estimates, the incremental cost of the revised standards (15/35) is approximately $5.0 to $5.1 billion using 3 and 7 percent discount rates, respectively. The incremental costs for the alternative standards are $6.8 to $6.9 billion using 3 and 7 percent discount rates, respectively. These cost numbers are highly uncertain because they include the extrapolated costs of full attainment in California and Salt Lake City. Approximately $4.5 billion of the incremental cost of achieving both 15/35 and 14/35 is attributable to these extrapolated full attainment costs. An analysis of the costs and benefits of attaining the 1997 standards in 2015 is provided in Appendix A.

For the purposes of comparison with the benefits, EPA uses the total social cost estimate which is slightly higher than the engineering cost. Total social costs (including the general equilibrium impacts on GDP) are estimated to be $5.4 billion in 2020 for the revised standards, and $7.9 billion for the alternative standards.

Table ES-4. Comparison of Total Annualized Engineering Costs Across PM NAAQS Scenarios (millions of 1999 dollars, 7% interest rate) [a]

	Scenario	
Source Category	*Revised Stds: 15/35*	*Alternative Revised Stds: 14/35*
EGU's	**$400**	**$1,100**
Mobile Sources	**$60**	**$60**
Non-EGU's	**$380**	**$1,300**
Incremental Residual Cost of Full Attainment[b]		
East	$3	$180
West	$300	$300
California	$4,000	$4,000
Total of Residual Costs of Full Attainment	**$4,300**	**$4,500**
Total Annualized Costs (incremental to the current standard) – using a 7% interest rate	**$5,100**	**$7,000**
Total Annualized Costs (incremental to the current standard) – using a 3% interest rate	**$5,050**	**$6,800**

a Upon review of emissions and air quality results of the control strategies applied in this RIA, some areas had residual nonattainment problems (requiring additional emissions reductions to meet the standard) as a result of our initial selection of controls. The incremental costs of fully attaining in these areas (the residual cost of full attainment) reflect extrapolated costs of additional control measures that would be necessary to bring areas with residual nonattainment into compliance. Chapter 4 provides details of the assessment.

b The incremental cost of residual nonattainment (beyond our modeled control strategy) for the West and California are extrapolated. The methodology used to derive these estimates is described in Chapter 6. These estimates are derived using a 7 percent discount rate. The incremental cost of residual non-attainment in the East are based on supplemental carbonaceous particle emission controls, which are detailed in Chapter 4.

ES-3. Uncertainties and Limitations

Air Quality Modeling and Emissions

- Overall, the air quality model performs well in predicting monthly to seasonal concentrations, similar to other state-of-the-science air quality model applications for $PM_{2.5}$. However, there is less certainty in analyses involving 24-hour model predictions than those involving longer-term averages concentrations and performance is better for the Eastern U.S. than for the West. In both the East and West, secondary carbonaceous aerosols are the most challenging species for the modeling system to predict in terms of evaluation against ambient data.

- Underestimation biases in the mobile source emission inventories lead to uncertainty as to the relative contribution of mobile source emissions to overall PM levels.

- Additional uncertainty is introduced as a result of our limited understanding concerning the collective impact on future-year emission estimates from economic growth estimates, increases in technological efficiencies, and limited information on the effectiveness of future control programs.

- The regional scale used for air quality modeling can understate the effectiveness of controls on local sources in urban areas as compared to area-wide or regional controls. This serves to obscure local-scale air quality improvements that result from urban-area controls.

Controls and Cost

- The technologies applied and the emission reductions achieved in these analyses may not reflect emerging control devices that could be available in future years to meet any requirements in SIPs or upgrades to some current devices that may serve to increase control levels.

- The effects from “learning by doing” are not accounted for in the emission reduction estimates for point and area sources. It is possible that an emissions control technology may have better performance in reducing emissions due to greater understanding of how best to operate and maintain the technology. As a result, we may understate the emission reductions estimated by these analyses. The mobile source control measures do account for these learning by doing effects.

- The effectiveness of the control measures in these analyses is based on an assumption that these controls are well maintained throughout their equipment life (the amount of time they are assumed to operate). To the extent that a control measure is not well maintained, the control efficiency may be less than estimated in these analyses. Since these control measures must operate according to specified permit conditions, however, it is expected that the maintenance of controls should yield control efficiencies at or very close to those used in these analyses. As a result, we may overstate the emission reductions estimated by these analyses.

- The application of area source control technologies in these analyses assume that a constant estimate for emission reduction is reasonable despite variation in the extent or scale of application (e.g. dust control plans at construction sites). To the extent that there are economies of scale in area source control applications, we may overstate the emission reductions estimated by these analyses.

- The cost extrapolation method used to develop full attainment costs is highly uncertain and may significantly under or overstate future costs of full attainment.

Benefits

- This analysis assumes that inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been specifically identified, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality are explored using the results of the expert elicitation.

- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because the composition of PM produced via transported precursors emitted from EGUs may differ significantly from direct PM released from automotive engines and other industrial sources. In accordance with advice from the CASAC, EPA has determined that no clear scientific grounds exist for supporting differential effects estimates by particle type, based on information in the most recent Criteria Document. In chapter 5, we provide a decomposition of benefits by PM component species to provide additional insights into the makeup of the benefits associated with reductions in overall $PM_{2.5}$ mass (See Tables 5-32 and 5-33).

- This analysis assumes that the concentration-response (CR) function for fine particles is approximately linear within the range of ambient concentrations under consideration (above the assumed threshold of 10 $\mu g/m^3$). Thus, we assume that the CR functions are applicable to estimates of health benefits associated with reducing fine particles in areas with varied concentrations of PM, including both regions that are in attainment with $PM_{2.5}$ standards and those that do not meet the standards. However, we examine the impact of this assumption by looking at alternative thresholds in a sensitivity analysis.

- A key assumption underlying the entire analysis is that the forecasts for future emissions and associated air quality modeling are valid. Because we are projecting emissions and air quality out to 2020, there are inherent uncertainties in all of the factors that underlie the future state of emissions and air quality levels.

ES-4. Conclusions and Insights

EPA's analysis has estimated the health and welfare benefits of reductions in ambient concentrations of particulate matter resulting from a set of illustrative control strategies to reduce emissions of $PM_{2.5}$ precursors. The results suggest there will be significant additional health and welfare benefits arising from reducing emissions from a variety of sources in and around projected nonattaining counties in 2020. While 2020 is the latest date by which states would generally need to demonstrate attainment with the revised standards, it is expected that benefits (and costs) will begin occurring earlier, as states begin implementing control measures to show progress towards attainment.

There are several important factors to consider when evaluating the relative benefits and costs of the attainment strategies for the revised 15/35 and alternative 14/35 standards:

- California accounts for a large share of the total benefits and costs for both of the evaluated standards (80 percent of the benefits and 78 percent of the costs of attaining the revised standards, and 50 percent of the benefits and 58 percent of the costs of attaining the alternative standards). Because we were only able to model a small fraction of the emissions controls that might be needed to reach attainment in California, the proportion of California benefits in the "residual attainment" category are large relative to other areas of the U.S. Both the benefits and the costs associated with the assumed reductions in California are particularly uncertain.

- The comparative magnitudes and distributions of benefits estimates for the revised and alternative standards are significantly affected by differences in assumed attainment strategies. As noted above, attainment with the revised standards was simulated using mainly local reductions, while a supplemental eastern regional SO2 reduction program was used for the alternative. Under the assumptions in the analyses, the regional strategy used in meeting the alternative standard resulted in significant additional benefits in attainment areas than the local area strategy used for the revised standard. This makes the difference in benefits between the revised and alternative standards larger than can be accounted for by only the 1 µg/m3 lower annual level for the alternative standards.

- Given current scientific uncertainties regarding the contribution of different components to the effects associated with $PM_{2.5}$ mass, this analysis continues to assume the contribution is directly proportional to their mass. In the face of uncertainties regarding this assumption, we believe that strategies which reduce a wide array of types of PM and precursor emissions will have more certain health benefits than strategies that are more narrowly focused. For this reason, the analysis provides a rough basis for comparing the assumed benefits associated with different components for different strategies. The illustrative attainment strategy for the revised standards results in a more balanced mix of reductions in different $PM_{2.5}$ components than does the regional strategy for the alterative standards. Until a more robust scientific basis exists for making reliable judgments about the relative toxicity of PM, it will not be possible to determine whether the strategy of reducing a wide array of PM types is the optimal approach.

- Because of the limitations and uncertainties in the emissions and air quality components of our assessment, the specific control strategies that might be the most effective in helping areas to reach attainment are still very uncertain. For example, the high likelihood of mobile sources emissions being significantly understated biases the analyses by requiring additional controls from other sources in both the base case and the analyses of the 1997, revised, and alternative standards.

- Previous analyses have focused on measuring cost-effectiveness by comparing control measures in terms of cost per ton of emissions reduced. In those analyses, direct PM controls usually appear to be less cost-effective because the cost per ton is in the tens of thousands of dollars per ton, while SO2 and NOx controls are on the order of thousands of dollars per ton. The current analysis demonstrates that when considered on a cost per microgram reduced basis, controls on directly emitted PM are often the most cost-effective, because of the significant local contribution of direct PM emissions to nonattaining monitors in urban areas. This finding suggests that states should consider ranking controls on a cost per microgram basis rather than a cost per ton basis to increase the overall cost-effectiveness of attainment strategies.

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Chapter 1: Introduction and Background

Synopsis

This chapter summarizes the purpose and results of this Regulatory Impact Analysis (RIA). This RIA estimates the costs and monetized human health and welfare benefits of attaining a revised $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) nationwide and one more stringent alternative. This document contains illustrative analyses that consider a limited number of emission control scenarios that States, Tribes and Regional Planning Organizations might implement to achieve the revised $PM_{2.5}$ NAAQS. According to the Clean Air Act, EPA must use health-based criteria in setting the NAAQS and cannot consider estimates of compliance cost. EPA is producing this RIA both to provide the public a sense of the benefits and costs of meeting a new $PM_{2.5}$ NAAQS and to meet the requirements of Executive Order 12866. This analysis contains several important improvements from the interim RIA that EPA issued January 17^{th}, 2006, including refinements to EPA's control measures database, emissions inventories, air quality modeling and benefits assessment.

1.1 Background

On December 20^{th}, 2005 EPA proposed to revise the National Ambient Air Quality Standards for fine particles ($PM_{2.5}$) and to replace the current standards for PM_{10} with a new standard for inhalable coarse particles based on a qualified $PM_{10-2.5}$ indicator.[1] On January 17^{th}, 2006 EPA published an interim RIA for the $PM_{2.5}$ standard. That interim RIA considered the costs and monetized human health benefits of attaining the proposed $PM_{2.5}$ standards and three alternative $PM_{2.5}$ standard options in five urban areas in 2015. Due to data and modeling limitations, that RIA did not address the proposed new $PM_{10-2.5}$ standard. These same data and modeling limitations preclude EPA from assessing the costs and benefits of retaining the existing PM_{10} standards. This $PM_{2.5}$ NAAQS RIA builds upon the approach in the five-city analysis to perform a national-scale assessment of costs and monetized human health and welfare benefits associated with illustrative scenarios for attainment of the revised and more stringent alternative revised $PM_{2.5}$ NAAQS.

1.2 Role of this RIA in the Process of Setting the NAAQS

This $PM_{2.5}$ NAAQS RIA is an illustrative analysis that provides useful insights into a limited number of emission control strategies States might adopt to achieve the revised $PM_{2.5}$ standard and one more stringent alternative. Because States are ultimately responsible for implementing strategies to meet the revised standard, the control scenarios in this RIA are necessarily illustrative in nature. They are therefore subject to important uncertainties and limitations, which we document in the relevant portions of the analysis. EPA in some cases weighed the available empirical data to make a judgment regarding the projected attainment status of certain urban areas. The subsections below describe each of these elements in greater depth.

[1] See: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_cr_fr.html

1.2.1 Understanding the Role of the RIA in the Context of the Clean Air Act and Executive Order Requirements

In setting primary ambient air quality standards, EPA's responsibility under the law is to establish standards that protect public health. The Clean Air Act ("Act") requires EPA, for each criteria pollutant, to set a standard that protects public health with "an adequate margin of safety." As interpreted by the Agency and the courts, the Act requires EPA to base this decision on health considerations; economic factors cannot be considered

This prohibition against the consideration of cost in the setting of the primary air quality standard, however, does not mean that costs or other economic considerations are unimportant or should be ignored. The Agency believes that consideration of costs and benefits are essential to making efficient, cost-effective decisions for *implementation* of these standards. The impact of cost and efficiency are considered by the States during this process, when States are making decisions regarding what timelines, strategies, and policies make the most sense.

This RIA is intended to inform the public about the potential costs and benefits that may result when a new $PM_{2.5}$ standard is implemented, but it is not relevant to establishing the standards themselves. EPA presents this analysis pursuant to Executive Order 12866 and the guidelines of OMB Circular A-4.[2] These documents present guidelines for EPA to assess the benefits and costs of the selected regulatory approach as well as one less stringent, and one more stringent, option.

1.2.2 The RIA as an Illustrative Analysis

The analytical goals of this RIA are somewhat different from other EPA analyses of national rules, or the implementation plans States develop, and the distinctions are worth brief mention. This RIA does not assess the regulatory impact of an EPA-prescribed national or regional rule such as the Clean Air Interstate Rule. Nor does this RIA attempt to model the specific actions that each State will take to implement a revised standard. Rather, this analysis attempts to estimate the costs and human health and welfare benefits of a reasonable array of cost-effective State implementation strategies. These strategies represent EPA's best approximation as to one set of actions that States might consider cost-effective to attain a revised $PM_{2.5}$ NAAQS. Because States—and not EPA—would implement a revised NAAQS, they will ultimately determine the appropriate emissions control scenario. While EPA used the best available data currently available to develop its illustrative control strategies, State implementation plans would likely vary from EPA's estimates due to differences in the data and assumptions that States use to develop these plans.

In particular, there are inherent uncertainties in our projection of future emissions out to 2020 and our use of regional scale air quality modeling. For example, a number of uncertainties arise from the baseline data incorporated in the analysis (especially the mobile source inventory and the projection of future year emissions). The regional scale used for air quality modeling may understate the effectiveness of controls on local sources in urban areas as compared to area-wide or regional controls.

[2] For a copy of these requirements, see: http://www.whitehouse.gov/OMB/inforeg/eo12866.pdf and http://www.whitehouse.gov/omb/circulars/a004/a-4.html.

It is also worth noting that during the time span for implementation of the PM2.5 standards there are likely to be development and implementation of emerging technologies and innovative measures that could achieve additional pollution reductions not identified in this analysis, or could achieve emissions reductions at lower cost than measures included in this analysis. EPA's experiences with technology advances over the past 30 years, and the promise of numerous cleaner technologies emerging today, strongly suggest that technological innovation and "learning by doing" will continue to produce new, cleaner processes and performance improvements that reduce air pollution at reasonable cost. The Clean Air Act itself has spurred such advances, as innovative companies have responded to the challenges of the Act with great success, producing breakthroughs such as alternatives to ozone-depleting chemicals and new super-performing catalysts for automobile emissions, as well as improvements in control efficiency and cost for technologies such as scrubbers and SCR. The estimates in this RIA of the cost and feasibility of emissions reductions do not reflect technological advances that may occur between now and the analysis years of 2015 and 2020. In addition, stationary and area source control cost estimates in this RIA do not reflect the phenomenon, documented in the economic literature, that "learning by doing" over time tends to reduce the per-unit cost of producing a product, including pollution control technologies, and can lead to achieving better control efficiency as well. The issue of technology development is especially relevant for our estimates of costs in California and Salt Lake City, where current control technologies are not expected to be sufficient to achieve attainment, and where our cost estimates are based on extrapolations from the cost of current technologies.

Finally, EPA recognizes that data on ammonia emissions from animal operations are currently very uncertain, and are likely inadequate for making specific regulatory and/or control decisions for these emissions in some locations. EPA anticipates that the National Air Emissions Monitoring Study (NAEMS) for animal operations will provide a more scientific basis for estimating emissions, as well as defining the scope of air quality impacts, from these sources. As such, an appropriate strategy for estimating and regulating emissions from animal operations will be developed as a result of the NAEMS, and further guidance regarding the need for, and scope of, potential ammonia controls from these sources will also be developed at that time. As such, we emphasize the illustrative nature of the specific ammonia control measures applied in this RIA, and potential air quality impacts associated with changes in ammonia emissions, and remind the reader that this analysis is not intended to recommend any particular control strategy for specific areas. To the extent that States consider ammonia controls, EPA anticipates that they would consult the results of the NAEMS when determining appropriate control strategies for individual nonattainment areas as part of the State Implementation Plan process.

1.2.3 Illustrative Attainment Determinations

EPA constructed illustrative attainment scenarios understanding that certain emissions inventory, emission control, air quality modeling and monitoring uncertainties are likely to inhibit our ability to model full attainment in all areas. For example, there are certain instances in which the modeled air quality results might not agree with data at the air quality monitor.[3] In other cases, well-defined uncertainties limit the air quality model's performance in specific geographical areas. In these cases EPA weighed the available empirical data as part of an informed judgment regarding the projected attainment status of that area; later in this document we clearly designate where such judgments were applied in attainment/nonattainment determinations and include the relevant rationale. This approach is consistent with the analytical objectives of the RIA—to provide an illustrative attainment analysis of projected costs and benefits to the nation, and is also consistent with the use of models in SIP guidance.

1.2.4 Role of this RIA in Implementing the Current Standard

While this RIA is principally designed to illustrate the costs and monetized human health benefits of attaining the revised and alternative revised standards in 2020, it also includes an appendix summarizing the costs and benefits of attaining the current standard in 2015. This analysis will provide useful information for States to consider in identifying potential emissions reductions for meeting the current standard, and as such is included as a stand-alone document in Appendix A. Note that because this analysis was intended to compare costs and benefits of attaining alternative standards by fixed dates, it did not attempt to identify for each designated $PM_{2.5}$ area measures that may be needed to meet subpart 1 Clean Air Act requirements, such as reasonably available measures and attainment as expeditiously as practicable. It is expected that additional costs and benefits will begin to accrue in earlier years as states comply with these requirements.

1.3 Statement of Need for the Regulation

Two sections of the Clean Air Act govern the establishment and revision of NAAQS. Section 108 (42 U.S.C. 7408) directs the Administrator to identify pollutants which "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 . . . ."

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 one "the attainment and maintenance of which in the judgment of the Administrator, based on [the] criteria and allowing an adequate margin of safety, [are] requisite to protect the public health."[4] 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, [are] requisite to protect the public welfare from any

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[3] For example, the causes for such disagreement can be attributable to inconsistencies in the speciation profile used in developing the model-based design values, and the speciation profile at the nearest speciation monitor; this difference can significantly understate the effectiveness of certain control strategies that affect primarily one $PM_{2.5}$ species. A complete technical discussion can be found in chapter three.

[4] The legislative history of section 109 indicates that a primary standard is to be set at "the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population," and that for this purpose "reference should be made to a representative sample of persons comprising the group rather than to a single person in such a group." (S. Rep. No. 91-1196, 91st Cong., 2d Sess. 10 (1970)).

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 Act directs the Administrator to review existing criteria and standards at 5-year intervals. When warranted by such review, the Administrator is to revise NAAQS. After promulgation or revision of the NAAQS, the standards are implemented by the States.

From an economic perspective, market failures arising from an "externality" represent one such reason for government intervention. An externality occurs when one party's actions impose uncompensated benefits or costs on another party. For example, the emissions from a factory may adversely affect the health of the surrounding pollution and result in soiling the property in local neighborhoods.

1.4 Changes in the Analysis and Methods between the Interim and Final RIA

This final RIA reflects four key changes in analytical scope and methodology from the interim RIA. First, we have incorporated new data into our emissions inventories. Second, this RIA broadens the geographic scope from the 5-city analysis of the interim RIA to the entire nation. Third, we have augmented our analysis of control strategies with updated information that facilitates the selection of least-cost controls. Finally, we have updated the uncertainty characterization of our benefits results using a recently completed expert elicitation study. We discuss details of each improvement in further chapters of this RIA.

1.4.1 Emissions Inventory Data

An "emissions inventory platform" is composed of the collection of emissions data and emissions processing assumptions used to create inputs to the air quality models. The emissions inventory platform used for this RIA is a modified version of the emissions inventory EPA used in the Clean Air Interstate Rule (CAIR) RIA released in March, 2005.[5] Since the development of the CAIR platform used for the Final CAIR in 2005, EPA updated the platform to improve the technical basis for the modeling work done for this RIA. We summarize these revisions here; Section 2.3 describes these updates in detail.

<u>Changes to the Baseline Emissions Inventory</u>

The inventory revisions (since CAIR) apply to both the baseline and projected inventories; we revised the 2001 base emissions, which we used to project non-EGU emissions to the 2015 and 2020 baseline years modeled. We changed the baseline inventory to incorporate new information not previously available and included revisions to PM emission factors from natural gas combustion, facility-specific inventory revisions, inclusion of newly available year-2000

[5] The documentation for this inventory is available at the EPA docket (number EPA-HQ-OAR-2003-0053-2047) and on the web at http://www.epa.gov/air/interstateairquality/pdfs/finaltech01.pdf.

Canadian inventory data, revised residential wood combustion emissions, and other more minor changes.[6]

Changes to the Projected Emissions Inventory

We also revised future baseline emissions for 2015 and 2020 for this RIA, for both the power sector and other sectors based upon more recent information. For example, several new consent decrees and pollution controls were included on a limited set of power sector sources in the post-CAIR modeling runs of the Integrated Planning Model (IPM).[7] These changes to IPM were small on a national scale, but important at a local scale in certain projected nonattainment areas. Details of these updates are provided in Section 2.3.

As compare to the data used for CAIR, the updates to all sectors resulted in a nationwide decrease of projected baseline emissions of NO_X by approximately 8,300 tons/yr and SO_2 by approximately 18,400 tons/yr with increases in $PM_{2.5}$ of ~5,900 tons/yr for all sources of emissions in 2020. In addition, we increased the reduction achieved for $PM_{2.5}$ emissions of the Heavy Duty Diesel rule for on-road mobile emissions based on corrected modeling input data; the emissions we used are 6% less in 2015 for all on-road mobile and 11% less in 2020 than the $PM_{2.5}$ on-road emissions used during CAIR. We changed our approach for future-year projection of non-EGU stationary sources by adjusting our assumption that emissions growth has a linear relationship with economic growth. For the stationary non-EGU parts of the inventory nationally, this change reduced 2020 emissions of VOC by 26%, NO_X by 23%, CO by 26%, SO_2 by 18%, NH_3 by 23%, and $PM_{2.5}$ by 28%.

Due to the significance of this emissions inventory forecasting assumption, EPA consulted with the Advisory Council on Clean Air Compliance Analysis and the Air Quality Modeling Subcommittee (Council) of the Science Advisory Board (SAB) on August 31, 2006 by public teleconference. In the consultation, EPA requested advice as to proper characterization of the interim emissions forecasting approach and the uncertainties involved. The review of this methodological assumption was completed on an expedited basis by the Council. On September 15, 2006, the Council members issued a letter to the EPA Administrator Stephen L. Johnson reporting their findings. In this letter, the Council recommended an alternative forecasting methodology for the stationary non-EGU source categories as preferred to the method used in this RIA. The Council members suggested the alternative would capture "the underlying technological change that is likely driving the historical decline in emissions, i.e., the efficiency gains in production processes and improvements in air pollution control technologies that can be expected over time." Specifically, the Council suggested using the National Emission Inventory in the 1990s to establish a declining emissions intensity as it relates to changes in the output by sector. As a default, the Council recommended assuming this historical rate of decline would continue to be constant in future years. In the letter to Administrator Johnson, the Council members did recognize that the time constraints involved with the PM NAAQS review and the limitations that might result in the EPA's ability to accomplish their recommendations.

[6] Chapter two discusses each of these changes in depth.
[7] A further discussion of the Integrated Planning Model may be found in chapter 2.

In response to the Council's recommendations, the EPA did endeavor to conduct a limited analysis using the Council's recommended approach for three important non-EGU stationary source sectors including Pulp and Paper Manufacturing, Petroleum Refining, and Chemicals and Allied Products for SO_2 emissions only. The court-ordered schedule for the PM NAAQS review did not allow for further investigation of this method for all non-EGU stationary source categories or relevant pollutants. We found that the Council's suggested approach resulted in essentially a downward trend in future year SO_2 emissions for these source categories implying negative emissions growth in the future for these source categories. Using an approach similar to the Counsel's suggested approach, future-year emissions would decline significantly from 2002 to 2020 for these industries. This result occurs because historical emissions reductions used in this analysis could not be directly attributed to Clean Air Act mandated controls and therefore the entire declining SO_2 emission trend for these three sectors was assumed to continue into the future. We recognize the limitations of this analysis since some historical emission reductions may have been due to Clean Air Act mandated controls (e.g., SIPs, NSPS) that are applied to individual facilities (rather than mandated controls that would be applicable to the entire sector), but given the limited time and quality of the control information in the emission inventory an accurate attribution of these historical emission reductions to the Clean Air Act was not possible. The EPA recognizes the need to find an improved growth forecasting methodology for the stationary non-EGU sectors and is committed to developing the necessary methods and models to achieve this goal in the near future. More information on this issue and copies of the background paper presented to the Council members are included in Appendix E of this document.

Additionally, Table 1-1 provides the impact of this change separately for non-EGU point and stationary area source of this change. The table shows that for these sectors, the emissions used for the RIA are significantly lower (14 –34%) than they would have been had emissions growth been assumed to track economic growth. The basis for this change is described in more detail at the end of Section 2.3.3. As further supporting material, Appendix D describes the impact of this changed assumption on air quality modeling results. Appendix D also explores the impact on future emissions for these sectors of an alternative approach for projecting emissions trends.

Table 1-1: National impact of changed growth assumption for nonEGU point and stationary area source emissions

		VOC	*NO_X*	*CO*	*SO_2*	*NH3*	*PMC*	*$PM_{2.5}$*
NonEGU Point	2020 RIA	1,276,263	2,659,652	3,907,508	2,623,357	78,784	197,462	574,820
	2020 with growth	1,936,662	3,537,339	5,475,138	3,244,133	106,607	296,438	841,942
	% Diff	34.10%	24.80%	28.60%	19.10%	26.10%	33.40%	31.70%
Stationary Area	2020 RIA	7,145,451	1,466,029	3,974,421	1,295,305	149,581	123,719	703,277
	2020 with growth	9,369,403	1,814,842	5,220,186	1,517,562	190,005	152,590	926,242
	% Diff	23.70%	19.20%	23.90%	14.60%	21.30%	18.90%	24.10%

Based on newly-collected data, we also improved projection approaches for pulp and paper facilities, refineries, and cement manufacturing by including the latest information about plant closures, consent decrees, and other planned emissions reductions. We made a number of other changes to our control approaches, assumptions about splitting $PM_{2.5}$ emissions into organic carbon, elemental carbon, and crustal material, and temporal allocation of annual emissions to months.

Impacts of Emission Inventory Changes

The impact of the revised base-year and future-year assumptions as compared to the CAIR platform for emissions in the continental U.S. is shown in Table 1-2. The table shows total and sector-specific changes in both 2001 and 2020 emissions estimates across the emissions platforms. The largest changes in the 2001 estimates are for VOC (4.6% increase) and $PM_{2.5}$ emissions (2.2% decrease). The 2020 emissions have significant changes for all pollutants shown: NO_X (10.5% decrease), SO_2 (14% decrease), VOC (4.9% decrease), $PM_{2.5}$ (19.9% increase), and NH_3 (7.3% decrease). These changes are also shown for NO_X, SO_2, VOC and $PM_{2.5}$ as charts in Figure 1-1.

Table 1-2: Comparison of CAIR and PM NAAQS Emissions in 1000 tons/yr for Key Criteria Pollutants[a]

	Year	*Platform*	*EGU Point*	*Non-EGU Point*	*Stationary Nonpoint*	*Nonroad Mobile*	*On-Road Mobile*	*Total*
NO_X	2001	CAIR	4,937	2,943	1,701	4,051	8,064	21,696
		PM NAAQS	4,936	2,946	1,712	4,057	8,064	21,715
		% Change	0.0%	0.1%	0.6%	0.1%	0.0%	0.1%
	2020	CAIR	2,187	3,457	2,040	2,672	2,438	12,794
		PM NAAQS	1,980	2,662	1,705	2,672	2,432	11,451
		% Change	–9.5%	–23.0%	–16.4%	0.0%	–0.2%	–10.5%
SO_2	2001	CAIR	10,901	2,959	1,344	433	271	15,908
		PM NAAQS	10,849	2,873	1,345	435	271	15,773
		% Change	–0.5%	–2.9%	0.1%	0.3%	0.0%	–0.9%
	2020	CAIR	4,387	3,674	1,565	281	34	9,941
		PM NAAQS	4,259	2,629	1,344	281	34	8,547
		% Change	–2.9%	–28.4%	–14.1%	0.0%	–0.3%	–14.0%
VOC	2001	CAIR	53	1,537	7,981	2,585	4,710	16,865
		PM NAAQS	53	1,538	8,746	2,586	4,710	17,633
		% Change	0.0%	0.0%	9.6%	0.1%	0.0%	4.6%
	2020	CAIR	46	1,745	7,963	1,530	1,768	13,051
		PM NAAQS	45	1,276	7,799	1,530	1,764	12,414
		% Change	–1.5%	–26.9%	–2.1%	0.0%	–0.3%	–4.9%
$PM_{2.5}$	2001	CAIR	599	705	3,480	308	161	5,253
		PM NAAQS	568	607	3,491	308	161	5,136
		% Change	–5.2%	–13.9%	0.3%	0.1%	0.0%	–2.2%
	2020	CAIR	523	934	3,460	193	66	5,176
		PM NAAQS	533	585	4,835	193	61	6,206
		% Change	1.8%	–37.3%	39.7%	0.0%	–7.5%	19.9%
NH_3	2001	CAIR	8	83	3,320	2	277	3,690
		PM NAAQS	8	80	3,330	2	277	3,697
		% Change	0.0%	–3.4%	0.3%	0.0%	0.0%	0.2%
	2020	CAIR	1	112	3,596	2	418	4,129
		PM NAAQS	1	79	3,328	2	417	3,827
		% Change	–1.9%	–29.6%	–7.5%	0.0%	–0.2%	–7.3%

[a] Estimates in this table are 2001 and 2020 baseline emission estimates.

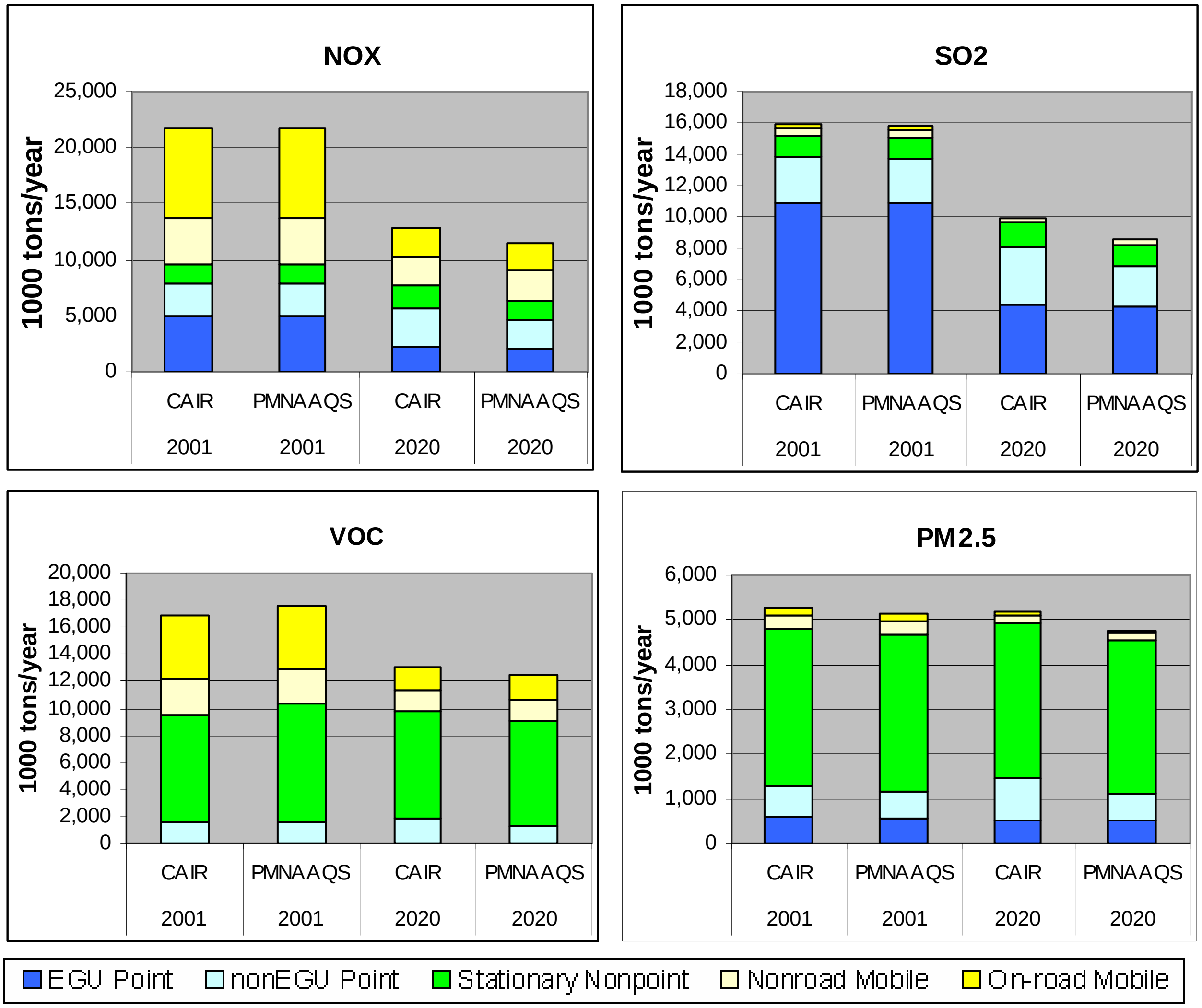

Figure 1-1: Comparison of NO_X, SO_2, VOC, and $PM_{2.5}$ Emissions between CAIR and PM NAAQS Platforms[a]

[a] Estimates in this table are 2001 and 2020 baseline emission estimates that do not reflect our illustrative control strategies.

1.4.2 Air Quality Modeling

This section summarizes the important differences and advances in the air quality modeling of the PM NAAQS Final RIA from the interim RIA, including the technical detail associated with these analyses and technical support documents.

Overview of Interim RIA Air Quality Modeling Approach

For the PM NAAQS Interim RIA, we used a Response Surface Model (RSM)[8] tool to estimate the air quality changes associated with various pollution control strategies. The RSM is a "model of the model" that can provide instantaneous estimates of air quality changes associated with changes in emissions from various source sectors with little bias or error relative to national-scale CMAQ modeling; this quick analysis allows users to quickly evaluate various control scenarios. The interim RIA applied this approach to consider control strategies in five selected urban areas. EPA intended to perform national air quality modeling to estimate national cost and benefit estimates of illustrative control strategies, but determined that the available datasets and tools were inadequate to complete such an analysis within the available timeframe. Most significantly, we concluded that the national-scale analysis based on then-current data and tools would not properly reflect the incremental costs and benefits of moving from the current standards to progressively more health-protective standards.[9]

Improvements to Our Air Quality Modeling Approach

For the PM NAAQS Final Rule RIA, we used the RSM as it was originally designed: as a screening tool to investigate cost-effective sector-based control scenarios. We then analyzed these strategies using EPA's Community Multi-Scale Air Quality (CMAQ) Modeling System, which is a national-scale photochemical grid model. These refinements to our air quality modeling approach enabled us to simulate the national air quality changes that occur as a result of our illustrative attainment scenarios. This air quality information, in turn, allows us to provide national-level estimates of the costs and benefits of the nation's ability to attain the proposed revised standard and alternative revised standards.

This final analysis also extends the local-scale dispersion modeling of the interim approach by including additional urban areas. We use local-scale air quality modeling (AERMOD) to (1) examine the spatial variability of direct $PM_{2.5}$ concentrations associated with emissions of primary $PM_{2.5}$ within each urban area, and (2) to quantify the impact of specific emissions source groups on ambient $PM_{2.5}$ concentrations at Federal Reference Method (FRM) monitoring sites. We focused this assessment on five urban areas: Birmingham, Seattle, Detroit, Chicago and Pittsburgh; these latter two urban areas are new for the final RIA. We selected these areas because they provide a mixture of emissions sources, meteorology, and associated $PM_{2.5}$ air quality issues. Because each of the chosen areas are representative of a wide array of conditions that arise across the country in other urban areas, we are able to apply insights learned from the narrow, city-specific analyses to a broader set of areas and circumstances nationally. In this RIA we also model the local-scale impacts of $PM_{2.5}$ controls on selected sources in these urban areas. This analysis complements the CMAQ-based regional-scale modeling analyses through its ability to estimate concentrations at a higher spatial resolution and an estimate of the impact of local sources of primary $PM_{2.5.}$

[8] For additional information regarding the development and application of the RSM, see the Response Surface Modeling Technical Support Document (TSD) for the PM NAAQS Proposal, February 2006, found in the docket.
[9] Some commenters used these city-specific estimates to derive national estimates, which significantly overstate the costs by 1 to 2 orders of magnitude.

1.4.3 Emission Control Data

In this RIA we both modified our process from the interim RIA for selecting cost-effective controls and augmented our emission control information. To select cost-effective emission controls, we extended a method used for the interim RIA that incorporates urban-area specific air quality modeling data into the controls selection decision. For each projected nonattainment area, we used information from the RSM regarding the estimated total reduction in daily and annual $PM_{2.5}$ design values yielded by a given ton of directly-emitted $PM_{2.5}$ and $PM_{2.5}$ precursor (NO_X, SO_2 and NH_3) abated at the nonattaining monitor. We then combined these estimates of air quality impact per ton with estimates of cost per ton for each precursor to derive an estimate of cost per microgram abated. We then ranked controls by cost per microgram to identify the most cost-effective controls for achieving the annual and daily standards. This method allowed us to select those emission controls for each projected nonattainment area that the air quality model estimated to have the greatest air quality impact per ton of precursor reduced. It also allowed us to approximate the amount of controls that would be required to reach attainment in each area. We also constrained our selection of controls with cost per ton caps (ranging from $20,000/ton to $350,000/ton) for each precursor in the projected nonattainment areas to ensure that we did not select controls with an excessively high cost per ton.

Next, we conducted a comprehensive review of the control strategies applied for the interim RIA, the results of which indicated a very high annualized cost per ton estimate (some with costs of more than $1 million/ton of emission reduction). As a result, EPA determined that better information was required regarding: the applicability of certain controls to some sources; the types of emission controls already in place at some sources; new and innovative control measures; and, the credibility of control measures currently in our emission controls database. Based on these results, EPA sought to improve its characterization of control measures in three ways. First, emissions inventory experts and others within EPA researched and identified those control measures that sources in projected nonattainment had either already implemented or were planning to adopt. This effort is described in more detail in Chapter 3 of this RIA.

Second, EPA reviewed and adjusted the applicability of PM control measures to point sources within its emission controls database. Our review, conducted by EPA regulatory project leads and sector experts, led in many cases to improvements in our data; for example, we refined the links that match known control techniques to key source categories. Another recommendation from this review led to the establishment of a ton-per-year threshold for small-emitting sources: our analysis no longer places controls on any sources that emit less than 5 tons per year, because it was determined that these sources were likely to have existing controls in place, and further control was typically not cost-effective and inefficient in reducing area-wide concentrations of PM. Furthermore, our review of mobile source emissions led to a thorough re-analysis of potential mobile source control strategies for use in our attainment scenarios.

Third, EPA reviewed the control measures in our controls database to determine if they were consistent with control measure data collected by Regional Planning Organizations (RPOs), organizations such as the State and Territorial Air Pollution Program Officers and the Association of Local Air Pollution Control Officers (STAPPA/ALAPCO), States such as California (reports prepared by the California Air Resources Board, or CARB) or local agencies such as the South Coast Air Quality Management District (SCAQMD). Our review of the other control measure data sets utilized by these organizations concluded that nearly all of the remaining data was either (a) already incorporated into our controls database, or (b) not sufficiently robust to warrant inclusion in the software tool.

Finally, while our review suggested that our database was mainly complete, EPA identified two additional control measures for various pollutants and source categories for which no measures had been previously available. One of these pollutant and source category combinations is SO_2 emissions from area sources, for which we added a new measure to control SO_2 emissions from home heating oil use based on data from the Clean Air Association of Northeastern States (NESCAUM) study completed in December 2005.[10] We also added a control measure that is intended to reduce area source $PM_{2.5}$ emissions from commercial cooking facilities (mostly restaurants) in response to this review.

The results of this review are available in Appendix I of this RIA. The analyses done for non-EGU sources and included in this final RIA reflect the incorporation of the changes that were recommended.

1.4.4 Benefits Uncertainty Characterization

In response to the recommendations of the National Research Council report on Estimating the Public Health Benefits of Proposed Air Pollution Regulations[11], the benefits assessment in this RIA includes the results of an expert elicitation to characterize uncertainty in the effect estimates used to estimate premature mortality resulting from exposures to PM. The goal of this expert elicitation was to evaluate uncertainty in the underlying causal relationship, the form of the mortality impact function (e.g., likelihood of a threshold, likelihood of a linear function at lower ambient concentration) and the fit of a specific model to the data (e.g., confidence bounds for specific percentiles of the mortality effect estimates). The expert elicitation also addresses issues such as the ability of long-term cohort studies to capture premature mortality resulting from short-term peak PM exposures. To provide a more robust characterization of the uncertainty in the premature mortality function than has been presented in prior RIA's, the analysis for the PM NAAQS was based on EPA's recently completed the full-scale expert elicitation. This elicitation incorporated peer-review comments on the pilot-scale study, which was used in the CAIR RIA.

Chapter 5 of this RIA includes benefits estimates based on the results of the full-scale study, which consist of twelve individual distributions for the coefficient or slope of the C-R function relating changes in annual average $PM_{2.5}$ exposures to annual, adult all-cause mortality. EPA has not combined the individual distributions in order to preserve the breadth and diversity of opinion on the expert panel. In applying these results in a benefits analysis context, EPA incorporated information about each expert's judgments concerning the shape of the C-R function (including the potential for a population threshold $PM_{2.5}$ concentration below which there is no effect on mortality), the distribution of the slope of the C-R function, and the likelihood that the $PM_{2.5}$-mortality relationship is or is not causal (unless the expert incorporated

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[10] NESCAUM. Low Sulfur Heating Oil in the Northeast States: An Overview of Benefits, Costs, and Implementation Issues. December 2005. Found on the Internet at http://www.nescaum.org/documents/report060101heatingoil.pdf.

[11] National Research Council (NRC). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

this last element directly in his slope distribution—see Industrial Economics, 2006). Chapter 5 includes estimates of benefits using mortality impact functions derived both from the epidemiology literature and the expert elicitation.

1.5 $PM_{2.5}$ Standard Alternatives Considered

This RIA analyzes the costs and human health and welfare benefits associated with attaining both the selected and one alternative standard; these are expressed in Table 1-3 below as combinations of the annual and daily standard:

Table 1-3: Annual and Daily $PM_{2.5}$ NAAQS Under Consideration

Combination of Annual and Daily Values, in µg/m^3	*Notes*
15/65	1997 Standards
15/35	Revised Standards
14/35	Alternative

1.6 Baseline and Pathways to Attainment

1.6.1 Selected Baseline Years

In the RIA, we have chosen 2015 and 2020 as the base years for analysis, which roughly approximate the maximum time period (10 years from designation) under the Clean Air Act for attainment of a NAAQS. Under the Act, States are required to develop plans to attain the standards "as expeditiously as practicable" based on reasonably available measures. In addition, States must attain the standards within five years unless EPA determines that an attainment date extension of an additional one to five years is appropriate, based on the severity of the nonattainment problem and the availability of control measures. For example, current $PM_{2.5}$ area designations became effective in 2005. An area receiving the full five year extension would have an attainment date of 2015 (with attainment based on air quality data for 2012-2014).

For analytical simplicity, we have chosen 2015 as our base year of analysis for attainment with the 1997 $PM_{2.5}$ standards (15 µg/m^3 annual, 65 µg/m^3 daily). Although the date of any new designations is uncertain, for the purpose of this analysis we are assuming that new designations would be effective in 2010 and we have chosen 2020 as the year in which to simulate attainment with the revised and alternative revised standards.

From now through 2020, a suite of regionally and nationally-implemented rules already in effect will lead to large emission reductions. These rules include: the Clean Air Interstate Rule (CAIR), the Clean Air Visibility Rule (CAVR) and the Clean Air Mercury Rule (CAMR), the Clean Air Non-Road Diesel Rule, the Heavy Duty Diesel Engines Rule, and the Light-Duty Vehicle Tier 2 vehicle and gasoline standards. These rules—as well as an array of state rules already in place—will produce substantial nation-wide reductions in SO_2, NO_X and directly emitted $PM_{2.5}$, thereby facilitating State attainment of the revised $PM_{2.5}$ NAAQS.

1.6.2 *Attainment Pathways*

Figures 1-2 and 1-3 below illustrate how a State might factor in the presence of the emission reductions associated with these national, regional and state rules when designing its "attainment pathway"—that is, the sequence and magnitude of emissions reductions necessary to meet the current or revised standards. These figures also describe the positive relationship that reductions in the annual design value have on the daily design value.

Figure 1-2 below illustrates a plausible attainment pathway that meets only the current $PM_{2.5}$ NAAQS. This pathway assumes that States will design control strategies that just meet the annual standard, which is controlling in most areas, by 2015; this point is identified on the figure as #1. Most states will have already met the existing daily standard of 65 $\mu g/m^3$ by 2015, as reflected by #3. Between 2015 and 2020, the analysis assumes that States may achieve levels cleaner than the annual standard as regional emissions reductions from the national rules continue to lower total emissions and thus reduce the annual and daily design value further below the standards by a small amount.

The attainment pathway for the revised and alternative revised NAAQS of 15/35 or 14/35 may be "steeper." The analysis assumes that States may achieve levels cleaner than the existing annual or daily standards in 2015 to make progress toward attainment of the revised and more stringent alternative standard in 2020. Figure 1-3 illustrates these more ambitious attainment pathways.

To attain the revised standard of 15/35, States must first attain the current annual standard of 15 $\mu g/m^3$ in 2015 to comply with the statutory deadline (#1). At that time, States may also elect to apply controls to ease attainment of 35 $\mu g/m^3$ in 2020; this establishes an attainment pathway to 15/35 that is identified by #3. As in Figure 1-2 of the previous example, between 2015 and 2020, the suite of national rules will produce additional emission reductions which are likely to reduce the annual design value below the standard, as identified by #2. Finally, between 2015 and 2020 States may implement additional local controls that target the daily standard and attain 35 $\mu g/m^3$ by 2020, as identified by #4.

The attainment pathway for the 14/35 alternative resembles that for 15/35, but accounts for the early progress States might seek to achieve in 2015 toward meeting the 14 $\mu g/m^3$ standard. The analysis assumes States may achieve levels cleaner than the existing 15 $\mu g/m^3$ annual standard between 2015 and 2020 to facilitate their attainment of the 14/35 $\mu g/m^3$ annual standard in 2020, as seen in point #1.[12] Progress toward the tighter 14 $\mu g/m^3$ annual standard in 2015 would also produce improvements in the daily design value beyond those seen for the 15/35 attainment scenario, as identified by point #3.

[12] The control strategy to simulate attainment with the 14/35 alternative includes an illustrative extension to the CAIR program to be implemented between 2015 and 2020. This program would create incentives for banking and trading of SO_2 allowances in 2015, which would produce the air quality improvements observed in the blue line below #1 of Figure 1-3. For further discussion of our control scenarios and this EGU cap, see Chapter 3.

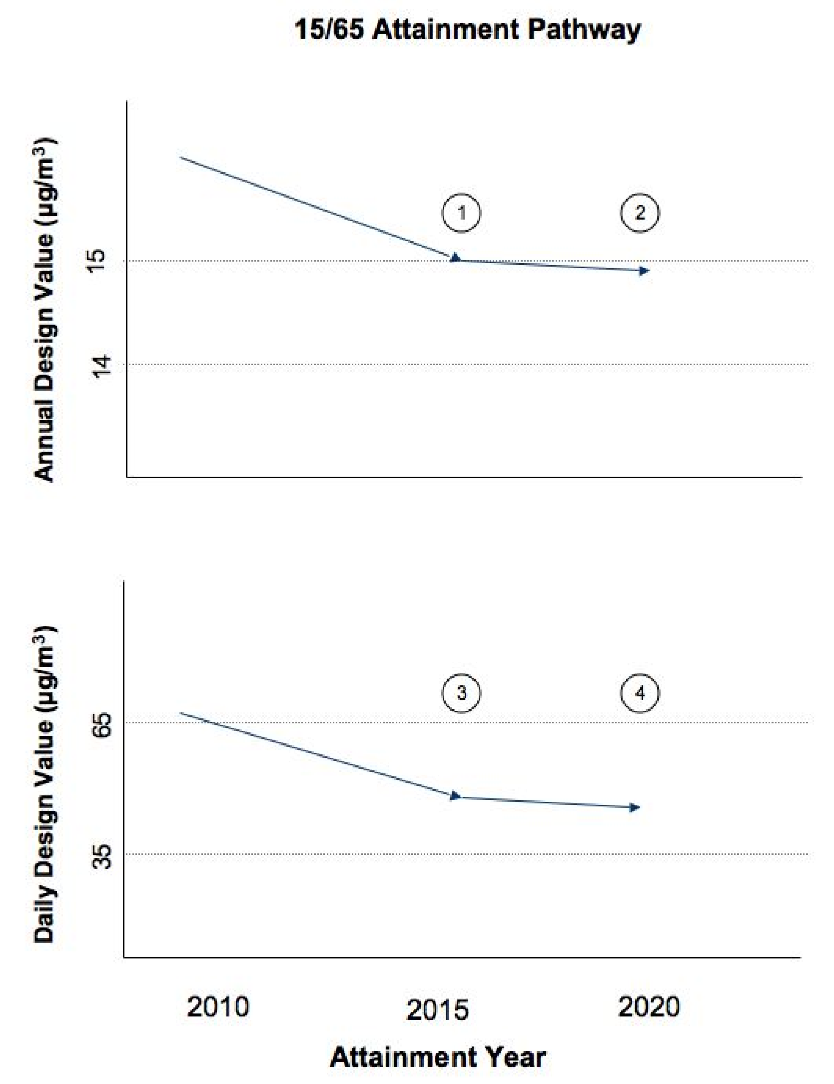

Figure 1-2. Illustrative Attainment Pathway for 1997 Standards

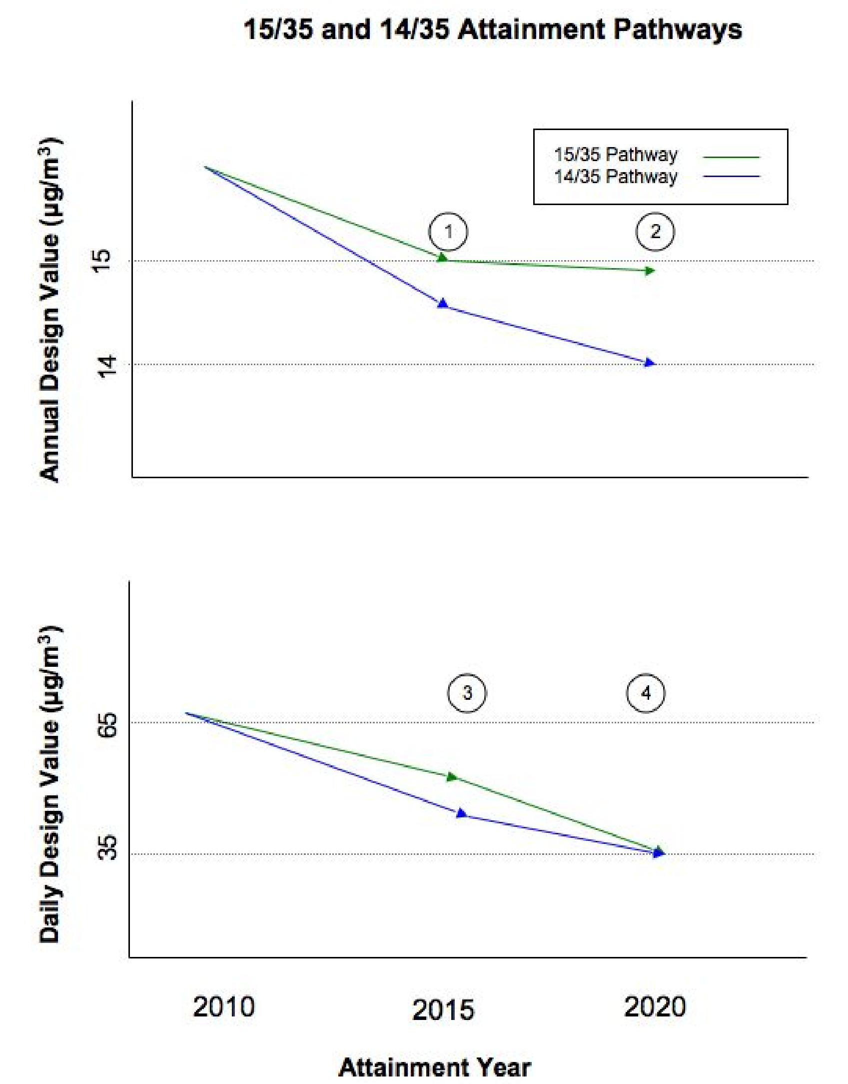

Figure 1-3. Illustrative Attainment Pathway for Revised and Alternative Standards

1.7 Control Scenarios Considered in this RIA

In developing control scenarios, EPA accounted for the level of emissions reductions that regional and national-scale rules would generate in each area. Based on this information, EPA developed a "control hierarchy" that expanded in geographic scope and breadth of sources as we simulated attainment with increasingly stringent standard alternatives.

1.7.1 Emissions Reductions Associated with National Rules Taking Effect by 2015 and 2020

Figure 1-4 below illustrates the historical downward trend in NO_x and SO_2 emissions due to the implementation of key national programs such as the Acid Rain program, the Clean Air Nonroad Diesel rule, the PM2.5 implementation rule, the Clean Air Interstate Rule and the Regional Haze rule.

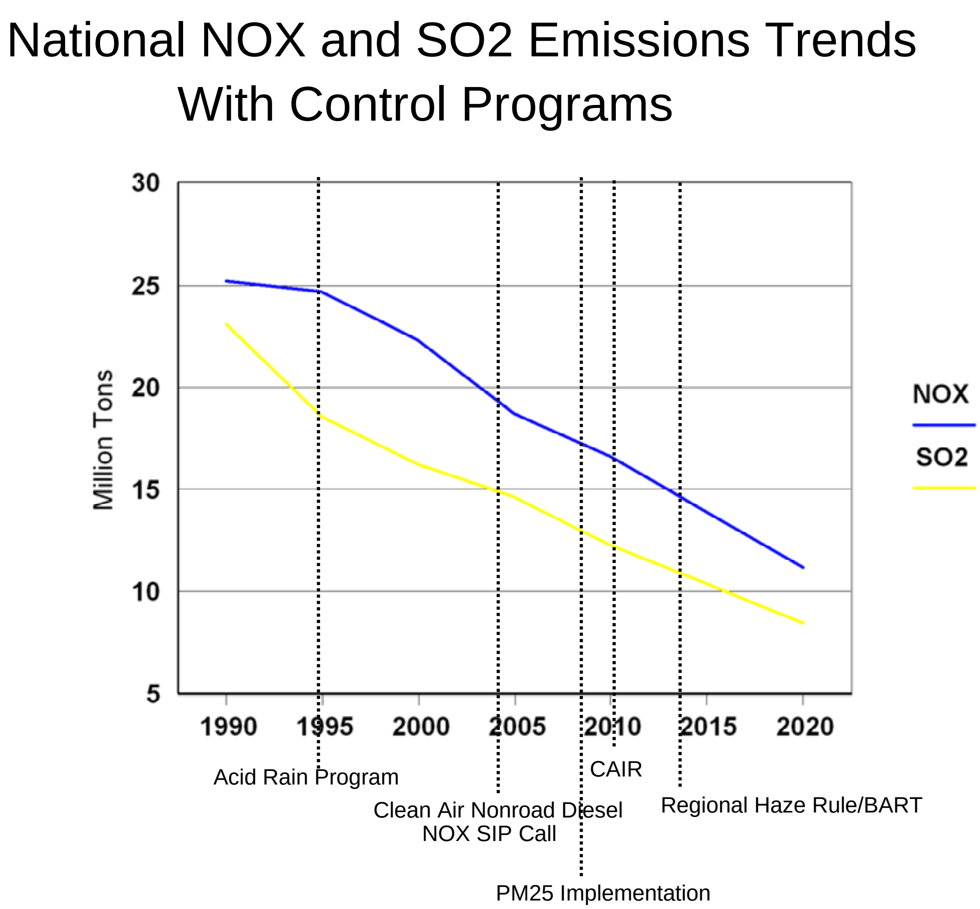

Figure 1-4. Regional and National NO_X and SO_2 Emissions Trends with Control Programs

1.7.2 Control Hierarchy

In examining alternative controls to meet the 1997 standards and the revised and alternative more stringent revised standards, our analyses selected emission controls according to a hierarchy of control strategies. This hierarchy increased the geographical breadth and stringency of controls as we analyzed successively more stringent NAAQS alternatives. Figure 1-5 below illustrates the relationship between the standard alternative and the geographical breadth.

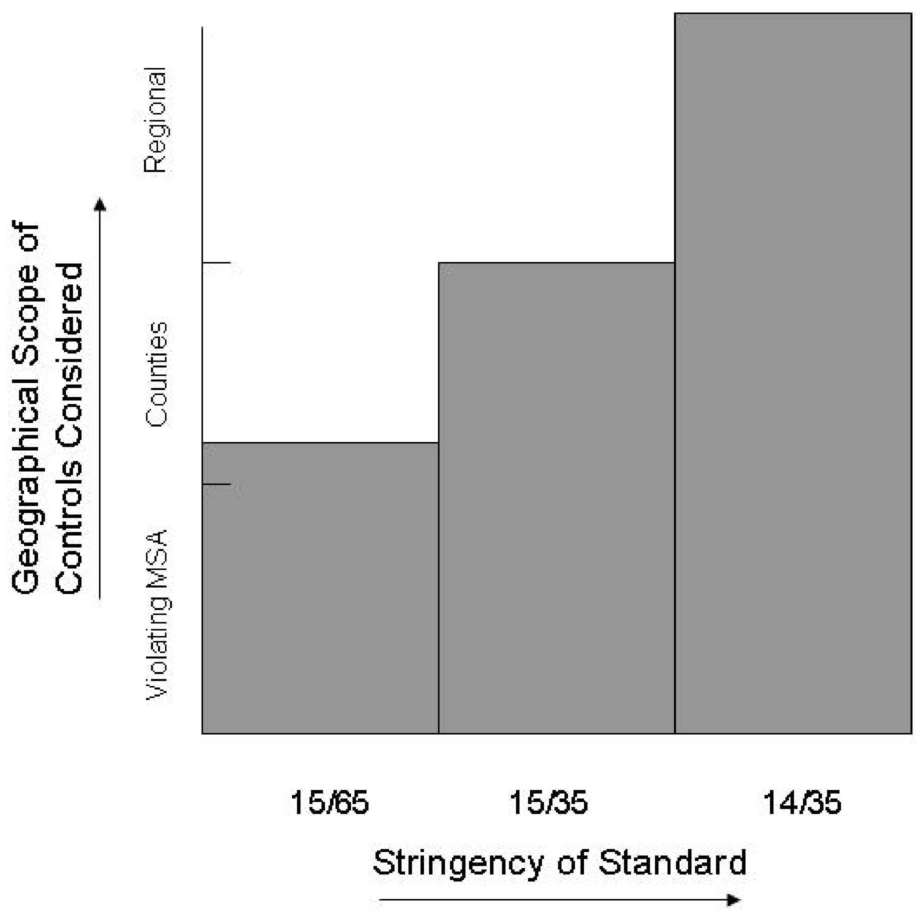

Figure 1-5. Relationship between the Stringency of the Standard and the Geographical Scope of Emission Controls Considered

This figure is an abstraction that is intended to show how we increased the geographical breadth of the control measures as we attempted to simulate attainment with more stringent standards. In general, controls selected to simulate attainment with the existing 15/65 standards were focused in counties within the Metropolitan Statistical Area (MSA) in which a nonattaining monitor was located. In a limited number of locations, controls were extended into counties surrounding these MSA's when sufficient controls were not available within the MSA. In selecting controls to meet the revised 15/35 suite of standards, controls were selected both within the MSA and in surrounding counties expected to contribute to the nonattaining monitor. We selected controls that are local known technologies in use today. If local known controls in the MSA and surrounding area are not enough to bring the area into attainment, then we considered developmental emission controls, which are new and developing control measures that have limited application in 2006, but are likely to be used more widely by 2020. Finally, in selecting controls to meet the alternative more stringent annual standard, a set of regional controls on SO_2 emission sources were considered in addition to controls in the MSAs and surrounding counties. In some areas, it was difficult to model full attainment with the regulatory options. To the extent that we did not simulate full attainment by using known and developmental controls, we applied supplemental carbonaceous particle controls to the modeled air quality results. If we were not able to simulate attainment using these controls, we made a final determination of attainment by weighing the empirical monitoring, modeling and emissions data. Finally, for California and Salt Lake City, due to the magnitude of the projected non-attainment problem, we extrapolated the cost of reaching full attainment. The combination of modeled (local known and developmental controls), supplemental, and extrapolated data form our attainment analysis.

1.7.3 Designation Process

EPA projects certain counties to violate the revised standards in 2020, and our control strategy methodology selects emissions controls both in those violating counties, and in surrounding counties that were identified as being likely to contribute to the violation in the nonattaining county. While this process is intended to provide an illustration of how attainment might be achieved in the nonattainment county using emission reductions in surrounding counties, this is not intended to suggest that these counties would or would not be part of EPA's official designated nonattainment areas.

The process for designating nonattainment areas for the revised PM NAAQS is defined within the Clean Air Act (42 U.S.C. §7407 (d)). EPA plans to complete final designations for areas violating the 24-hour PM2.5 standard by April 2010. The designation process is complex and incorporates information from the States and EPA on a wide range of factors, both for areas with violations and for nearby areas that are potentially contributing to such violations.

In past guidance, EPA has stated that it would use the metropolitan area as the presumptive definition of the source area that contributes to an area's PM2.5 nonattainment problem (Holmstead, 2003; Wegman, 2004). However, these presumptive boundaries can be modified based on a number of factors, including air quality, pollutant emissions, population density and the degree of urbanization, traffic and commuting patterns, growth, meteorology, geography/topography, jurisdictional boundaries (including boundaries of previously designated nonattainment areas), and level of control of emission sources. For each area with a violating monitor, the Governor provides to EPA its recommended nonattainment area boundary and related supporting information. The EPA Administrator takes these recommendations into consideration in designating final nonattainment area boundaries.

1.7.4 Summary of Controls Considered for the Current NAAQS and Each Standard Alternative

This analysis considers an array of stationary and mobile source emission controls to simulate attainment with the revised and more stringent alternative standards. To attain the revised standards in the East, our control strategy consisted primarily of controls on directly emitted carbonaceous particles on point and area sources; to achieve these standards in the West, we applied both carbonaceous particle and nitrous oxide controls on stationary sources. The attainment strategy in the East for the alternative more stringent standards included additional SO_2 emission controls on both Electrical Generating Units in the CAIR region and non-EGU SO_2-emitting stationary sources in a multi-state region within the mid-west. Additional information regarding the composition of our control strategy can be found in Chapter 3.

1.7.5 Full Attainment Scenario for California

California poses a unique $PM_{2.5}$ nonattainment challenge in this RIA due both to the magnitude of their existing and projected air quality problem for the revised and more stringent alternative standards, as well as to a number of California-specific limitations in our data and tools. Our analysis suggests that many areas of California are projected to exceed the revised and more stringent alternative standards in 2015 and 2020 by a substantial margin, even after the application of all known cost-effective controls. There are four factors that inhibit our ability to simulate attainment, or near attainment, in California:

1. The magnitude of projected non-attainment is larger than any other state, making the task of simulating attainment much more challenging than elsewhere in the nation.
2. We exhausted our emission controls database, which prevented us from controlling all emission sources that contribute to nonattainment.[13]
3. Key uncertainties exist with regard to both emissions inventories and air quality modeling in the West, which may understate the effectiveness of certain controls.
4. The relatively broad spatial resolution of our air quality modeling (36 km) means that emission reductions from local sources are not accurately "captured" by the relevant nonattaining monitors, resulting in possible understatements of local control efficiencies.[14]

Consequently, providing a credible attainment pathway for California that includes the estimated costs of full attainment entails a specialized treatment in this RIA. While in this analysis we cannot demonstrate full attainment with known controls, in the following chapters we provide information that suggests that there are pathways California can follow to attain the current and alternative NAAQS; we also provide a bounding estimate of attainment cost for each alternative NAAQS. Specifically, we:

1. *Document the uncertainties and limitations of the emissions inventories and CMAQ air quality model in California.* We describe the modeling and emissions uncertainties in California and provide a qualitative characterization of the magnitude that these uncertainties may have on our ability to simulate attainment.
2. *Estimate the costs of achieving the nonattainment increment that is residual after the application of all cost-effective controls*. To derive the cost of achieving this air

[13] That is to say that there were more emissions of $PM_{2.5}$ precursors than there were control measures available to abate these emissions.
[14] For further discussion of the CMAQ air quality model grid scale and its implications for our controls analysis, see chapter four.

quality increment, we use information regarding the cost of achieving the modeled attainment increment. We document the limitations of this analysis and, because of the high level of uncertainty associated with these cost estimates, present them apart from the estimates for the remainder of the nation.

3. *Characterize the effect that California's emission reduction programs may have on future attainment*. For example, the State has recently developed ambitious emission reduction programs for goods movement that have the potential to substantially improve air quality in nonattainment areas.[15] While this RIA attempts to incorporate the emissions reductions from some of these control measures, differences between EPA and California emissions inventories prevented us from fully capturing the air quality improvements associated with this strategy. Additional information regarding the goods movement plan may be found in Chapter 3.

The cost analysis is found in Chapter 6, while the remainder of the analyses are located in Chapter 4.

1.8 Benefits of Attaining Revised and Alternative Standards in 2020

Tables 1-4 through 1-8 summarize the estimated reductions incidence of mortality and morbidity associated with attaining the revised and more stringent alternative $PM_{2.5}$ standards. These tables also present the valuation estimates associated with these reductions in incidence.

The tables below summarize the estimates of mortality and morbidity that use effect estimates derived from the expert elicitation effort described above in section 1.4.4. In these tables we provide incidence and valuation estimates based on data-derived and expert-elicitation derived mortality functions, for both our modeled and full attainment scenarios. The expert-elicitation derived incidence and valuation estimates include upper and lower-bound estimates based on the two experts who provided the highest and lowest mortality impact functions. Chapter 5 of this RIA complements these summary tables by including the results of the full-scale study.

[15] For additional information regarding the California Goods Movement Initiative, see: "Proposed Emission Reduction Plan for Ports and Goods Movement in California," located at www.arb.ca.gov/planning/gmerp/gmerp.htm

Table 1-4.Estimated Reduction in Incidence of Mortality Effects Associated with Attaining the Revised and More Stringent Alternative Standards

	Reduced incidence of mortality[a]	
	15/35 (µg/m3)	*14/35 (µg/m3)*
Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature[b]		
	2,500	4,400
	Confidence Intervals	*Confidence Intervals*
	(1,000 – 4,100)	(1,700 – 7,100)
Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature		
	Lower-bound EE: 1,200	Lower-bound EE: 2,200
	Upper-bound EE: 13,000	Upper-bound EE: 24,000
	Confidence Intervals	*Confidence Intervals*
	CI for lower bound EE result: (0 – 5,800)	CI for lower bound EE result: (0 – 11,000)
	CI for upper bound EE result: (6,400 – 19,000)	CI for upper bound EE result: (12,000 – 35,000)

[a] Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of mortality estimates associated with each of the twelve expert responses can be found in Chapter 5.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs..

The estimates in the table below are stratified into modeled partial attainment and full attainment. Modeled partial attainment estimates are derived from modeled air quality improvements from our illustrative control strategies which do not attain the revised or more stringent alternative standards in all areas. For those areas which our air quality models do not project to attain (for reasons explained in Chapter 4) we estimate full attainment by "rolling-back" the violating air quality monitors so that they just attain the revised or more stringent alternative standards. This approach allowed us to develop a nationwide estimate of the monetized human health benefits. For a complete discussion of the monitor roll-back approach, see Chapter 4.

Table 1-5. **Estimated Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the Revised and More Stringent Alternative Standards (90 Percent Confidence Intervals Provided in Parentheses)**

	Revised Standards (15/35)		Alternative Revised Standards (14/35)	
Estimate	*Modeled Partial Attainment*	*Full Attainment (Partial Plus Residual)*	*Modeled Partial Attainment*	*Full Attainment (Partial Plus Residual)*
Chronic bronchitis (age >25 and over)	1,000 (190 – 1,900)	2,600 (490 – 4,800)	2,900 (540—5,300)	4,600 (850—8,300)
Nonfatal myocardial infarction (age >17)	1,900 (1,100 – 2,800)	5,000 (2,700 – 7,200)	5,300 (2,900 – 7,800)	8,700 (4,800 – 13,000)
Hospital admissions—respiratory (all ages)[b]	200 (100 – 310)	530 (260 – 800)	620 (310 – 930)	980 (490 – 1,500)
Hospital admissions—cardiovascular (age >17)[c]	440 (280 – 600)	1,100 (690 – 1,500)	1,300 (830 – 1,800)	2,100 (1,300 – 2,800)
Emergency room visits for asthma (age <19)	530 (310 – 740)	1,200 (730 – 1,700)	2,400 (1,400 – 3,400)	3,200 (1,900 – 4,500)
Acute bronchitis (age 8–12)	2,800 (–90 – 5,600)	7,300 (–260 – 15,000)	7,700 (–260 – 16,000)	13,000 (–440 – 25,000)
Lower respiratory symptoms (age 7–14)	18,000 (8,600 – 27,000)	56,000 (27,000 – 84,000)	46,000 (22,400 – 70,000)	88,000 (43,000 – 130,000)
Upper respiratory symptoms (asthmatic children, age 9–18)	13,000 (4,100 – 22,000)	41,000 (13,000 – 70,000)	34,000 (11,000 – 57,000)	65,000 (20,000 – 110,000)
Asthma exacerbation (asthmatic children, age 6–18)	16,000 (1,800 – 47,000)	51,000 (5,600 – 150,000)	42,000 (4,600 – 120,000)	79,000 (8,900 – 230,000)
Work loss days (age 18–65)	110,000 (100,000 – 130,000)	350,000 (300,000 – 390,000)	300,000 (260,000 – 340,000)	550,000 (480,000 – 620,000)
Minor restricted-activity days (age 18–65)	680,000 (570,000 – 780,000)	2,000,000 (1,700,000 – 2,300,000)	1,800,000 (1,500,000 – 2,000,000)	3,300,000 (2,700,000 – 3,800,000)

Table 1-6. Estimated Monetary Valuation of Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the Revised and more stringent Alternative Standards (90 Percent Confidence Intervals Provided in Parentheses)

	Revised Standards (15/35)		Alternative Revised Standards (14/35)	
Estimate	*Modeled Partial Attainment*	*Full Attainment (Partial Plus Residual)*	*Modeled Partial Attainment*	*Full Attainment (Partial Plus Residual)*
Chronic bronchitis (age >25 and over)	$420 ($33 – $1,500)	$1,100 ($83 – $3,700)	$1,200 ($91 – $4,100)	$1,900 ($150 – $6,600)
Nonfatal myocardial infarction (age >17)				
3% Discount Rate	$160 ($43 – $350)	$420 ($110 – $910)	$440 ($120 – $970)	$730 ($200 – $1,600)
7% Discount Rate	$160 ($40 – $350)	$410 ($110 – $890)	$430 ($110 – $950)	$700 ($180 – $1,600)
Hospital admissions—respiratory (all ages)[d]	$3.3 ($1.6 – $4.9)	$8.5 ($4.2 – $13.0)	$10.0 ($4.9 – $15.0)	$16.0 ($7.8 – $23.0)
Hospital admissions—cardiovascular (age >17)[e]	$9.0 ($5.7 – $13.0)	$23.0 ($14.0 – $32.0)	$27.0 ($17.0 – $38.0)	$43.0 ($27.0 – $59.0)
Emergency room visits for asthma (age <19)	$0.14 ($0.08 – $0.22)	$0.34 ($0.19 – $0.51)	$0.66 ($0.36 – $1.00)	$0.88 ($0.48 – $1.30)
Acute bronchitis (age 8–12)	$1.00 (–$0.04 – $2.60)	$2.70 (–$0.10 – $6.70)	$2.80 (–$0.10 – $7.10)	$4.60 (–$0.17 – $12.00)
Lower respiratory symptoms (age 7–14)	$0.29 ($0.11 – $0.54)	$0.90 ($0.34 – $1.70)	$0.75 ($0.28 – $1.40)	$1.40 ($0.54 – $2.70)
Upper respiratory symptoms (asthmatic children, age 9–18)	$0.35 ($0.09 – $0.75)	$1.10 ($0.29 – $2.40)	$0.90 ($0.24 – $1.90)	$1.80 ($0.45 – $3.70)
Asthma exacerbation (asthmatic children, age 6–18)	$0.67 ($0.07 – $2.20)	$2.10 ($0.23 – $7.00)	$1.70 ($0.19 – $5.80)	$3.30 ($0.36 – $11.00)
Work loss days (age 18–65)	$14 ($12 – $15)	$43 ($37 – $48)	$33 ($28 – $37)	$65 ($56 – $73)
Minor restricted-activity days (age 18–65)	$17 ($2 – $33)	$51 ($5 – $99)	$44 ($4 – $86)	$81 ($7 – $160)

Table 1-7: Estimated Annual Monetized Benefits in 2020 of Illustrative Implementation Strategies for the Selected and Alternative $PM_{2.5}$ NAAQS, Incremental to Attainment of the Current Standards

Note: Unquantified benefits are not included in these estimates, thus total benefits are likely to be larger than indicated in this table.

	Total Full Attainment Benefits[a, b] (billions 1999$)			
	15/35 (µg/m3)		*14/35 (µg/m3)*	
<u>Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature</u>[c]				
Using a 3% discount rate	$17 *Confidence Intervals* ($4.1 – $36)		$30 *Confidence Intervals* ($7.3 - $63))	
Using a 7% discount rate	$15 *Confidence Intervals* ($3.5 – $31)		$26 *Confidence Intervals* ($6.4 - $54)	
<u>Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature</u>				
Using a 3% discount rate	$9 to $76 Confidence Intervals		$17 to $140 Confidence Intervals	
	Lower Bound Expert Result ($0.8 - $42)	Upper Bound Expert Result ($19-$150)	Lower Bound Expert Result ($1.7 - $77)	Upper Bound Expert Result ($36 - $280)
Using a 7% discount rate	$8 to $64 Confidence Intervals		$15 to $120 Confidence Intervals	
	Lower Bound Expert Result ($0.8 - $36)	Upper Bound Expert Result ($16 - $130)	Lower Bound Expert Result ($1.6 - $66)	Upper Bound Expert Result ($31 - $240)

[a] Results reflect the use of two different discount rates: 3% and 7%, as recommended in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b) and OMB Circular A-4 (OMB, 2003). Results are rounded to two significant digits for ease of presentation and computation.

[b] Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of benefits estimates associated with each of the twelve expert responses can be found in tables 5-13 through 5-16.

[c] Based on Pope et al 2002, used as primary estimate in recent RIAs.

1.9 Cost of Attaining Proposed Revised and Alternative Revised Standards in 2020

Table 1-8 summarizes the total annualized cost of meeting the current standard and the alternative scenarios using 3 and 7 percent discount rates. Total annualized costs are estimated from a baseline inventory in 2020 that reflects controls for CAIR/CAMR/CAVR and other on-the-books rules. Similar to the benefit analysis discussed above, the costs presented below reflect modeled partial attainment (by sector), incremental costs for areas to comply with residual nonattainment, and the total annualized cost of full attainment (summing the costs of partial and residual nonattainment estimates). The incremental cost of the revised standards (15/35) is approximately $5.0 to $5.1 billion using 3 and 7 percent discount rates, respectively. The incremental costs for the more stringent revised alternative standards are $6.8 to $7 billion using 3 and 7 percent discount rates, respectively. These cost numbers are highly uncertain because they include the extrapolated costs of full attainment in California and Salt Lake City. Approximately $4.5 billion of the incremental cost of achieving both 15/35 and 14/35 is attributable to these extrapolated full attainment costs. An analysis of the costs and benefits of attaining the 1997 standards in 2015 is provided in Appendix A.

Table 1-8: Comparison of Total Annualized Engineering Costs Across PM NAAQS Scenarios (millions of 1999 dollars) [a]

	Scenario	
Source Category	*Revised Stds: 15/35*	*Alternative Revised Stds:: 14/35*
I. Modeled Partial Attainment		
A. Electric Generating Units (EGU) Sector		
Local Controls on direct PM	$340	$350
Local Controls for NO_X	$59	$55
Regional EGU program (equivalent to a Phase III of CAIR)	n/a	$680
Total	**$400**	**$1,100**
B. Mobile Source Sector[b]		
Local Measures - direct PM	$30	$30
Local Measures – Nox	$31	$31
Total	**$60**	**$60**
C. Non-EGU Sector		
Point Sources (Ex: Pulp & Paper, Iron & Steel, Cement, Chemical Manu.)		
SO_2 Regional Program for Industrial Sources	n/a	$1,000
Local Known Controls	$300	$240
Area Sources (Ex: Res. Woodstoves, Agriculture)	$44	$46
Developmental Controls (Point & Areas Sources)	$32	$36
Total	**$380**	**$1,300**
II. Incremental Cost of Residual Nonattainment[c,d]		
East	$3	$180
West	$300	$300
California	$4,000	$4,000
Total	**$4,300**	**$4,500**
III. Full Attainment (Partial, plus Residual Nonattainment)		
Total Annualized Costs (using a 7% interest rate)	**$5,100**	**$7,000**
Total Annualized Costs (using a 3% interest rate)	**$5,050**	**$6,800**

a All estimates provided reflect a baseline of 2020 which include implementation of several national programs (e.g. CAIR, CAMR, CAVR), and compliance with the current standard of 15/65.

b Because we applied all available national mobile source emission controls to simulate attainment with the 1997 standards, there are no incremental costs attributable to these national rules for our 15/35 and 14/35 control strategies. See Appendix A for details regarding the estimated cost of these national rules.

c Upon review of emissions and air quality results of the control strategies applied in this RIA, some areas were indicated with residual nonattainment (requiring additional reductions to meet the standard) as a result of our initial selection of controls. The incremental costs of residual nonattainment reflect supplemental controls and extrapolated costs of additional control measures that would be necessary to bring areas with residual nonattainment into compliance. Chapter 4 provides details of the assessment. Numbers may not sum due to rounding.

d The incremental cost of residual non-attainment for the West and California are extrapolated. The methodology used to derive these estimates is described in Chapter 6. These estimates are derived using a 7 percent discount rate.

1.10 Net Benefits

Table 1-9 below summarizes the net benefits of attaining a revised and more stringent alternative $PM_{2.5}$ NAAQS. The first of these two tables summarize the full attainment benefits, economic costs and net benefits at a 3 and 7% discount rate. In this table we provide benefits estimated using concentration-response (C-R) functions developed from both the expert elicitation and the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs**.**

Note that the economic cost estimates derived at a 3 and 7 percent discount rate vary only slightly. This lack of variability is due to three factors. First, many of the control technologies contained no capital equipment. For example, emission controls such as fuel switching do not involve a capital expenditure. Second, for some sources we lacked information regarding the capital life of emission controls. Third, for controls that involved capital equipment, capital expenditures tended to be a small portion of total annualized cost. As a result, the costs were not very sensitive to the use of a different discount rate.

Table 1-9: Comparison of Full Attainment Benefits with Social Costs[f], Incremental to Attainment of 1997 Standards (Billion 1999$)

	Revised standard of 15/35 ($\mu g/m^3$)					Alternative standards of 14/35 ($\mu g/m^3$)				
	Benefits[a]		*Costs*[b]	*Net benefits*[c]		*Benefits*[a]		*Costs*[b]	*Net benefits*[c]	
<u>Benefits Based on Mortality Function from the American Cancer Society Study and Morbidity Functions from the Published Scientific Literature</u>[d]										
3%	$17		$5.4	$12		$30		$7.9	$22	
7%	$15		$5.4	$9		$26		$7.9	$18	
<u>Benefits Range Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from the Published Scientific Literature</u>[e]										
	Low Mean	High Mean		Low Mean	High Mean	Low Mean	High Mean		Low Mean	High Mean
3%	$9	$76	$5.4	$3.5	$70	$17	$140	$7.9	$8.7	$130
7%	$8	$64	$5.4	$2.4	$59	$15	$120	$7.9	$6.7	$110

[a] Results reflect the use of two different discount rates: 3% and 7%, as recommended in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b) and OMB Circular A-4 (OMB, 2003). Results are rounded to two significant digits

[b] Includes roughly $180 Million in supplemental engineering costs.

[c] Estimates rounded to two significant digits after calculations.

[d] based on Pope et al 2002, used as primary estimate in previous RIAs.

[e] Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. The distribution of benefits estimates associated with each of the twelve expert responses can be found in Chapter 5.

[f] For the purposes of comparison with the benefits, EPA uses the total social cost estimate which is slightly higher than the engineering cost

A comparison of the benefits and costs of attaining the revised and alternative standards yields two important observations. First, the comparative magnitude and distribution of benefits estimates for the revised and more stringent alternative standards is significantly affected by differences in assumed attainment strategies. As noted above, attainment with the revised standards was simulated using mainly local reductions, while a supplemental eastern regional SO_2 reduction program was used for the more stringent alternative. Under the assumptions in the analyses, the regional strategy resulted in significant additional benefits in attainment areas, making the difference in benefits between the revised and alternative standards larger than can be accounted for by the 1 $\mu g/m^3$ lower annual level for the alternative standards.

Second, given current scientific uncertainties regarding the contribution of different components to the effects associated with $PM_{2.5}$ mass, this analysis continues to assume the contribution is directly proportional to their mass. In the face of uncertainties regarding this assumption, it is reasonable to suggest that strategies that reduce a wide array of types of PM and precursor emissions will have more certain health benefits than strategies that are more narrowly focused. For this reason, the analysis provides a rough basis for comparing the assumed benefits associated with different components for different strategies. The illustrative attainment strategy for the revised standards results in a more balanced mix of reductions in different $PM_{2.5}$ components than does the regional strategy for the more stringent alterative standards. Until a more robust scientific basis exists for making reliable judgments about the relative toxicity of PM, it will not be possible to determine whether the strategy of reducing a wide array of PM types is suboptimal or not.

Third, California accounts for a large share of the total benefits and costs for both of the evaluated standards (80 percent of the benefits and 78 percent of the costs of attaining the revised standards, and 50 percent of the benefits and 58 percent of the costs of attaining the alternative standards). Because we were only able to model a small fraction of the emissions controls that might be needed to reach attainment in California, the proportion of California benefits in the "residual attainment" category are large relative to other areas of the U.S. Both the benefits and the costs associated with the assumed reductions in California are particularly uncertain.

1.11 Uncertainties and Limitations

Air Quality Modeling and Emissions

- Overall, the air quality model performs well in predicting monthly to seasonal concentrations, similar to other state-of-the-science air quality model applications for $PM_{2.5}$. Thus, there is less certainty in analyses involving 24-hour model predictions than those involving longer-term averages concentrations and better for the Eastern U.S. than for the West. The air quality model performs well in predicting the formation of sulfates, which are the dominant species in the East. In both the East and West, secondary carbonaceous aerosols are the most challenging species for the modeling system to predict in terms of evaluation against ambient data.
- A number of uncertainties arise from use of baseline data from EPA's National Emissions Inventory. Of particular concern is the apparent disparity between modeled contributions of mobile source emissions and ambient-based techniques, which suggest

that the mobile source emission inventory of directly emitted $PM_{2.5}$ is biased low by a significant amount.

- Additional uncertainty is introduced as a result of our limited understanding concerning the collective impact on future-year emission estimates from economic growth estimates, increases in technological efficiencies, and limited information on the effectiveness of control programs.
- The regional scale used for air quality modeling can understate the effectiveness of controls on local sources in urban areas as compared to areawide or regional controls.

Controls & Cost

A number of limitations and uncertainties are associated with the analysis of non-EGU point, EGU point and area source emission controls:

- The technologies applied and the emission reductions achieved in these analyses may not reflect emerging control devices that could be available in future years to meet any requirements in SIPs or upgrades to some current devices that may serve to increase control levels.

- The effects from "learning by doing" are not accounted for in the emission reduction estimates for point and area sources. It is possible that an emissions control technology may have better performance in reducing emissions due to greater understanding of how best to operate and maintain the technology. As a result, we may understate the emission reductions estimated by these analyses. The mobile source control measures do account for these effects.

- The effectiveness of the control measures in these analyses is based on an assumption that these controls are well maintained throughout their equipment life (the amount of time they are assumed to operate). To the extent that a control measure is not well maintained, the control efficiency may be less than estimated in these analyses. Since these control measures must operate according to specified permit conditions, however, it is expected that the maintenance of controls should yield control efficiencies at or very close to those used in these analyses. As a result, we may overstate the emission reductions estimated by these analyses.

- EPA believes that the EGU cost assumptions used in the analysis reflect, as closely as possible, the best information available to the Agency today. Cost estimates for SO_2 reductions from EGUs are based on results from the Integrated Planning Model and assume that the electric utility industry will be able to meet the environmental emission caps at least cost. However, to the extent that transaction and/or search costs, combined with institutional barriers, restrict the ability of utilities to exhaust all the gains from emissions trading, costs are underestimated by the model. Utilities in the IPM model also have "perfect foresight." To the extent that utilities misjudge future conditions affecting the economics of pollution control, costs may be understated as well. However, economic models of the power sector and empirical evidence show that projected compliance costs are typically over-estimated by the EPA; industry takes advantage of cap and trade more effectively than EPA can predict. The EGU analysis using IPM does not take into account the potential for advancements in the capabilities of pollution control technologies for SO_2 and NO_x removal as well as reductions in their costs over time. As configured in this application, IPM does not take into account demand response (i.e., consumer reaction to electricity prices).

- The application of area source control technologies in these analyses assume that a constant estimate for emission reduction is reasonable despite variation in the extent or scale of application (e.g. dust control plans at construction sites). To the extent that there are economies of scale in area source control applications, we may overstate the emission reductions estimated by these analyses.
- The full attainment cost estimates for California and Salt Lake City are extrapolated, and as such are more uncertain than the attainment cost estimates for other areas. As we describe in Chapter 6, this method does not incorporate the impacts of learning-by-doing or technological innovation. The method is also very sensitive to the air quality data used to derive the shape of the curve.

Benefits

- This analysis assumes that inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been specifically identified, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality are explored using the results of the expert elicitation.

- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because the composition of PM produced via transported precursors emitted from EGUs may differ significantly from direct PM released from automotive engines and other industrial sources . In accordance with advice from the CASAC, EPA has determined that no clear scientific grounds exist for supporting differential effects estimates by particle type, based on information in the most recent Criteria Document. In chapter 5, we provide a decomposition of benefits by PM component species to provide additional insights into the makeup of the benefits associated with reductions in overall PM2.5 mass (See Tables 5-32 and 5-33).

- This analysis assumes that the C R function for fine particles is approximately linear within the range of ambient concentrations under consideration (above the assumed threshold of 10 µg/m3). Thus, we assume that the CR functions are applicable to estimates of health benefits associated with reducing fine particles in areas with varied concentrations of PM, including both regions that are in attainment with PM2.5 standards and those that do not meet the standards. However, we examine the impact of this assumption by looking at alternative thresholds in a sensitivity analysis.

- A key assumption underlying the entire analysis is that the forecasts for future emissions and associated air quality modeling are valid. Because we are projecting emissions and air quality out to 2020, there are inherent uncertainties in all of the factors that underlie the future state of emissions and air quality levels.

1.12 Organization of this Regulatory Impact Analysis

This RIA includes the following eight chapters and twelve appendices:

- *Chapter 2: Defining the $PM_{2.5}$ Air Quality Problem*. This chapter analyzes current and future-year $PM_{2.5}$ speciation, source apportionment and projected nonattainment in 2015 and 2020. This chapter also details the emissions inventories that we use to project future-year air quality

- *Chapter 3: Controls Analysis*. This chapter documents our analysis of various control strategies to simulate attainment with the current standard.

- *Chapter 4*: *Air Quality Impacts*. This chapter details the results of the air quality modeling we performed to simulate attainment with the current, revised and alternative standards.

- *Chapter 5: Benefits Analysis and Results*. This chapter presents our estimates of the incremental health impacts and monetized human health and visibility benefits associated with attainment of the revised and more stringent alternative standards.

- *Chapter 6*: *Cost and Economic Impacts*. This chapter provides the estimated incremental engineering and social cost associated with the revised and more stringent alternative standards.

- *Chapter 7: Comparison of Costs and Benefits*. This chapter compares the estimated costs and benefits of attaining each standard alternative.

- *Chapter 8*: *Statutory and Executive Order Impact Analyses*. This chapter addresses each of the statutory and executive orders.

- *Appendix A*: *2015 Attainment Analysis of 1997 Standards*. This appendix documents the emission controls we applied, and the air quality modeling we performed, to simulate attainment of the 1997 standards in 2015.

- *Appendix B: AERMOD Local-Scale Analysis*. This appendix details the use of the AERMOD dispersion model to characterize the local-scale impacts of emission controls

- *Appendix C: Impact per Ton Estimates*. This appendix summarizes the Response Surface Model-derived estimates of the quantitative relationship between reductions in $PM_{2.5}$ precursors and the formation of $PM_{2.5}$ in various urban areas.

- *Appendix D*: *Emission Inventory Growth Sensitivity Analysis*. This appendix analyzes the effect of recent changes to emissions growth assumptions by comparing the 2015 air quality impacts with and without the new assumption.

- *Appendix E*: *Summary of Non-EGU Stationary Source Controls*. This appendix lists the costs and control efficiencies non-EGU stationary source control measures in AirControlNET.

- *Appendix F*: *Economic Impact Analysis*. This appendix provides additional information regarding the economic impact analysis to assess the incremental social costs of attaining the revised and more stringent alternative standards.

- *Appendix G*: *Health Based Cost Effectiveness Analysis.* This appendix provides the results of the health-based cost effectiveness analysis.

- *Appendix H: Additional Details on Benefits Methodologies*. This appendix provides additional information regarding the benefits methodologies used in chapter 5.

- *Appendix I*: *Visibility Benefits Methodology*. This appendix describes the methods we used in estimating visibility-related benefits.

- *Appendix J*: *Additional Sensitivity Analyses Related to the Benefits Analysis*. This appendix provides additional sensitivity analyses related to valuation and physical effects.

- *Appendix K*: *Supplemental Air Quality Information.* This appendix includes maps of the air quality results as well as pie charts of the model-predicted changes in $PM_{2.5}$ speciation by each projected non-attainment area.

- *Appendix L*: *Changes to AirControlNET Database.* This appendix lists the changes made to the emission controls in AirControlNET as a result of the quality assurance process.

- *Appendix M*: *Projected $PM_{2.5}$ Annual and Daily Design Values*. This appendix contains the projected base case and control case design values for 2015 and 2020.

- *Appendix N: Comparison of Projected $PM_{2.5}$ Using 36 kilometer and 12 kilometer air quality modeling*. This appendix presents the results of an analysis examining the sensitivity of projected $PM_{2.5}$ concentrations to the use of a 36 or 12 kilometer CMAQ grid resolution.

- *Appendix O*: *CMAQ Model Performance Evaluation for 2001*. This sensitivity analysis examines the ability of the CMAQ model to replicate base year $PM_{2.5}$ concentrations.

1.12 References

Holmstead, J. Designations for the Fine Particle National Ambient Air Quality Standards. Memorandum to Regional Administrators, Regions I – X. April 1, 2003. Available at: http://www.epa.gov/pmdesignations/documents/pm25_desig_guidance_final.pdf

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Wegman, L. Additional Guidance on Defining Area Boundaries for PM2.5 Designations. Memorandum to Air Division Directors, Regions I-X. February 13, 2004. Available at: http://www.epa.gov/pmdesignations/documents/PM25desigs-2003defsv2.pdf

Chapter 2: Defining the $PM_{2.5}$ Air Quality Problem

Synopsis

This chapter characterizes the nature, scope and magnitude of the current and future-year $PM_{2.5}$ problem. It includes 1) a summary of the spatial and temporal distribution of the major chemical components of $PM_{2.5,}$ and their likely origin from direct emissions or atmospheric transformations of gaseous precurors; 2) brief summary insights from recent U.S. studies that attempt to apportion components of $PM_{2.5}$ mass to various emission sources; 3) an overview of 'current' and projected emissions inventories that we used to estimate air quality impacts for our regulatory base case and control cases; and 4) estimates of projected air quality in 2015 and 2020, which form the regulatory base cases for this analysis.

2.1 Composition of $PM_{2.5}$

Particulate matter (PM) is a highly complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles range in size from those smaller than 1 nanometer (10^{-9} meter) to over 100 micrometer (µm, or 10^{-6} meter) in diameter (for reference, a typical strand of human hair is 70 um in diameter and a grain of salt is about 100 um). Atmospheric particles can be grouped according to several classes according to their aerodynamic and physical sizes, including ultrafine paticles (<0.1 um), accumulation mode or 'fine' particles (< 1 to 3 um), and coarse particles (>1 to 3 um). For regulatory purposes, fine particles are measured as $PM_{2.5}$ and inhalable or thoracic coarse particles are measured as $PM_{10-2.5}$, corresponding to their size (diameter) range in micrometers and referring to total particle mass under 2.5 and between 2.5 and 10 micrometers, respectively. The EPA currently has standards that measure $PM_{2.5}$ and PM_{10}.

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from particles' ability to shift between solid/liquid and gaseous phases, which is influenced by concentration and meteorology, especially temperature.

- Particles are made up of different chemical components. The major chemical components include carbonaceous materials (carbon soot and organic compounds), and inorganic compounds including, sulfate and nitrate compounds that usually include ammonium, and a mix of substances often apportioned to crustal materials such as soil and ash (Figure 2-1). The different components that make up particle pollution come from specific sources and are often formed in the atmosphere. As mentioned above, particulate matter includes both "primary" PM, which is directly emitted into the air, and "secondary" PM, which forms indirectly from fuel combustion and other sources. Primary PM consists of carbonaceous materials (soot and accompanying organics)—emitted from cars, trucks, heavy equipment, forest fires, some industrial processes and burning waste—and both combustion and process related fine metals and larger crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations. Secondary PM forms in the atmosphere from gases. Some of these reactions require sunlight and/or water vapor. Secondary PM includes:

- Sulfates formed from sulfur dioxide emissions from power plants and industrial facilities;
- Nitrates formed from nitrogen oxide emissions from cars, trucks, industrial facilities, and power plants; and
- Organic carbon formed from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

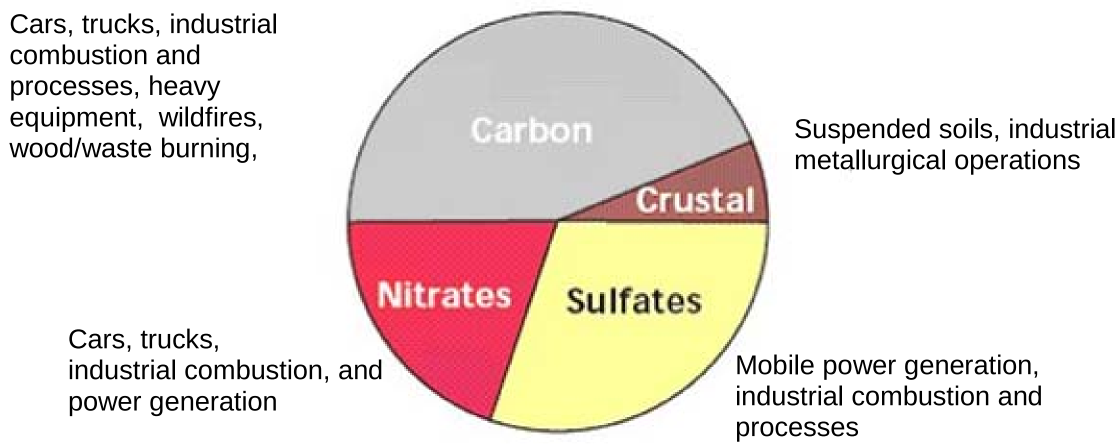


Figure 2-1. National Average of Source Contribution to Fine Particle Levels

Source: The Particulate Matter Report, USEPA 454-R-04-002, Fall 2004. Carbon reflects both organic carbon and elemental carbon. Organic carbon accounts for emissions from automobiles, biogenics, gas-powered off-road vehicles, and wildfires. Elemental carbon is mainly from diesel powered sources.

In addition, ammonia from sources such as fertilizer and animal feed operations contributes to the formation of sulfates and nitrates that exist in the atmosphere as ammonium sulfate and ammonium nitrate. As noted in Chapter 1, EPA recognizes that data on ammonia emissions from animal operations are currently very uncertain, and are likely inadequate for making specific regulatory and/or control decisions for these emissions in some locations. EPA anticipates that the National Air Emissions Monitoring Study (NAEMS) for animal operations will provide a more scientific basis for estimating emissions, as well as defining the scope of air quality impacts, from these sources.

Note that fine particles can be transported long distances by wind and weather and can be found in the air thousands of miles from where they formed. The chemical makeup of particles varies across the United States, as illustrated in Figure 2-2. For example, the higher regional emissions of SO_2 in the East result in higher absolute and relative amounts of sulfates as compared to the western U.S. Fine particles in southern California generally contain more nitrates than other areas of the country. Carbon is a substantial component of fine particles everywhere.

2.1.1 Seasonal and Daily Patterns of $PM_{2.5}$

Fine particles often have a seasonal pattern. As shown in Figure 2-3, $PM_{2.5}$ values in the eastern half of the United States are typically higher in the third calendar quarter (July-September) when meteorological conditions are more favorable for the formation and build up of sulfates from the higher sulfur dioxide (SO_2) emissions from power plants in that region. Fine particle concentrations tend to be higher in the first (January -March) and fourth (October through December) calendar quarters urban areas in the West, in part because fine particle nitrates and carbonaceous particles are more readily formed in cooler weather, and wood stove and fireplace use increases direct emissions of carbon.

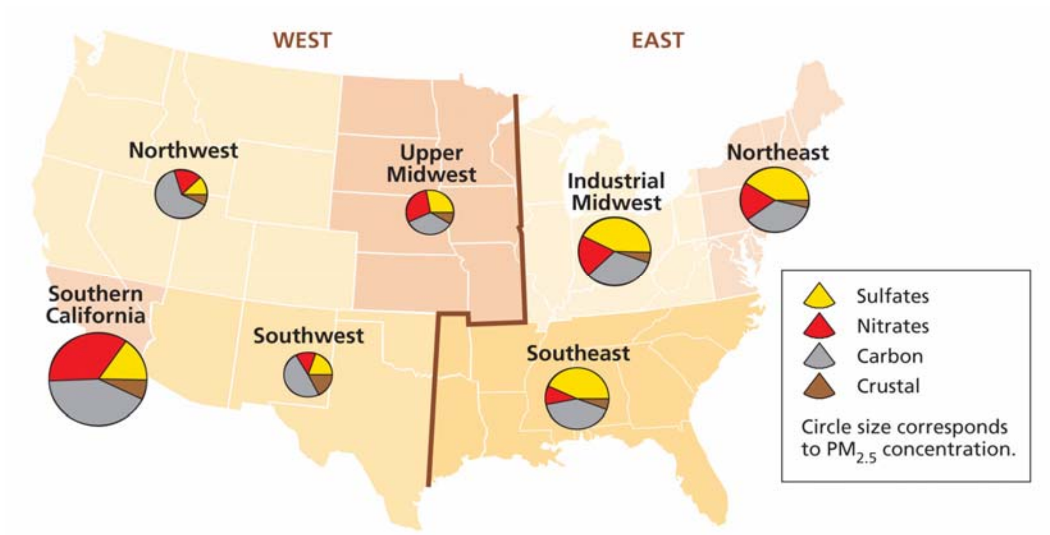


Figure 2-2. Average $PM_{2.5}$ Composition in Urban Areas by Region, 2003

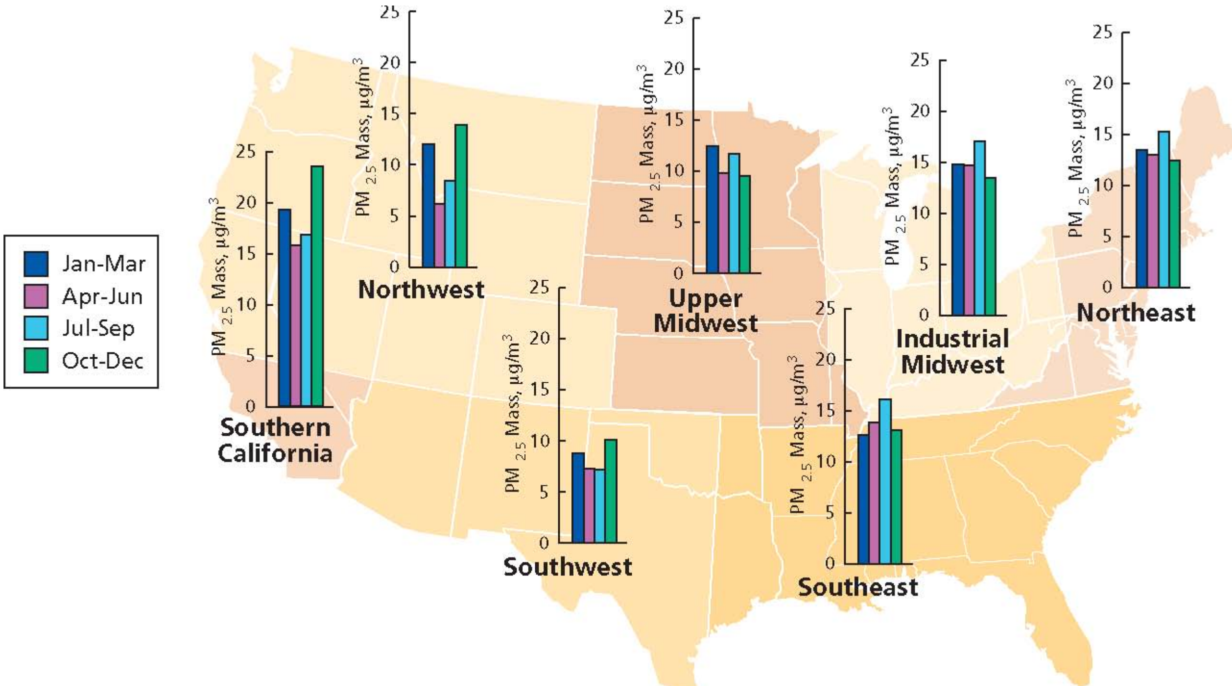


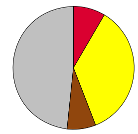
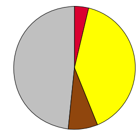
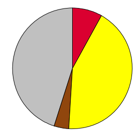
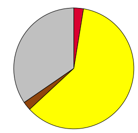
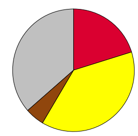
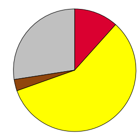
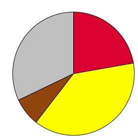
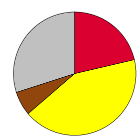
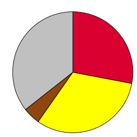
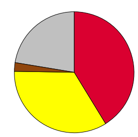
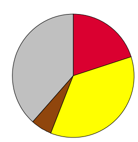
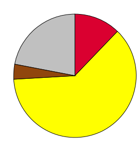
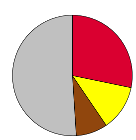
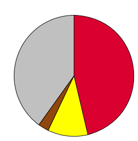
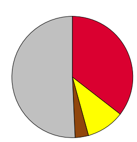
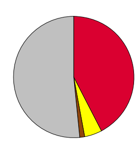
Figure 2-3. Seasonal Averages of $PM_{2.5}$ Concentration by Region, 1999–2003

Seasonal patterns are also present in the concentrations and composition of the highest daily values of $PM_{2.5}$. Unlike daily ozone levels, which are usually elevated in the summer, daily $PM_{2.5}$ values at some locations can be high at any time of the year. Table 2-1 provides 2003 data on daily $PM_{2.5}$ values and their composition on high mass days for various urban sites within large metropolitan areas (in the East: Birmingham, AL; Atlanta, GA; New York City, NY; Cleveland, OH; Chicago, IL; and St. Louis, MO; in the West: Salt Lake City, UT; and Fresno, CA). Mass is proportioned into four categories: sulfates, nitrates, crustal, and total carbonaceous mass (TCM, the sum of elemental carbon (EC) and organic carbon mass (OCM)). For each site, the table shows the 2003 annual average speciation pattern, the profile for the five highest $PM_{2.5}$ mass days in that year—both individually and averaged together—and corresponding Federal Reference Method (FRM) mass values (annual average, five highest days, and average of five highest). The table shows some notable differences in the percentage contribution of each of the species to total mass when looking at the high end of the distribution versus the annual average; this information can have implications for the types of controls that may be more effective in meeting the daily versus the annual standard in each projected nonattainment area. In all of the eastern city sites, the percentage of sulfates is somewhat higher on the five high days as compared to the annual averages. In the two western cities, the percentage of nitrates is higher on the five high days as compared to the annual averages. TCM constitutes a somewhat lower percentage on the five high days compared to the annual averages in most cities.

2.1.2 Composition of $PM_{2.5}$ as Measured by the Federal Reference Method

The speciation measurements in the preceding analyses represented data from EPA's Speciation Trends Network, along with adjustments to reflect the fine particle mass associated with these ambient measurements. In order to more accurately predict the change in $PM_{2.5}$ design values for particular emission control scenarios, EPA characterizes the composition of $PM_{2.5}$ as measured by the Federal Reference Method (FRM). The current $PM_{2.5}$ FRM does not capture all ambient particles measured by speciation samplers as presented in the previous sections. The FRM-measured fine particle mass reflects losses of ammonium nitrate (NH_4NO_3) and other semi-volatile organic compounds (SVOCs; negative artifacts). It also includes particle-bound water (PBW) associated with hygroscopic species (positive artifacts) (Frank, 2006). Comparison of FRM and collocated speciation sampler NO_3^- values in Table 2-2 show that annual average NO_3 retention in FRM samples for six cities varies from 15% in Birmingham to 76% in Chicago, with an annual average loss of 1 g/m^3. The volatilization is a function of temperature and relative humidity (RH), with more loss at higher temperatures and lower RH. Accordingly, nitrate is mostly retained during the cold winter days, while little may be retained during the hot summer days.

Table 2-1: $PM_{2.5}$ Composition on High Mass Days in Select Urban Areas, 2003

Urban Area	Statistic*	Composition Percents (%) Amm. Nitrate	Amm. Sulfate	Crustal	TCM	$PM_{2.5}$ mass** (µg/m3)	Annual average	Average of 5 highest days
Birmingham, AL	• Annual average	8.5	35.6	7.6	48.3	**17.9**		
	• Average of 5 highest $PM_{2.5}$ mass days	3.8	40.0	7.8	48.3	**40.7**		
	• Highest $PM_{2.5}$ mass day	1.9	55.1	5.5	37.4	**46.6**		
	• 2nd highest $PM_{2.5}$ mass day	4.2	26.9	11.0	57.9	**40.4**		
	• 3rd highest $PM_{2.5}$ mass day	15.3	15.7	10.7	58.4	**39.2**		
	• 4th Highest $PM_{2.5}$ mass day	2.7	51.1	7.4	38.7	**39.1**		
	• 5th Highest $PM_{2.5}$ mass day	2.6	34.6	6.4	56.3	**38.3**		
Atlanta, GA	• Annual average	8.1	42.8	4.0	45.0	**15.2**		
	• Average of 5 highest $PM_{2.5}$ mass days	2.6	60.1	2.3	34.3	**35.2**		
	• Highest $PM_{2.5}$ mass day	2.0	70.5	1.9	25.6	**37.8**		
	• 2nd highest $PM_{2.5}$ mass day	2.0	47.8	2.5	47.8	**37.1**		
	• 3rd highest $PM_{2.5}$ mass day	2.4	67.6	2.1	27.9	**36.8**		
	• 4th Highest $PM_{2.5}$ mass day	3.2	50.8	2.9	43.1	**35.0**		
	• 5th Highest $PM_{2.5}$ mass day	3.6	67.5	1.9	27.0	**29.3**		
New York City, NY	• Annual average	20.2	38.3	5.1	36.4	**13.1**		
	• Average of 5 highest $PM_{2.5}$ mass days	11.6	57.9	3.0	27.4	**40.5**		
	• Highest $PM_{2.5}$ mass day	3.6	58.3	5.5	32.6	**45.9**		
	• 2nd highest $PM_{2.5}$ mass day	5.0	69.0	1.4	24.6	**45.8**		
	• 3rd highest $PM_{2.5}$ mass day	27.8	42.1	3.1	27.0	**38.2**		
	• 4th Highest $PM_{2.5}$ mass day	5.1	59.4	4.6	30.9	**36.4**		
	• 5th Highest $PM_{2.5}$ mass day	9.7	62.2	2.0	26.1	**36.0**		
Cleveland, OH	• Annual average	22.3	38.3	7.4	32.1	**17.6**		
	• Average of 5 highest $PM_{2.5}$ mass days	21.4	42.5	6.3	30.0	**44.1**		
	• Highest $PM_{2.5}$ mass day	32.7	43.2	2.3	21.7	**57.9**		
	• 2nd highest $PM_{2.5}$ mass day	25.1	41.5	4.0	29.3	**46.4**		
	• 3rd highest $PM_{2.5}$ mass day	4.8	64.4	8.7	22.1	**45.5**		
	• 4th Highest $PM_{2.5}$ mass day	8.8	37.5	14.7	39.0	**35.7**		
	• 5th Highest $PM_{2.5}$ mass day	31.4	20.5	4.0	44.0	**35.0**		
Chicago, IL	• Annual average	28.0	31.8	4.6	35.6	**15.2**		
	• Average of 5 highest $PM_{2.5}$ mass days	41.2	34.0	2.3	22.4	**34.4**		
	• Highest $PM_{2.5}$ mass day	46.0	30.7	1.2	22.1	**38.3**		
	• 2nd highest $PM_{2.5}$ mass day	49.2	36.4	0.8	13.6	**35.3**		
	• 3rd highest $PM_{2.5}$ mass day	51.8	27.7	1.2	19.3	**35.1**		
	• 4th Highest $PM_{2.5}$ mass day	5.6	61.7	3.8	28.9	**32.5**		
	• 5th Highest $PM_{2.5}$ mass day	47.8	16.1	5.3	30.8	**30.7**		
St. Louis, MO	• Annual average	20.0	36.0	5.6	38.4	**14.5**		
	• Average of 5 highest $PM_{2.5}$ mass days	12.2	61.9	3.9	22.0	**35.9**		
	• Highest $PM_{2.5}$ mass day	6.2	69.1	3.6	21.0	**50.6**		
	• 2nd highest $PM_{2.5}$ mass day	5.0	67.0	2.0	26.0	**36.0**		
	• 3rd highest $PM_{2.5}$ mass day	6.4	69.2	3.2	21.3	**33.1**		
	• 4th Highest $PM_{2.5}$ mass day	5.0	58.9	8.2	28.1	**30.8**		
	• 5th Highest $PM_{2.5}$ mass day	40.2	42.3	2.7	14.7	**28.9**		
Salt Lake City, UT	• Annual average	28.3	12.2	8.5	51.1	**10.0**		
	• Average of 5 highest $PM_{2.5}$ mass days	46.3	10.8	2.9	40.0	**40.6**		
	• Highest $PM_{2.5}$ mass day	50.6	6.3	2.5	40.5	**59.5**		
	• 2nd highest $PM_{2.5}$ mass day	43.5	11.9	2.6	42.0	**52.1**		
	• 3rd highest $PM_{2.5}$ mass day	42.4	13.5	3.7	40.4	**34.2**		
	• 4th Highest $PM_{2.5}$ mass day	48.2	5.9	4.7	41.3	**28.7**		
	• 5th Highest $PM_{2.5}$ mass day	45.4	20.2	1.5	32.8	**28.4**		
Fresno, CA	• Annual average	35.5	10.2	3.6	50.7	**18.0**		
	• Average of 5 highest $PM_{2.5}$ mass days	42.4	4.7	1.3	51.6	**54.2**		
	• Highest $PM_{2.5}$ mass day	55.2	4.6	2.1	38.2	**59.0**		
	• 2nd highest $PM_{2.5}$ mass day	58.4	8.5	0.9	32.2	**56.3**		
	• 3rd highest $PM_{2.5}$ mass day	17.5	1.5	1.3	79.7	**54.4**		
	• 4th Highest $PM_{2.5}$ mass day	35.1	5.3	1.0	58.6	**52.6**		
	• 5th Highest $PM_{2.5}$ mass day	44.6	3.7	1.3	50.3	**50.0**		

* The 5 highest days shown (and aggregated) for each site actually represent the 5 highest days (based on collocated FRM mass; see next bullet) that the speciation monitor sampled. FRM monitors at different locations in the metropolitan area and/or collocated FRM measurements on days that the speciation sampler did not record valid data may have had higher values than some or all of the 5 high values shown. Event-flagged data were omitted from this analyses.

** '$PM_{2.5}$ mass' concentration represents the collocated (w/ speciation monitor) same-day FRM measurement unless not available, in which case the speciation monitor gravimetric mass was substituted.

Key:

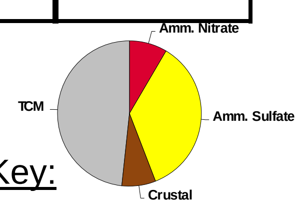


Table 2-2: Annual average FRM and STN $PM_{2.5}$ NO_3^- and NH_4NO_3 concentrations at six sites during 2003

Sampling Site Location	*No. of Observations*	*FRM Mass*	NO_3^- (μg/m³)			NH_4NO_3 (μg/m³)		Percent of NH_4NO_3 in $PM_{2.5}$ FRM Mass	
			STN[a]	*FRM*[b]	*Difference (STN – FRM)*	*STN*	*FRM*	*STN*	*FRM*
Mayville, WI	100	9.8	2.5	1.5	1.0	3.2	1.9	33%	19%
Chicago, IL	76	14.4	2.8	2.1	0.7	3.7	2.8	25%	19%
Indianapolis, IN	92	14.8	2.5	1.3	1.3	3.2	1.6	22%	11%
Cleveland, OH	90	16.8	2.9	1.7	1.2	3.7	2.2	22%	13%
Bronx, NY	108	15.0	2.4	1.1	1.3	3.1	1.4	21%	9%
Birmingham, AL	113	17.0	1.1	0.2	0.9	1.4	0.2	8%	1%

[a] On denuded nylon-membrane filters for al sites except for Chicago, where denuded Teflon-membrane followed by nylon filters were used.

[b] On undenuded Teflon-membrane filters.

$PM_{2.5}$ FRM measurements also include water associated with hygroscopic aerosol. This is because the method derives fine particle concentrations from sampled mass equilibrated at 20–23 °C and 30–40% RH. At these conditions, the hygroscopic aerosol collected at more humid environments will retain their particle-bound water. The water content is higher for more acidic and sulfate-dominated aerosols. Combining the effects of reduced nitrate and hydrated aerosol causes the estimated nitrate and sulfate FRM mass to differ from the measured ions simply expressed as dry ammonium nitrate and ammonium sulfate. The composition of FRM mass is denoted as SANDWICH based on the Sulfate, Adjusted Nitrate Derived Water and Inferred Carbon approach from which they are derived. The $PM_{2.5}$ mass estimated from speciated measurements of fine particles is termed ReConstructed Fine Mass (RCFM). The application of SANDWICH adjustments to speciation measurements at six sites is illustrated in Table 2-2 and Figure 2-4. EPAs modeling incorporates these SANDWICH adjustments thru the Speciated Modeling Attainment Test (SMAT).

2.1.3 Current and Projected Composition of Urban $PM_{2.5}$ for Selected Areas

Based on our CMAQ modeling, a local perspective of $PM_{2.5}$ levels and composition is provided in this section in order to further elaborate further on the nature of the $PM_{2.5}$ air quality problem after implementation of the CAIR/CAMR/CAVR rules, the national mobile rules for light and heavy-duty vehicles and nonroad mobile sources, and current state programs that were on the books as of early 2005.[1] As an illustrative example, a localized analysis of current ambient and future-year speciation is provided for two cities, one in the East and one in the West.

[1] Multi-pollutant legislation modeling. (Multi-pollutant analyses and technical support documents. http://www.epa.gov/airmarkets/mp/.)

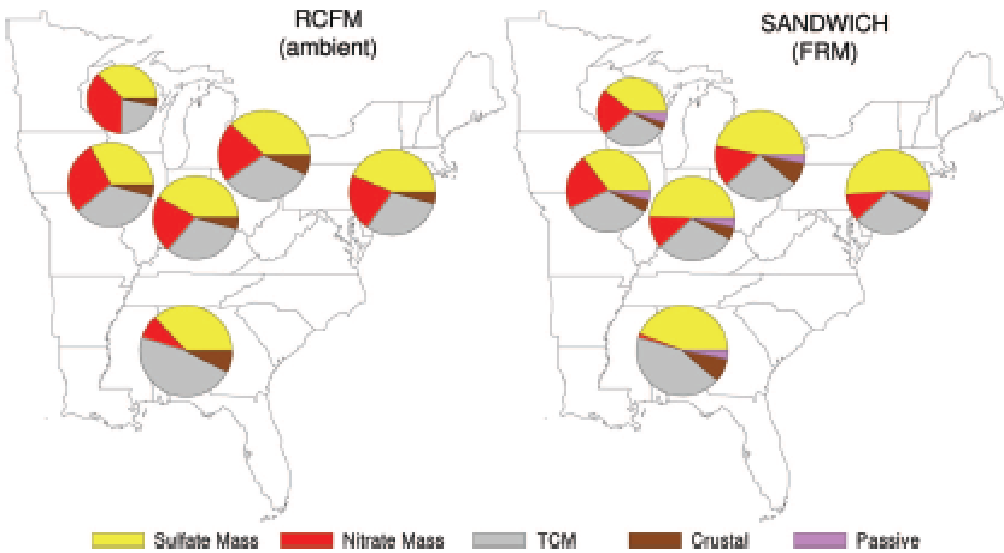


Figure 2-4. RCFM (left) versus SANDWICH (right) Pie Charts Comparing the Ambient and $PM_{2.5}$ FRM Reconstructed Mass Protocols on an Annual Average Basis
Estimated NH_4* and PBW for SANDWICH are included with their respective sulfate and nitrate mass slices. Circles are scaled in proportion to $PM_{2.5}$ FRM mass.

Figure 2-5 shows projected $PM_{2.5}$ component species concentrations (i.e., sulfate, nitrate, elemental carbon, organic aerosols, crustal, and uncontrollable $PM_{2.5}$) for current ambient data (5 year weighted average, 1999–2003) and a 2020 regulatory base case with the addition of the controls mentioned in the previous paragraph. Note that organic aerosols include directly emitted organic carbon and organic carbon particles formed in the atmosphere from anthropogenic sources and biogenic sources. Uncontrollable $PM_{2.5}$ is based upon a 0.5 $\mu g/m^3$ $PM_{2.5}$ blank mass correction used in the Speciated Modeled Attainment Test (SMAT) approach, in which a number of adjustments and additions were made to the measured species data to provide for consistency with the chemical components retained on the FRM Teflon filter.[2] The analysis provided here specifically looks at one area in the East (Detroit), and one in the West (Salt Lake City).

[2] Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Applications of the Speciated Modeling Attainment Test (SMAT), Updated November 8, 2004 (EPA Docket #: OAR-2003-0053-1907).

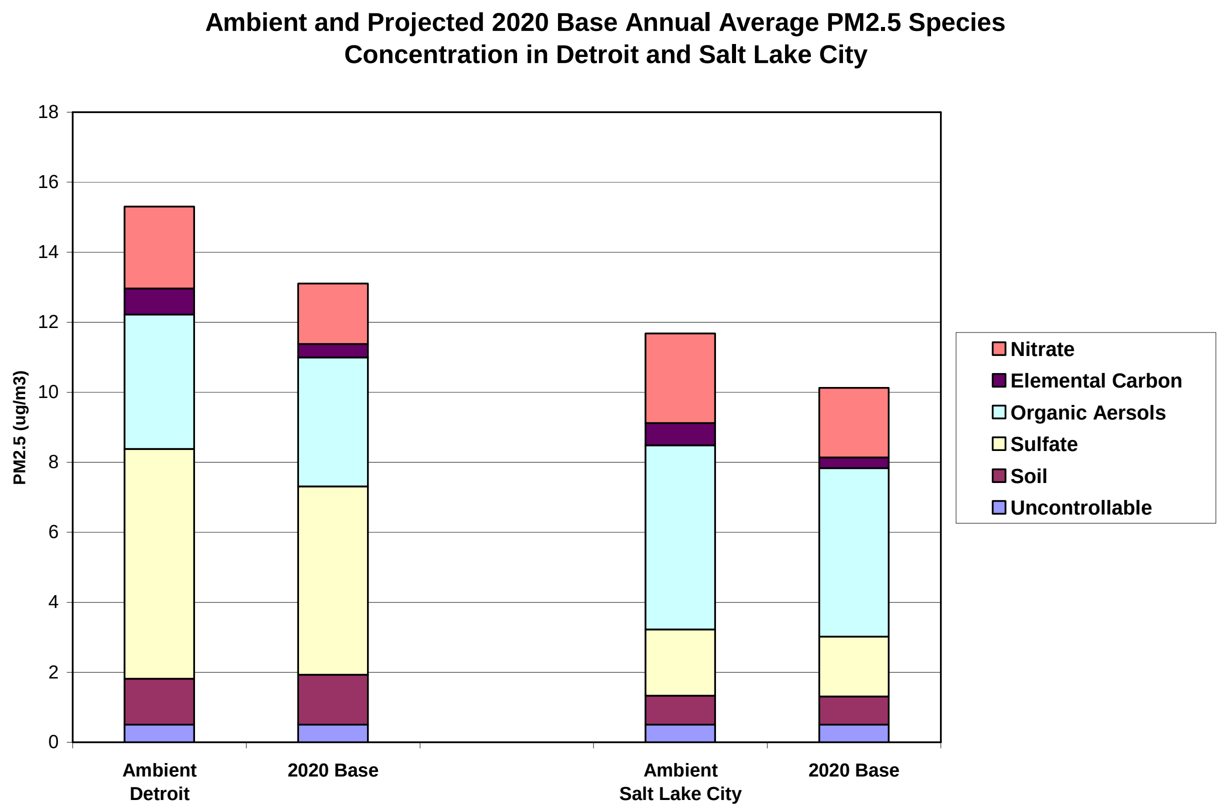


Figure 2-5. Base Case and Projected $PM_{2.5}$ Component Species Concentrations in Detroit and Salt Lake City

Note: The ambient and projected 2020 base case annual design values above are averages taken across multiple urban area monitors. Thus, while the average 2020 Detroit base case design value reflected above is lower than the projected base case design values at certain Detroit monitors.

Notably, organic aerosols constitute a large fraction of the overall remaining $PM_{2.5}$ mass in Detroit and Salt Lake City. Sulfate is a considerable part of the total $PM_{2.5}$ mass in both cities and is the largest contributor to $PM_{2.5}$ mass in Detroit. Nitrate is a relatively small source of $PM_{2.5}$ for Detroit but nitrate is the second largest contributor to the remaining $PM_{2.5}$ problem in Salt Lake City; the exception is that on higher days, nitrate represents the largest contributor in Salt Lake City. The relatively large contribution of sulfate to $PM_{2.5}$ mass in Detroit is characteristic of the urban air pollution mixture in the East, while the nitrate contribution to $PM_{2.5}$ mass in Salt Lake City is characteristic of that found in the West.

Both local and regional sources contribute to particle pollution. Figure 2-6 shows how much of the $PM_{2.5}$ mass can be attributed to local versus regional sources for 13 selected urban areas. In each of these urban areas, monitoring sites were paired with nearby rural sites. When the average rural concentration is subtracted from the measured urban concentration, the estimated local and regional contributions become apparent. Urban and nearby rural $PM_{2.5}$ concentrations suggest substantial regional contributions to fine particles in the East. The measured $PM_{2.5}$ concentration is not necessarily the maximum for each urban area. Regional concentrations are derived from the rural IMPROVE monitoring network.[3]

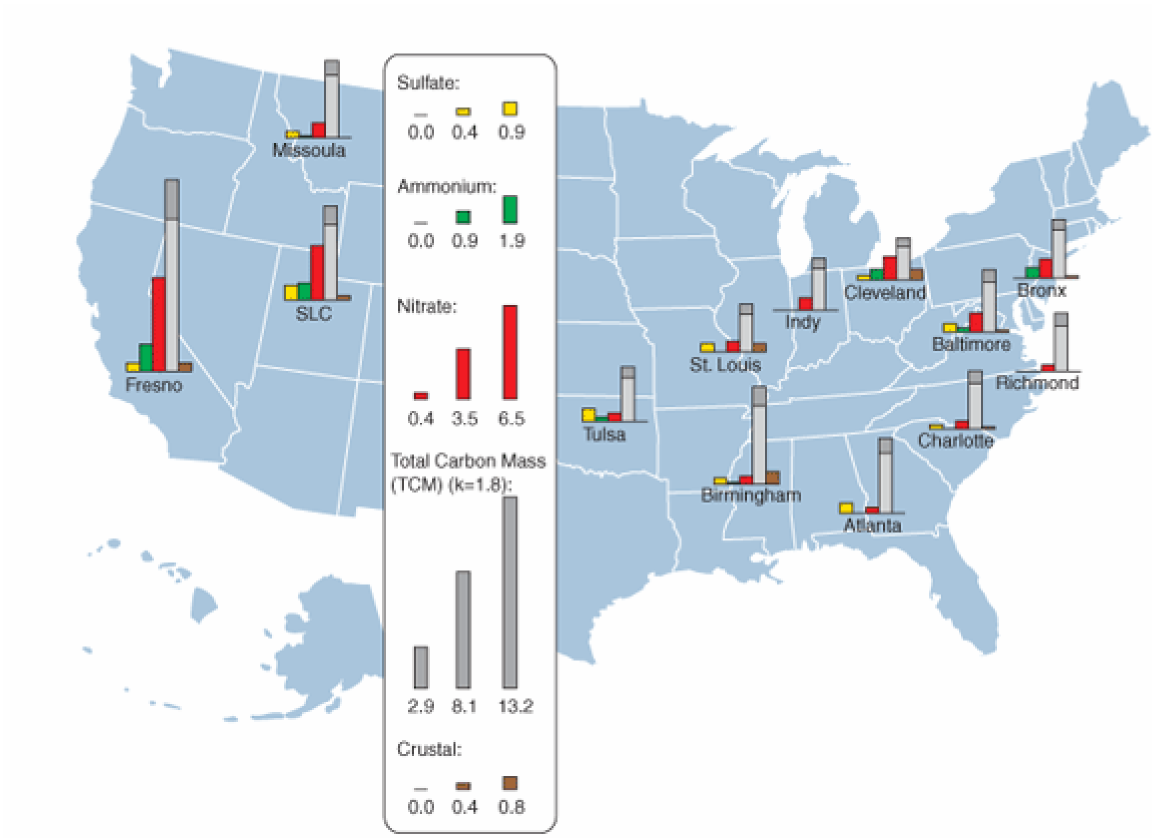


Figure 2-6. Estimated "Urban Excess" of 13 Urban Areas by $PM_{2.5}$ Species Component
The urban excess is estimated by subtracting the measured $PM_{2.5}$ species at a regional monitor location (assumed to be representative of regional background) from those measured at an urban location.

Note: Total Carbon Mass (TCM) is the sum of Organic Carbon (OC) and Elemental Carbon (EC). In this graph, the light grey is OC and the dark grey is EC. See: Turpin, B. and H-J, Lim, 2001: Species contributions to $PM_{2.5}$ mass concentrations: Revisiting common assumptions for estimating organic mass, Atmospheric Environment, 35, 602-610.

As shown in Figure 2-6, we observe a large urban excess across the U.S. for most $PM_{2.5}$ species but especially for total carbon mass. All of these locations have consistently high urban excess for total carbon mass with Fresno, CA and Birmingham, AL having the largest observed measures. Larger urban excess of nitrates is seen in the western U.S. with Fresno, CA and Salt Lake City, UT significantly higher than all other areas across the nation. These results indicate that local sources of these pollutants are indeed contributing to the $PM_{2.5}$ air quality problem in these areas. As expected for a predominately regional pollutant, only a modest urban excess is observed for sulfates.[4]

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[3] Interagency Monitoring of Protected Visual Environments (IMPROVE) http://vista.cira.colostate.edu/improve
[4] Pittsburgh provides an exception to this observation, as our air quality analysis indicated that sulfates are directly emitted.

In the East, regional pollution contributes more than half of total $PM_{2.5}$ concentrations. Rural background $PM_{2.5}$ concentrations are high in the East and are somewhat uniform over large geographic areas. These regional concentrations come from emission sources such as power plants, natural sources, and urban pollution and can be transported hundreds of miles and reflects to some extent the more dense clustering of urban areas in the East as compared to the West. The local and regional contributions for the major chemical components that make up urban $PM_{2.5}$ are sulfates, carbon, and nitrates. Implementation of the promulgated CAIR-CAVR-CAMR program, mobile source regulations, and current state and local programs will address regional contribution to $PM_{2.5}$ associated with NO_x and SO_2. Nitrates and sulfates formed from NOx and SO2 are generally transported over wide areas leading to substantial background contributions in urban areas. Carbonaceous emissions are also transported but to a far lesser degree. Mobile source regulations which apply on a national basis will also help address the local contribution of carbonaceous PM. However, states will clearly need to consider local emission control measures to address the local contribution to $PM_{2.5}$.

A tabular summary of urban excess amounts by species is shown below in Table 2-3. This table represents a regional summary of Figure 2-6. It clearly shows the predominance of urban excess levels of carbon across the USA. In the West, nitrates also contribute to local urban excess levels.

Table 2-3: Summary of Urban Excess Amounts by Species

	West (3 sites)			East (10 sites)			Overall (13 sites)		
Chemical Species	Min	Max	Average	Min	Max	Average	Min	Max	Average
Sulfate	0.4	0.9	0.6	0	0.8	0.3	0	0.9	0.3
Estimated Ammonium	0.4	2.3	1.4	0.3	1.1	0.6	0.3	2.3	0.8
Nitrate	1.0	6.5	3.7	0.4	1.5	0.8	0.4	6.5	1.5
Total Carbonaceous Mass (k=1.4)	4.2	10.5	6.6	2.4	5.4	3.3	2.4	10.5	4.1
Total Carbonaceous Mass (k=1.8)	5.3	13.2	8.3	2.9	6.7	4.2	2.9	13.2	5.1
"Crustal"	-0.1	0.5	0.2	0	0.8	0.2	0	0.8	0.2

Because this RIA addresses control strategies to meet alternative standards that are implemented in future years, it is important to examine the extent to which the concentration and composition patterns found in the data summarized above would change as a result of regulations that have already been adopted at the national, state, and local level. This section provides results from CMAQ modeling to forecast the nature of the $PM_{2.5}$ air quality problem in 2020, taking into account the net reductions expected from implementation of the CAIR/CAMR/CAVR rules, the national mobile rules for light and heavy-duty vehicles and nonroad mobile sources, and current state programs that were on the books as of early 2005.[5] The national changes in PM2.5 levels are summarized and presented in Chapter 3.

2.2 Source Apportionment Studies of $PM_{2.5}$

Determining sources of fine particulate matter is complicated in part because the concentrations of various components are influenced by both primary emissions and secondary atmospheric reactions. As described earlier, when attempting to characterize the sources affecting $PM_{2.5}$ concentrations, it is important to note that both regional and local sources impact ambient levels. In the eastern US, regional fine particles are often dominated by secondary particles including sulfates, organics (primary and secondary) and nitrates. These are particles which form through atmospheric reactions of emitted sulfur dioxide, oxides of nitrogen and ammonia, and are transported over long distances. Conversely, local contributions to fine particles are likely dominated by directly emitted particulate matter from sources such as gasoline and diesel vehicles[6], industrial facilities (e.g., iron and steel manufacturing, coke ovens, or pulp mills), and residential wood and waste burning.

Development of effective and efficient emission control strategies to lower $PM_{2.5}$ ambient concentrations can be aided by determining the relationship between the various types of emissions sources and elevated levels of $PM_{2.5}$ at ambient monitoring sites. Source apportionment analyses such as receptor modeling are useful in this regard by both qualifying and quantifying potential fine particulate regional and local source impacts on a receptor's ambient concentrations. The goal is to apportion the mass concentrations into components attributable to the most significant sources. Receptor modeling techniques are observation-based models which utilize measured ambient concentrations of $PM_{2.5}$ species to quantify the contribution that regional and local sources have at a given receptor which, in this case, is an ambient monitoring location.[7] These techniques are very useful in characterizing fine particulate source contributions to ambient $PM_{2.5}$ levels; however, there are inherent limitations including but not limited to the adequacy (e.g., vintage and representativeness) of existing source profiles in identifying source groups or specific sources, availability and completeness of ambient datasets to fully inform these techniques, and current scientific understanding and measured data to relate tracer elements to specific sources, production processes, or activities. Additionally, commingling of similar species from different sources in one "factor" can make it difficult to relate the "factor" to a particular source.

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[5] Multi-pollutant legislation modeling. (Multi-pollutant analyses and technical support documents. http://www.epa.gov/airmarkets/mp/.)

[6] Note that while we believe that the mobile source sector is a substantial contributor to total $PM_{2.5}$ mass; our current mobile source inventory is likely significantly underestimated and information on control measures is incomplete. For this reason, we believe there are more mobile source reductions available than those that we model in our controls analysis.

[7] Currently, two established receptor models are widely used for source apportionment studies: the Chemical Mass Balance (CMB) model and Positive Matrix Factorization (PMF). The CMB receptor model relies on measured source profiles as well as ambient species measurements to produce a source contribution estimate at the receptor location, while the PMF technique decomposes the ambient measurement data matrix into source profiles and contributions by utilizing the underlying relationship (i.e., correlations) between the individually measured species.

A literature compilation summarizing 27 source apportionment studies was conducted as part of a research and preparation program for the CAIR (EPA, 2005) rule, which was focused on $PM_{2.5}$ transport).[8] Literature selected in this compilation represented key source apportionment research, focusing primarily on recent individual source apportionment studies in the eastern U.S. The sources identified are grouped into seven categories: secondary sulfates, mobile, secondary nitrates, biomass burning, industrial, crustal and salt, and other/not identified. Some of these studies are based on older ambient databases and more recent ambient data have shown improvement and reduced levels of ambient $PM_{2.5}$ concentrations across the U.S., especially in the East, which affects the quantitative conclusions one may draw from these studies. Notably, the relative fraction of sulfates has continued to decrease with the implementation of the acid rain program and removal of sulfur from motor vehicle fuels. More routine monitoring for specific tracer compounds that are unique to individual sources can lead to better separation of blended "factors" such as secondary commingled sulfates and organic aerosols which are more attributed to emissions from vehicles and vegetation. Western studies have focused on sources impacting both high population areas such as Seattle, Denver, the San Joaquin Valley, Los Angeles, San Francisco as well as national parks.[9,10,11,12,13,14,15,16,17,18] More routine monitoring for specific tracer compounds that are unique to individual sources can lead to better separation of blended "factors" such as secondary commingled sulfates and organic aerosols which are more attributed to emissions from vehicles and vegetation.

As mentioned previously, the sources of $PM_{2.5}$ can be categorized as either direct emissions or contributing to secondary formation. The results of the studies showed that approximately 20 to 60% of the fine particle mass comes from secondarily formed nitrates and sulfates depending on the area of the country, with nitrates predominantly affecting the West, sulfates in the East and a mixture of the two in the Industrial Midwest. The precursors of these particles are generally gaseous pollutants such as sulfur dioxide or oxides of nitrogen, which react with ammonia in the atmosphere to form ammonium salts. Dominant sources of SO_2 include power generation facilities, which, along with motor vehicles, are also sources of NO_x. The result of recent and future reductions in precursor emissions from electrical generation utilities and motor vehicles,

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[8] Second Draft Technical Report (Revision 1), Compilation of Existing Studies on Source Apportionment for $PM_{2.5}$, August 22, 2003 (Contract No. 68-D-02-061; Work Assignment 1-05). http://www.epa.gov/oar/oaqps/pm25/docs/compsareports.pdf

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however, will lead to a reduction in precursor contributions which would aid in limiting the production of secondary sulfates and nitrates. Also, reductions in gasoline and diesel fuel sulfur will reduce mobile source SO_2 emissions. In addition, secondary organic carbon aerosols (SOA) also make a large contribution to the overall total $PM_{2.5}$ concentration in both the Eastern and Western United States. For many of the receptor modeling studies, the majority of organic carbon is attributed to motor vehicle emissions (including both gasoline and diesel). While vehicles emit organic carbon particulate, the various organic gases also emitted by these sources react in the atmosphere to form SOA which shows a correlation to the other secondarily formed aerosols due to common atmospheric reactions. Other common sources of the organic gases which form SOA include vegetation, vehicles, and industrial VOC and SVOC emissions. However, due to some limits on data and a lack of specific molecular markers, current receptor modeling techniques have some difficulty attributing mass to SOA. Therefore, currently available source apportionment studies may be attributing an unknown amount of SOA in ambient PM to direct emissions of mobile sources; concurrently, some secondary organic aerosol found in ambient samples may, as mentioned above, be coming from mobile sources and not be fully reflected in these assessments. Research is underway to improve estimates of the contribution of SOA to total fine particulate mass.

While gaseous precursors of $PM_{2.5}$ are important contributors, urban primary sources still influence peak local concentrations that exceed the NAAQS, even if their overall contributions are smaller. The mixture of industrial source contributions to mass vary across the nation and include emissions from heavy manufacturing such as metal processing (e.g., steel production, coke ovens, foundries), petroleum refining, and cement manufacturing, among others. Other sources of primary $PM_{2.5}$ are more seasonal in nature. One such source is biomass burning, which usually contributes more during the winter months when households burn wood for heat, but also contributes episodically during summer as a result of forest fires. Other seasonal sources of primary PM include soil, sea salt and road salting operations that occur in winter months. The extent of these primary source contributions to local $PM_{2.5}$ problems varies across the U.S. and can even vary within an urban area. The key for individual areas is to understand the nature of the problem (i.e., determining the relationship between various types of emissions sources and elevated levels of $PM_{2.5}$ at ambient monitoring) in order to develop effective and efficient emission control strategies to reduce $PM_{2.5}$ ambient concentrations through local control program scenarios.

2.3 Emissions Inventories Used in this RIA

The next step in our analysis was to develop the emission inventories that we would use to model the projected air quality of our regulatory base case. This section summarizes the projection years we used as our regulatory base case and the key attributes of the emission inventories we used to model this base case.

2.3.1 Targeted Projection Years

We have chosen 2015 as our base year of analysis to assess the costs and benefits of attaining the 1997 standards and 2020 for analyzing attainment with the revised daily, and the alternative more stringent annual standards. 2015 serves as a logical base year for the 1997 $PM_{2.5}$ NAAQS because according the Clean Air Act, it is the final date by which States would implement controls to attain the current $PM_{2.5}$ standards (15 $\mu g/m^3$ annual, 65 $\mu g/m^3$ daily). 2020 is the final year by which states would implement controls to attain revised standards.

The following nationally implemented rules will either take effect between 2015 and 2020 or will take effect before 2015 and continue to provide additional emission benefits between 2015 and 2020 due to factors such as additional fleet turnover: the Clean Air Interstate Rule (CAIR), the Clean Air Visibility Rule (CAVR) and the Clean Air Mercury Rule (CAMR), the Clean Air Non-Road Diesel Rule, the Heavy Duty Diesel Rule, Light-Duty Vehicle Tier 2, and the NO_x SIP Call. These rules will produce substantial reductions in SO_2, NO_x and directly emitted $PM_{2.5}$, thereby reducing the target reductions many states will set during implementation of the revised $PM_{2.5}$ NAAQS below the levels that would otherwise need to set.

2.3.2 Rules Included in 2015 and 2020 Baselines

We have included nearly all national rules and many local rules and consent decrees in our preparation of emissions for 2015 and 2020. These rules can be divided into three categories: EGUs, non-EGU stationary sources, and mobile sources. The following 3 subsections provide details on the rules included.

EGU Emission Sources

The power sector emission projections include title IV of the Clean Air Act (the Acid Rain Program), the NO_x SIP Call, various New Source Review (NSR) settlements, and several State rules affecting emissions of SO_2, NO_x, Hg, and CO_2 that were finalized prior to April of 2004. The NSR settlements include agreements between EPA and Southern Indiana Gas and Electric Company (Vectren), Public Service Enterprise Group, Tampa Electric Company, We Energies (WEPCO), Virginia Electric & Power Company (Dominion), and Santee Cooper. The Integrated Planning Model (IPM) also includes various current and future State programs in Connecticut, Illinois, Maine, Massachusetts, Minnesota, New Hampshire, North Carolina, New York, Oregon, Texas, and Wisconsin. IPM includes State rules that have been finalized and/or approved by a State's legislature or environmental agency as of April, 2004.

In addition, the power sector modeling includes three recently finalized rules; CAIR, CAMR, and CAVR. These rules begin to come into effect in 2009 and will result in significant reductions of SO_2, NO_x, and Hg from the power sector. Figure 2-7 illustrates the emission cap levels for the power sector under CAIR, CAMR and CAVR. Figure 2-8 illustrates the historical and projected state-wide emissions from EGU's.

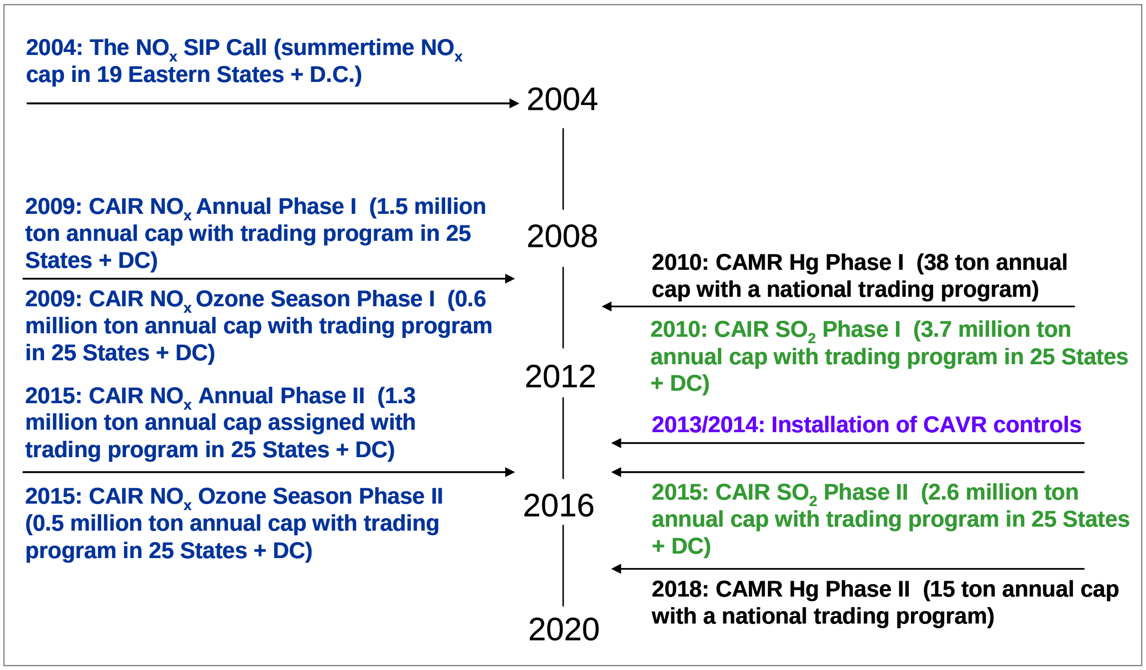


Figure 2-7. Emission Cap Levels and Timing for the Electric Power Sector under CAIR/CAMR/CAVR

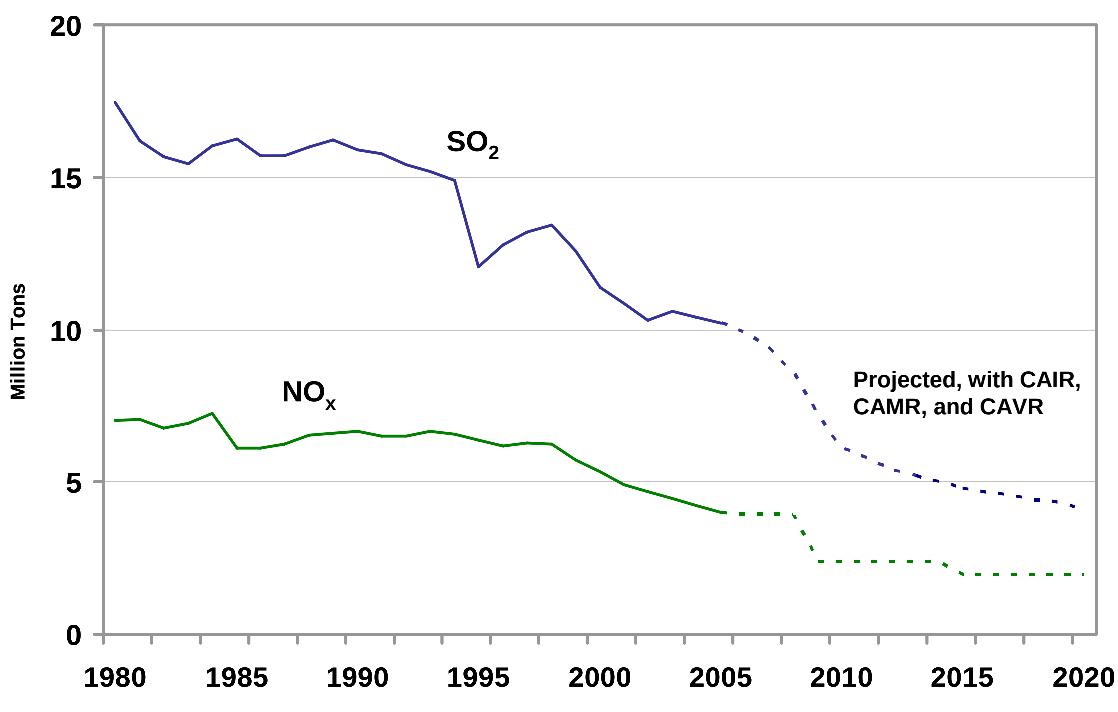


Figure 2-8. Historical and Projected Nationwide SO_2 and NOx Emissions from EGUs (million tons)

Reductions from Stationary non-EGU emission sources

The non-EGU point and stationary area source emissions category include reductions from most national rules, with the exception of the Clean Air Visibility Rule (CAVR) which was included in the EGU emissions. Although we anticipate that CAVR will impact some non-EGU point sources, the information needed to determine which sources are affected by this rule was not available in time for our modeling work. Since that time, Regional Planning Organizations have in some cases determined which facilities are affected by CAVR.

The rules which become effective between 2015 and 2020 contain controls we used for projecting future non-EGU point and stationary area emissions are listed in Table 2-4, along with the pollutants reduced by each. A “X” in a cell of the table indicates that we assumed some reduction from the control described. The reductions in some cases were facility-specific; therefore, it is not possible to include the exact reductions assumed here. The “All” column indicates that all criteria pollutants were reduced; this only happens in the case of plant closures.

Table 2-4: List of emissions reduction types included for non-EGU stationary sources

Type	*Summary Description*	*All*	*VOC*	*NO_x*	*SO_2*	*PM_{10}*	*$PM_{2.5}$*
Local	Atlanta SIP: Control on large nonEGU Point sources			X			
	Bay Area SIP: Foam Product Manufacturing		X				
	Bay Area SIP: Fugitive Emisssions, Refinery		X				
	Bay Area SIP: Prohibition of Contaminated Soil		X				
	Bay Area SIP: Surface Prep and Cleanup Standard		X				
	Dallas SIP: Cement Kiln Emission Limits			X			
	Dallas SIP: Point Source NOx Rules			X			
	St. Louis SIP: Industrial Surface Coating Manufacturing		X				
Closures	Auto plant closures	X					
	Coke oven closures	X					
	Libby MT closures	X					
	Medical Waste Combustor closures	X					
	Pulp and paper closures	X					
	Refinery closure	X					
Settlements	DOJ Settlements			X	X		
	Refinery consent decrees			X	X	X	X
National	NOX SIP Call, all affected nonEGUs			X			
	NOX SIP Call, Cement plant review			X			
	Hospital/Medical/Infectious Waste Incineration (HMIWI) Rule			X	X	X	X
	MACT: Asphalt Processing & Roofing		X				
	MACT: Auto & Light Duty Truck Surface Coating		X				
	MACT: Cellulose Products Manufacturing (Rayon production)		X				
	MACT: Combustion Sources at Kraft, Soda and Sulfite Pulp & Paper Mills		X				
	MACT: Commercial Sterilizers		X				
	MACT: Fabric Printing, Coating and Dyeing		X				
	MACT: Gas Distribution (Stage 1)		X				
	MACT: General MACT (Spandex production)		X				
	MACT: Generic MACT (Ethylene manufacture)		X				
	MACT: Hazardous Organic NESHAP (SOCMI industry)		X				
	MACT: Industrial, Commercial, and Institutional Boilers and Process Heaters					X	X
	MACT: Iron & Steel Foundries		X				
	MACT: Large Appliances Surface Coating		X				
	MACT: Lime Manufacturing				X	X	X
	MACT: Metal Can Surface Coating		X				
	MACT: Metal Coil Surface Coating		X				
	MACT: Metal Furniture Surface Coating		X				

Type	*Summary Description*	*All*	*VOC*	*NO_x*	*SO_2*	*PM_{10}*	*$PM_{2.5}$*
	MACT: Misc. Metal Parts & Products Surface Coating		X				
	MACT: Miscellaneous Coating Manufacture		X				
	MACT: Miscellaneous Organic Chemical Manufacturing (Alkyd resins)		X				
	MACT: Miscellaneous Organic Chemical Manufacturing (Chelating Agents)		X				
	MACT: Miscellaneous Organic Chemical Manufacturing (Explosives)		X				
	MACT: Miscellaneous Organic Chemical Manufacturing (Phthalate plasticizers)		X				
	MACT: Miscellaneous Organic Chemical Manufacturing (Polyester resins)		X				
	MACT: Municipal Solid Waste Landfills		X				
	MACT: Oil and natural gas		X				
	MACT: Paper and Other Web Surface Coating		X				
	MACT: Petroleum Refineries		X				
	MACT: Pharmaceutical Production		X				
	MACT: Plastic Parts and Products Surface Coating		X				
	MACT: Plywood & Composite Wood Products		X				
	MACT: Polymers & Resins III (phenol resins)		X				
	MACT: Polymers and Resins IV, Acrylonitrile manufacture		X				
	MACT: Polyvinylidene chloride		X				
	MACT: Portland Cement Manufacturing					X	X
	MACT: Publicly Owned Treatment Works		X				
	MACT: Reinforced Plastics Composites Production		X				
	MACT: Rubber tire manufacture		X				
	MACT: Secondary Aluminum					X	X
	MACT: Taconite Iron Ore Processing					X	X
	MACT: Wet Formed Fiberglass Mat Production		X				
	MACT: Wood Building Products		X				

On-Road and Nonroad Mobile Emission Sources

The on-road and nonroad mobile projected base case emissions used for this work include emissions reductions achieved by all national rules through August 4, 2006, including:

- Nonroad Diesel Rule
  - http://www.epa.gov/nonroad-diesel/2004fr/420f04029.htm
- NonRoad Engine Rule
  - http://www.epa.gov/otaq/regs/nonroad/2002/f02037.pdf
- Tier 2 Vehicle and Gasoline Sulfur Program
  - http://www.epa.gov/otaq/regs/ld-hwy/tier-2/index.htm
- Heavy Duty Diesel (Trucks & Buses) Rule
  - http://www.epa.gov/otaq/regs/hd-hwy/2000frm/f00026.pdf

There have been no new OTAQ rules finalized since the mobile inventories developed for this work were created in 2006.

For a complete set of OTAQ's rules affecting nonroad equipment, readers should refer to the EPA web site http://www.epa.gov/nonroad. For a complete set of OTAQ's rules affecting onroad vehicles, readers should refer to the EPA web site http://www.epa.gov/otaq/hwy.htm.

2.3.3 Emission Inventory Platform Changes

In Section 1.4.1, we provided an overview about the updates to the emissions inventory platform as compared to the platform used for CAIR. This section describes these changes in more detail.

Changes in Non-EGU Sectors

As described previously, an "emissions inventory platform" is made up of the collection of emissions data and emissions processing assumptions used to create inputs to the CMAQ and AERMOD models. The platform used for this RIA is based on the emissions work originally prepared for the Clean Air Interstate Rule. Since then, EPA has made a number of updates to the platform in order to improve the technical basis for the modeling work done for the current RIA. This section provides details on those updates.

Natural Gas Combustion PM Emissions. In June 2005, EPA released new emission factors for PM_{10} and $PM_{2.5}$ emissions from natural gas combustion that were significantly lower than those used to compute the inventories used for CAIR. For this RIA, we used ratios of the new emission factors to the old emission factors to adjust the CAIR 2001 emissions. For PM_{10} the resulting adjustment decreased emissions from these sources by 93% to 95%, depending on the process. For $PM_{2.5}$ the resulting emissions from these sources decrease by 94% to 97%, depending on the processes. The net result of these adjustments was a significant decrease in $PM_{2.5}$ and PM_{10} emissions from all natural gas combustion sources for EGUs, non-EGU point sources, and stationary area sources.

Facility-Specific Inventory Updates. Several facility-specific inventory updates were made, some of which were based on comments received during development of CAIR. These are listed here:

- We lowered SO_2 emissions from the Alumnitec plant in Garland County, Arkansas to reduce 2001 emissions from 34,350 tons/yr to 1.2 tons/yr, based on CAIR comments from the State of Arkansas about a permit limit for this facility. This had impacts on 2015 and 2020 emissions. Although the reduction as compared to CAIR in those years is confounded by other changes made to the non-EGU point projections, they are at least as large as the 2002 reduction.

- We updated non-EGU point emissions for eleven North Dakota facilities based on CAIR comments. These updates inserted new SO_2 and $PM_{2.5}$ emissions as provided by North Dakota, resulting in the following significant emissions changes:
    - NO_X increased 3,178 tons/year
    - $PM_{2.5}$ increased 1,058 tons/year
    - SO_2 decreased 44,550 tons/year

- We reduced overestimated 2001 NH_3 emissions from 3,276 tons/yr to 472 tons/yr at the IMC Phosphates Company's Faustina Plant in St. James Parrish, Louisiana, based on the 2002 NEI. This change also reduced future-year emissions from the CAIR platform by a similar percentage (in combination with other changes documented here).

- We reduced overestimated 2001 $PM_{2.5}$ and SO_2 emissions at the Blue Circle Cement, Atlanta Plant (now known as the Lafarge Plant) in Fulton County, Georgia; SO_2 emissions were reduced from 8,863 to 1,617 tons/year, and. $PM_{2.5}$ emissions were reduced from 4,829 to 27 tons/year. We reduced PM_{10} emissions by the same fraction as the $PM_{2.5}$ emissions, though these emissions have little impact on this analysis. These changes were based on the 2002 NEI emissions for the plant documented in that inventory as the Lafarge Plant.

- There were a number of other non-EGU point changes that were not made to the modeled inventories, but were accounted for in the analysis of control strategies, where the affected counties were in the controlled regions. The county totals of these changes are shown in Table 2-5, below.

Table 2-5: Non-EGU Point Changes Accounted for in the Selection of Controls But Not Made to the Emissions Inventory Used for Modeling

State	*County*	*$PM_{2.5}$ Used*	*Improved $PM_{2.5}$ Estimate*
California	San Bernardino Co	2,368	1,228
Connecticut	New London Co	494	74
Florida	Escambia Co	7,564	2,533
Florida	Okaloosa Co	5,299	0
Florida	Polk Co	2,410	28
	Florida Subtotal	15,273	2,561
Georgia	De Kalb Co	1,029	1
Georgia	Floyd Co	5,776	96
Georgia	Fulton Co	12,519	39
Georgia	Glynn Co	485	11
	Georgia Subtotal	19,808	147
Maine	Aroostook Co	4,049	88
Minnesota	Koochiching Co	1,741	92
New Mexico	San Juan Co	1,363	791
Wyoming	Laramie Co	1,115	0
	Total	46,210	4,981

Year 2000-based future-year Canadian emissions. We incorporated newly-provided Canadian emissions for the year 2000, the latest publicly available data provided by Canada. We had used 1996-specific data for the CAIR modeling. The new data includes both 2000-specific data that we used in modeling 2001, as well as data projected to 2015 and 2020 that we used for our 2015 and 2020 modeling cases. These 2000-based data are available at http://www.epa.gov/ttn/chief/net/canada.html#data. The primary impacts of these data are shown in Table 2-6, which shows Canadian emissions for the base and future baseline runs. These impacts included increasing the coverage of the Canadian point source inventory to the western and northern Provinces.

Table 2-6: Comparison of base and future Canadian emissions data used for CAIR with data used for PM NAAQS platform.

Year and platform	Sector	VOC	NO_X	CO	SO_2	PM_{10}	PM_{25}	NH_3
2001 CAIR	point	168,510	165,379	745,280	1,531,262			1,046
	oarea	1,534,896	266,846	1,179,560	229,949	1,348,873	321,025	532,747
	onroad	642,127	1,076,261	5,835,996	24,721	44,033	40,999	20,876
	nonroad	389,189	872,434	3,511,506	97,051	65,736	57,372	1,295
2001 PM NAAQS	point	292,001	722,372	1,333,091	2,298,482	257,818	139,611	26,185
	oarea	1,697,011	396,215	1,802,167	202,456	1,538,716	393,076	591,848
	onroad	446,357	936,741	6,311,110	28,004	21,181	19,432	19,691
	nonroad	354,704	773,868	2,915,516	63,258	68,737	60,054	997
% Differences	point	73%	337%	79%	50%			2403%
	oarea	11%	48%	53%	-12%	14%	22%	11%
	onroad	-30%	-13%	8%	13%	-52%	-53%	-6%
	nonroad	-9%	-11%	-17%	-35%	5%	5%	-23%
2015 CAIR	point	168,510	165,379	745,280	1,531,262			1,046
	oarea	1,702,479	273,048	1,290,294	184,471	1,755,401	407,052	532,786
	onroad	184,525	425,252	1,846,188	1,894	10,564	9,758	20,704
	nonroad	279,865	834,120	4,193,585	92,432	54,228	45,917	1,295
2015 PM NAAQS	point	352,933	936,225	1,779,640	2,263,622	313,445	192,427	36,539
	oarea	1,980,323	546,792	2,580,300	217,318	2,029,769	521,416	334,398
	onroad	161,610	303,018	3,868,575	29,758	2,789	4,614	4,269
	nonroad	309,134	725,271	3,425,397	1,100	45,839	53,584	45,454
% Differences	point	109%	466%	139%	48%			3393%
	oarea	16%	100%	100%	18%	16%	28%	-37%
	onroad	-12%	-29%	110%	1471%	-74%	-53%	-79%
	nonroad	10%	-13%	-18%	-99%	-15%	17%	3410%
2020 CAIR	point	168,510	165,379	745,280	1,531,262			1,046
	oarea	1,702,479	273,048	1,290,294	184,471	1,755,401	407,052	532,786
	onroad	184,525	425,252	1,846,188	1,894	10,564	9,758	20,704
	nonroad	279,865	834,120	4,193,585	92,432	54,228	45,917	1,295
2020 PM NAAQS	point	363,753	947,153	1,837,407	2,246,305	325,113	198,792	38,923
	oarea	1,961,958	540,043	2,060,965	361,421	216,806	2,152,792	500,377
	onroad	142,543	198,910	3,803,189	33,237	3,112	3,568	3,376
	nonroad	309,134	725,271	3,425,397	1,100	45,839	53,584	45,454
% Differences	point	116%	473%	147%	47%			3621%
	oarea	15%	98%	60%	96%	-88%	429%	-6%
	onroad	-23%	-53%	106%	1655%	-71%	-63%	-84%
	nonroad	10%	-13%	-18%	-99%	-15%	17%	3410%

Residential Wood Combustion. We replaced earlier data on residential wood combustion emissions with data from the 2002 National Emission Inventory (final, February 2006) for that sector. This included all emissions from fireplaces and woodstoves, much of which was submitted after extensive and thorough preparation of these data by the states. This update extensively affected VOC and $PM_{2.5}$ emissions. Table 2-6 lists residential wood combustion VOC and $PM_{2.5}$ emissions by state, and compares the data used for the CAIR analysis with the numbers we used for the current RIA. In addition, we modified the projection method for this sector to no longer use DOE estimates of wood fuel usage and instead use a 1% growth rate in new woodstoves and a 1% decrease in old woodstoves. These rates were applied nationally and result in an overall decrease in emissions from 2001 to 2020 using the new approach, since new woodstoves emit far less than old ones. The data to support this change was collected as part of the woodstove change-out program development in OAQPS. These changes affects both current and projected emissions from this source category.

Table 2-7: Changes to 2001 and 2020 emissions from residential wood combustion sector

	2001 VOC		2020 VOC		2001 PM2.5		2020 PM2.5	
State	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*
Alabama	11,210	54,987	4,206	44,540	4,271	4,009	2,804	2,748
Arizona	5,369	7,224	1,879	6,158	1,794	2,066	1,099	1,552
Arkansas	7,411	6,178	2,075	5,004	2,815	2,485	1,379	2,013
California	57,849	19,193	17,979	16,416	19,615	39,756	10,668	34,779
Colorado	14,234	35,495	4,982	36,285	4,752	11,388	2,910	10,511
Connecticut	9,044	82,136	2,355	81,725	3,664	8,521	1,670	6,902
Delaware	2,848	5,952	1,029	4,821	1,306	1,228	826	995
District of Columbia	704	247	254	229	217	84	137	64
Florida	24,163	12,030	8,728	10,840	10,268	4,398	6,490	3,276
Georgia	21,945	15,633	7,926	13,254	9,588	6,499	6,060	4,706
Idaho	5,241	14,979	1,834	12,133	1,891	2,263	1,158	1,833
Illinois	29,187	33,473	10,542	33,924	9,127	7,517	5,769	5,692
Indiana	46,732	10,932	16,880	9,347	16,351	4,259	10,336	2,998
Iowa	13,928	13,632	2,847	11,348	4,313	5,864	1,543	4,217
Kansas	14,568	18,535	2,978	19,159	4,538	4,464	1,623	3,720
Kentucky	19,568	17,305	7,342	14,345	7,473	7,501	4,907	5,385
Louisiana	7,772	5,582	2,176	4,734	3,162	2,319	1,549	1,679
Maine	11,862	59,816	3,089	48,451	5,346	12,570	2,436	10,181
Maryland	17,297	39,434	6,248	31,942	7,643	8,194	4,831	6,637
Massachusetts	16,965	66,217	4,418	53,636	7,303	13,689	3,328	11,088
Michigan	41,525	32,539	14,999	31,760	17,142	8,139	10,836	5,773
Minnesota	36,113	38,159	7,381	37,464	11,986	11,312	4,287	9,062
Mississippi	6,515	22,689	2,444	20,837	2,732	4,829	1,794	3,445
Missouri	28,962	25,201	5,920	20,114	9,916	11,580	3,547	8,166
Montana	7,082	7,488	2,479	6,349	2,561	3,025	1,569	2,169
Nebraska	4,101	4,935	838	4,107	1,299	2,124	465	1,527
Nevada	1,837	3,532	643	3,560	629	1,083	386	932
New Hampshire	9,133	38,652	2,378	31,308	3,777	8,019	1,721	6,496
New Jersey	26,977	40,494	7,478	34,147	11,413	9,361	5,537	7,786
New Mexico	4,810	3,989	1,684	3,456	1,704	1,565	1,044	1,133
New York	90,283	366,610	25,027	296,950	38,875	60,584	18,858	49,073

	2001 VOC		2020 VOC		2001 PM2.5		2020 PM2.5	
State	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*	*CAIR*	*PMNAAQS*
North Carolina	27,724	24,321	10,014	20,231	11,732	10,477	7,416	7,531
North Dakota	5,071	4,904	1,036	4,199	1,669	2,000	597	1,454
Ohio	30,882	14,962	11,154	12,119	11,626	8,937	7,349	7,239
Oklahoma	7,391	7,148	2,070	5,885	2,629	3,136	1,288	2,246
Oregon	14,919	125,937	4,637	134,065	5,223	36,859	2,841	34,229
Pennsylvania	39,109	25,537	10,841	22,002	16,795	10,286	8,147	7,497
Rhode Island	1,986	1,097	517	1,016	665	375	303	284
South Carolina	12,326	48,863	4,452	54,721	5,596	5,261	3,537	3,649
South Dakota	5,976	5,844	1,222	5,027	2,034	2,361	728	1,720
Tennessee	19,238	16,844	7,218	13,973	7,486	7,048	4,915	5,074
Texas	24,904	22,760	6,973	19,379	8,417	8,554	4,124	6,155
Utah	4,489	4,471	1,571	3,622	1,456	1,465	892	1,187
Vermont	5,268	9,944	1,372	9,171	2,416	3,663	1,101	2,983
Virginia	24,542	53,825	8,864	43,598	9,736	9,885	6,154	7,123
Washington	18,514	77,346	5,754	67,641	6,850	19,479	3,725	17,011
West Virginia	9,974	7,303	3,603	6,067	4,062	3,026	2,568	2,116
Wisconsin	39,802	98,891	14,377	107,994	13,808	20,802	8,728	19,857
Wyoming	3,750	3,772	1,312	3,342	1,190	1,432	728	1,058
US Total	**891,097**	**1,657,038**	**278,024**	**1,482,394**	**340,858**	**425,744**	**186,708**	**344,949**

Growth and Control Changes. Improving the emissions inventory and modeling platform for regulatory analyses is an ongoing process. One improvement made for this analysis is the method used to estimate future-year emissions for stationary non-EGU point and non-point sources. After observing a disconnect between our emissions forecasts and the historical record, we recognized the need to modify future-year emissions forecasts for these specific source categories. An examination of the historical data suggests our previous methods have over-predicted emissions especially in the longer-forecast periods required for the NAAQS and other programs. To address this issue, we developed an 'interim' emission projection approach that assumes no growth to emissions for many stationary non-EGU sources in estimating future-year emissions. This change does not impact mobile sources and EGUs future-year emission estimates. We believe this methodology better aligns our forecasts of future growth in the stationary non-EGU sectors with historical trends. It is our intent that this interim forecasting approach provides some understanding of the potential uncertainties implied by the past methodology and the historical record for the stationary non-EGU source categories. In the future, we intend to pursue improved methods and models that provide more consistency with the historical record and reasonable assumptions regarding future conditions. More information is provided in Appendix D on the interim approach and a sensitivity analysis of the implications of this method relative to our previous forecasting methods.

Assumptions regarding the projection of the emissions inventory have implications for our estimates of emission control cost and monetized human health benefits. To the extent that we over-estimate growth in future emissions, then we apply emission controls to reduce emissions beyond a level necessary to meet attainment. This "over-control" would then bias control costs upwards; it would also bias estimated benefits high, as we would monetize the human health benefits of achieving a larger increment of air quality change than necessary to reach attainment.

Conversely, if we under-estimate future emissions growth, then we fail to apply enough emission controls to attain fully. This “under-control” would then bias both estimated control cost low; it would also bias estimated benefits low, as we would monetize the human health benefits of achieving a smaller increment of air quality change than necessary to reach attainment. We believe our ‘interim’ method reduces the bias in future-year estimates used in this analysis compared to our approach in the RIA for the proposed rule.

Due to the significance of this emissions inventory forecasting assumption, EPA consulted with the Advisory Council on Clean Air Compliance Analysis and the Air Quality Modeling Subcommittee (Council) of the Science Advisory Board (SAB) on August 31, 2006 by public teleconference. In the consultation, EPA requested advice as to proper characterization of the interim emissions forecasting approach and the uncertainties involved. The review of this methodological assumption was completed on an expedited basis by the Council. On September 15, 2006, the Council members issued a letter to the EPA Administrator Stephen L. Johnson reporting their findings. In this letter, the Council recommended an alternative forecasting methodology for the stationary non-EGU source categories as preferred to the method used in this RIA. The Council members suggested the alternative would capture “the underlying technological change that is likely driving the historical decline in emissions, i.e., the efficiency gains in production processes and improvements in air pollution control technologies that can be expected over time.” Specifically, the Council suggested using the National Emission Inventory in the 1990s to establish a declining emissions intensity as it relates to changes in the output by sector. As a default, the Council recommended assuming this historical rate of decline would continue to be constant in future years. In the letter to Administrator Johnson, the Council members did recognize that the time constraints involved with the PM NAAQS review and the limitations that might result in the EPA’s ability to accomplish their recommendations.

In response to the Council’s recommendations, the EPA did endeavor to conduct a limited analysis using the Council’s recommended approach for three important non-EGU stationary source sectors including Pulp and Paper Manufacturing, Petroleum Refining, and Chemicals and Allied Products for SO_2 emissions only. The court-ordered schedule for the PM NAAQS review did not allow for further investigation of this method for all non-EGU stationary source categories or relevant pollutants. We found that the Council’s suggested approach resulted in essentially a downward trend in future year SO_2 emissions for these source categories implying negative emissions growth in the future for these source categories. Using an approach similar to the Council’s suggested approach, future-year emissions would decline significantly from 2002 to 2020 for these industries. This result occurs because historical emissions reductions used in this analysis could not be directly attributed to Clean Air Act mandated controls and therefore the entire declining SO_2 emission trend for these three sectors was assumed to continue into the future. We recognize the limitations of this analysis since some historical emission reductions may have been due to Clean Air Act mandated controls (e.g., SIPs, NSPS) that are applied to individual facilities (rather than mandated controls that would be applicable to the entire sector), but given the limited time and quality of the control information in the emission inventory an accurate attribution of these historical emission reductions to the Clean Air Act was not possible. The EPA recognizes the need to find an improved growth forecasting methodology for the stationary non-EGU sectors and is committed to developing the necessary methods and models to achieve this goal in the near future. More information on this issue and copies of the background paper presented to the Council members are included in Appendix D of this document.

Changes to Assumptions for Key Sectors in Nonattainment Areas

In addition to the changed growth assumption, we made a variety of key improvements to our assumptions that we considered most relevant for PM nonattainment areas. One general aspect of these changes was to identify some facilities that were actually closed in 2001, but which were included in our 2001 modeling prior to the discovery of that issue. For all such facilities, we ensured that future-year emissions were identical to base-year emissions, so that the difference between a future baseline run and 2001 would be zero. This approach, which we refer to below as the "no impact approach," causes such sources to have minimal impact on the calculation of future-year nonattainment estimates. Since this calculation applies the difference between 2001 and the future baseline to the ambient data, a difference of zero minimizes the effect of such sources on the calculation.

The following list below provides details on updates made to the control part of our projections for stationary non-EGU sources:

- For the pulp and paper industry, we applied the "no impact approach" to several facilities that closed prior to 2001.

- For the pulp and paper industry, we also reflected plant closures for facilities that have closed since 2001.

- We added consent decrees reducing NOx, SO_2 and $PM_{2.5}$ emissions from the refineries listed in Table 2-7.

- We removed any VOC reductions from MACT programs that had implementation dates prior to 2001.

- We eliminated reductions from control programs which we assessed had reductions that would be accounted for using our growth assumption. Consequently, we did not assume any additional reductions from the NSPS or RICE programs.

- We added existing and planned automobile plant closures, some of which were announced in 2005.

- We removed industrial facilities in Lincoln County, Montana that had closed since 2001.

- We reviewed the NO_X SIP Call reductions for cement plants and made updates to these where needed.

- The CAIR on-road mobile emissions did not completely account for the effects of recent emissions standards that affect the PM emissions for 2007 and newer model year heavy duty diesel vehicles. As a result of this issue, CAIR PM emissions for 2010, 2015, and 2020 from heavy duty vehicles were slightly higher than OTAQ intended and did not reflect the complete benefits of the emission standards described in the rule. This issue was corrected in this platform. The net impact on $PM_{2.5}$ emissions from mobile sources was a 11% reduction in on-road mobile $PM_{2.5}$ in 2020; this decrease is reflected in our analysis for the current RIA.

Table 2-8: Changes to refinery emissions based on consent decrees

			NOX			SO2			PM2.5		
State	County	Plant	2001	2015	% Diff	2001	2015	% Diff	2001	2015	% Diff
Arkansas	Union Co	LION OIL COMPANY	1,881	1,881	0%	972	850	-13%	268	268	0%
California	Contra Costa Co	CHEVRON PRODUCTS COMPANY	2,560	1,643	-36%	1,143	1,008	-12%	248	248	0%
California	Contra Costa Co	MARTINEZ REFINING COMPANY	3,262	3,262	0%	1,155	867	-25%	508	508	0%
California	Los Angeles Co	ARCO PRODUCTS CO	2,536	1,962	-23%	3,227	2,262	-30%	433	433	0%
California	Los Angeles Co	ULTRAMAR INC (NSR USE ONLY)	331	331	0%	248	239	-3%	153	153	0%
California	Los Angeles Co	CHEVRON PRODUCTS CO.	1,674	921	-45%	1,222	618	-49%	65	65	0%
California	Los Angeles Co	HUNTWAY REFINING CO (EIS USE	7	7	0%	0	0	-90%	0	0	0%
California	Los Angeles Co	MOBIL OIL CORP (EIS USE)	1,668	504	-70%	1,001	1,001	0%	211	211	0%
California	Solano Co	EXXONMOBIL REFINING AND SUPPLY	3,257	3,257	0%	5,830	3,767	-35%	168	168	0%
Colorado	Adams Co	CONOCO INC DENVER REFINERY	814	562	-31%	2,538	601	-76%	218	218	0%
Colorado	Adams Co	COLORADO REFINING CO TOTAL PETROLEUM	260	234	-10%	531	10	-98%	471	266	-43%
Delaware	New Castle Co	MOTIVA ENTERPRISES, LLC - DELAWARE CITY	5,301	3,617	-32%	38,183	9,755	-74%	280	158	-43%
Hawaii	Honolulu Co	CHEVRON- HAWAII REFINERY	2,221	2,018	-9%	4,369	1,829	-58%	376	376	0%
Illinois	Crawford Co	MARATHON ASHLAND PETROLEUM LLC	5,944	3,575	-40%	4,093	406	-90%	400	400	0%
Illinois	Madison Co	CLARK REFINING AND MARKETING INC	1,475	0	-100%	5,721	0	-100%	110	0	-100%
Illinois	Madison Co	EQUILON ENTERPRISES LLC	10,750	10,146	-6%	36,262	8,455	-77%	947	762	-19%
Illinois	Will Co	CITGO PETROLEUM CORP-LEMONT REFINERY	2,700	1,844	-32%	20,358	1,697	-92%	379	315	-17%
Illinois	Will Co	MOBIL OIL-JOLIET REFINING CORP.	3,195	1,664	-48%	25,203	14,694	-42%	267	148	-44%
Kansas	Mc Pherson Co	NATIONAL COOPERATIVE REFINERY ASSN	1,421	1,256	-12%	2,336	1,378	-41%	344	344	0%
Kentucky	Boyd Co	MARATHON ASHLAND PET LCC	4,279	2,834	-34%	6,868	775	-89%	261	261	0%
Louisiana	Calcasieu Par	CONOCO INC/LAKE CHARLES REFINERY	1,487	985	-34%	1,719	1,148	-33%	1,176	1,176	0%
Louisiana	Calcasieu Par	CITGO PETROLEUM CORP/LAKE CHARLES MFG CM	8,164	5,715	-30%	8,083	345	-96%	663	663	0%
Louisiana	East Baton Rouge Par	EXXONMOBIL REF & SUPPLY CO/B R REFINERY	3,291	2,107	-36%	3,578	679	-81%	1,057	1,057	0%
Louisiana	Plaquemines Par	TOSCO REFINING CO/ALLIANCE REFINERY	4,582	4,582	0%	5,046	3,021	-40%	1,421	1,421	0%
Louisiana	St Bernard Par	MOBIL OIL CORP/CHALMETTE REFINERY	2,174	1,304	-40%	462	462	0%	494	494	0%
Louisiana	St Charles Par	ORION REFINING CORP	1,104	1,104	0%	606	545	-10%	42	42	0%
Louisiana	St John The Baptist	MARATHON ASHLAND PETROLEUM LLC/GARYVILLE	2,399	1,470	-39%	317	136	-57%	238	238	0%
Louisiana	St Landry Par	VALERO REFINING CO/KROTZ SPRINGS REFINER	491	422	-14%	634	350	-45%	140	140	0%
Michigan	Wayne Co	MARATHON ASHLAND PETROLEUM LLC	2,349	2,139	-9%	1,514	459	-70%	156	156	0%
Minnesota	Dakota Co	Koch Petroleum Group LP - Pine Bend	3,783	2,286	-40%	2,585	786	-70%	272	229	-16%
Minnesota	Washington Co	Marathon Ashland Petroleum LLC	844	509	-40%	1,476	492	-67%	292	292	0%
Mississippi	Jackson Co	CHEVRON USA	4,675	3,174	-32%	5,965	4,375	-27%	0	0	
Mississippi	Warren Co	ERGON REFINING INC	46	28	-39%	9	9	0%	0	0	0%
Montana	Cascade Co	MONTANA REFINING	80	48	-41%	779	116	-85%	16	16	0%
Montana	Yellowstone Co	CONOCO	683	434	-37%	1,233	1,016	-18%	138	138	0%
Montana	Yellowstone Co	CENEX	897	596	-34%	3,270	2,175	-33%	129	65	-49%
Montana	Yellowstone Co	EXXON CO USA	715	467	-35%	2,941	1,614	-45%	270	270	0%
New Jersey	Gloucester Co	Valero Refining Co.- N.J.	1,338	736	-45%	5,037	50	-99%	150	15	-90%
New Mexico	Eddy Co	ARTESIA REFINERY	370	221	-40%	1,816	83	-95%	243	43	-82%
Ohio	Lucas Co	SUN COMPANY, INC.	2,685	1,380	-49%	6,016	1,415	-76%	254	79	-69%
Ohio	Lucas Co	BP OIL COMPANY, TOLEDO REFINERY	1,880	1,591	-15%	1,326	762	-43%	260	260	0%

Ohio	Stark Co	MARATHON ASHLAND PETROLEUM LLC, CANTON R	862	737	-14%	798	332	-58%	36	36	0%
Oklahoma	Carter Co	TPI PETROLEUM, INC.	523	523	0%	506	73	-86%	451	115	-74%
Oklahoma	Kay Co	CONOCO INC.	3,060	2,024	-34%	2,937	1,082	-63%	155	155	0%
Oklahoma	Tulsa Co	SUN COMPANY INC.	594	357	-40%	2,875	369	-87%	51	51	0%
Pennsylvania	Delaware Co	BAYWAY REF CO/MARCUS HOOK REF	2,044	1,947	-5%	1,686	143	-92%	150	72	-52%
Pennsylvania	Delaware Co	SUNOCO INC (R&M)/MARCUS HOOK REFINERY	1,593	993	-38%	4,769	2,950	-38%	117	60	-49%
Pennsylvania	Delaware Co	FPL ENERGY MH50 LP/MARCUS HOOK	19	11	-40%	0	0	0%	0	0	0%
Pennsylvania	Philadelphia Co	SUN REFINING (FORMERLY CHEVRON)	3,023	1,674	-45%	5,124	487	-90%	419	419	0%
Pennsylvania	Philadelphia Co	SUN REFINING & MARKETING CO.	1	1	0%	1	0	-90%	0	0	
Texas	Galveston Co	BP AMOCO TEXAS CITY BUSINESS UNIT	7,439	4,448	-40%	7,673	774	-90%	607	315	-48%
Texas	Galveston Co	MARATHON ASHLAND PETROLEUM LLC	848	493	-42%	1,773	35	-98%	251	51	-80%
Texas	Galveston Co	VALERO REFINING CO - TEXAS	1,956	1,690	-14%	1,077	236	-78%	343	88	-74%
Texas	Harris Co	EXXONMOBIL REFINING & SUPPLY CO	7,548	5,097	-32%	1,073	295	-73%	500	409	-18%
Texas	Harris Co	SHELL OIL CO	8,136	8,136	0%	11,902	2,160	-82%	401	401	0%
Texas	Hutchinson Co	PHILLIPS 66CO	2,712	2,712	0%	10,615	789	-93%	0	0	
Texas	Jefferson Co	MOBIL OIL CORPORATION	6,827	4,126	-40%	14,012	384	-97%	136	108	-21%
Texas	Live Oak Co	DIAMOND SHAMROCK REFINING CO LP	535	535	0%	609	564	-7%	89	89	0%
Texas	Nueces Co	CITGO REFINING & CHEMICALS CO	1,787	1,083	-39%	2,029	712	-65%	250	250	0%
Texas	Nueces Co	COASTAL REFINING AND MARKETING INC	1,786	1,670	-7%	3,597	1,808	-50%	340	270	-21%
Texas	Nueces Co	VALERO REFINING CO--TEXAS	1,509	1,275	-16%	186	147	-21%	245	84	-66%
Texas	Nueces Co	KOCH PETROLEUM GROUP LP	697	551	-21%	182	20	-89%	201	34	-83%
Texas	Nueces Co	KOCH PETROLEUM GROUP LP	2,071	2,063	0%	153	152	-1%	64	63	-2%
Texas	Nueces Co	CITGO REFINING & CHEMICALS CO LP	317	191	-40%	170	143	-16%	32	32	0%
Utah	Davis Co	SALT LAKE REFINERY	582	416	-29%	795	289	-64%	106	90	-14%
Utah	Salt Lake Co	SALT LAKE CITY REFINERY	558	441	-21%	1,162	682	-41%	40	40	0%
Virginia	York Co	BP AMOCO PETROLEUM PRODUCTS - YORKTOWN	3,393	3,281	-3%	3,960	1,534	-61%	412	412	0%
Washington	Skagit Co	PUGET SOUND REFINING COMPANY	922	922	0%	2,687	1,177	-56%	102	53	-48%
Washington	Whatcom Co	TOSCO REFINING COMPANY	726	726	0%	2,346	235	-90%	91	91	0%
Washington	Whatcom Co	ARCO CHERRY POINT REFINERY	2,739	2,169	-21%	1,816	929	-49%	100	100	0%

Other ancillary data changes. We determined that the organic carbon fraction in the speciation profile code "NCOAL" used for CAIR is not representative of most coal combustion occurring in the U.S. This profile has an organic carbon fraction of about 20%, which includes an adjustment factor of 1.2 to account for other atoms, like oxygen, that are attached to the carbon. For this work, we have reverted back to the profile code "22001" for coal combustion, which has an organic carbon fraction of 1.07% (again including the 1.2 factor adjustment). This is the same profile that EPA used for previous rulemaking efforts including the Heavy Duty Diesel Rule and Nonroad Rule, which were done (and publicly reviewed) prior to the introduction of the NCOAL profile. The impact of this change is significant in that it reduces the amount and severity of unrealistic organic carbon hotspots.

We also revised several key monthly temporal profile datasets, which we use to compute month-specific emissions from the annual inventory emissions. These revisions included:

- Updating a nondairy agricultural NH_3 monthly temporal profile, based on latest inverse modeling by EPA's Office of Research and Development (EPA ORD). This change improved the nitrate prediction performance by CMAQ.

- Revising a dairy cow monthly profile. This was a minor change.

- Updated residential wood combustion (RWC) monthly temporal profiles to include the latest data from the RPOs, 2002 NEI, and States. This change significantly improves the distribution of RWC emissions to reflect a more realistic, climate-specific distribution.

In addition, we have updated the $PM_{2.5}$ speciation factors for future-year gas and diesel speciation. We now use a different profile in the 2001 base and the future baseline runs that account for changes in the percentage of $PM_{2.5}$ emissions coming from brake and tire wear rather than exhaust. As emissions decrease in the future, a smaller proportion of emissions in the future are from exhaust, which has a different $PM_{2.5}$ species signature than brake and tire wear. This approach was used in the modeling for the Nonroad Rule and Heavy Duty Diesel Engine Rule, but was inadvertently left out of the CAIR modeling work. The impacts of this change are minimal.

Significant Processing Changes. Lastly, we included two significant software updates in this work. First, a new version of the SMOKE model is employed in our data processing. This version is largely the same as the version used for CAIR, with the exception of an updated plumerise algorithm, which changes the vertical distribution of emissions from large point sources. The new approach tends to have more emissions at the surface than the old approach, particularly during afternoon hours. Second, we used the Biogenic Emission Inventory System version 3.13 (BEIS3.13) instead of BEIS version 3.12, which was used for the CAIR modeling. While these are notable changes to the processing approach, the resulting impacts of both of these changes on the RIA results are minimal.

EGU Sector

EPA uses the Integrated Planning Model (IPM) to examine a broad variety of issues facing the electric power sector. IPM considers all aspects of wholesale generation resources, power system reliability, environmental compliance, fuel usage, transmission capability, capacity requirements, and other fundamental issues in developing forward forecasts for plant dispatch, power prices, and capacity and transmission expansion. IPM is unique in its ability to provide an assessment that integrates power, environmental and fuel markets. Structurally, IPM is a dynamic linear optimization model which enables the projection of the behavior of the power system over a specified future period. The optimization logic determines the least-cost means of meeting electric generation and capacity requirements while complying with specified constraints including air pollution regulations, transmission bottlenecks, fuel market restrictions and plant-specific operational constraints.

IPM is designed to accurately represent and forecast power sector dispatch, utilization, capital investments, and fuel forecasts, while also being able to forecast emissions from power sector sources. IPM produces unit specific emissions of SO_2, NO_x, Hg, and CO_2 for every power producing unit in the country. This data is then fed into air quality modeling and serves as the basis for the assessment of the environmental impacts of emissions from EGUs.

Since the time CAIR was finalized in March of 2005, EPA has updated the modeling done with IPM to better reflect the requirements under CAIR and also to incorporate more recent data. For example, a Final Rule to include Delaware and New Jersey in the annual CAIR requirements for SO_2 and NO_x was finalized in March, 2006. Modeling done for the Final CAIR (March, 2005) included these two States for the ozone-season NO_x requirements only.

Another important update to IPM is based upon more recent data regarding pollution controls, New Source Review (NSR) settlements, and consent decrees. EPA's last update to IPM occurred in early 2004, and since that time new pollution control equipment has either been installed or is under construction on various power facilities. In addition, there have been a number of NSR settlements and consent decrees requiring surrender of Title IV Acid Rain Program SO_2 allowances and/or installation of pollution controls on certain electricity generating facilities. EPA has documented these updates and will include this information in the next version of IPM (v3.0), to be completed in the fall of 2006. However, in light of the air quality issues in certain parts of the country, and aware that some of these new updates may have a significant positive impact on air emissions in these areas, EPA concluded that a small subset of these updates should be included in updated power sector modeling. The updates focused on areas of particular air quality concern: Atlanta, Georgia, Detroit, Michigan, Louisville, Kentucky, St. Louis, Missouri, and Steubenville, Ohio. EPA identified units in these areas that were projected to lack advanced pollution controls for SO_2 removal in 2020 based upon EPA's most recent IPM results from the fall of 2005, and applied pollution controls for SO_2, NO_x, and particulates to these units if new information was available indicating that those controls either exist on the units, are under construction, or will be installed based upon a recent consent decree or settlement. Table 2-8 summarizes the units and controls that were updated in IPM.

Table 2-8: Summary of Unit Updates Applied to IPM

Unit #	*State*	*County*	*Plant Name*	*NA Area*	*Controls Added*	*Year of Control Addition*	*PM Controls Added*
1	Georgia	Bowen	Bowen	Atlanta	Wet Scrubber	2010	---
3	Michigan	Monroe	Monroe	Detroit	Wet Scrubber	2007	---
4	Michigan	Monroe	Monroe	Detroit	Wet Scrubber	2007	---
1	Illinois	Randolph	Baldwin Energy Complex	St. Louis	Scrubber	2013	Baghouse
3	Illinois	Randolph	Baldwin Energy Complex	St. Louis	Scrubber	2013	Baghouse
6	Indiana	Jefferson	Clifty Creek	Louisville	Wet Scrubber	2010	
1	Ohio	Jefferson	W.H. Sammis[a]	Steubenville	SNCR	2007	Baghouse
2	Ohio	Jefferson	W.H. Sammis[a]	Steubenville	---	2007	Baghouse
3	Ohio	Jefferson	W.H. Sammis[a]	Steubenville	SNCR	2007	Baghouse
4	Ohio	Jefferson	W.H. Sammis[a]	Steubenville	SNCR	2007	Baghouse

[a] W.H. Sammis agreement calls for a plant-wide 50% SO_2 reduction requirement or 1.1 lbs mm/Btu in 2008.

The updated power sector emissions from revised modeling using IPM, which incorporate the changes previously discussed, were used in the analysis of both the 1997 PM NAAQS (15 μ/m^3 annual and 65 μ/m^3 daily) and the proposed revised standards (15 μ/m^3 annual and 35 μ/m^3 daily). For the other alternative standard (14 μ/m^3 annual, 35 μ/m^3 daily), additional changes were made to the power sector modeling and those changes are discussed in a subsequent chapter.

Another notable change to power sector assumptions is the siting of new power plants. In the past, EPA has assumed that all counties would be eligible for the siting of new power capacity, regardless of attainment status. EPA has revised this methodology for purposes of this illustrative analysis and no longer sites new capacity in future (2015) nonattainment counties, based on EPA's most recent baseline air quality modeling. This includes twenty counties, including eleven counties in California, and one or two each in Alabama, Georgia, Illinois, Indiana, Michigan, Montana, Ohio, and Pennsylvania.

2.4 Projected Air Quality and Nonattainment in 2015 and 2020

As a first step in both defining the future year $PM_{2.5}$ air quality problem and developing illustrative control scenarios to simulate attainment, this analysis used the CMAQ air quality model to project 2015 and 2020 annual and 98th percentile daily $PM_{2.5}$ levels. This modeling provided a base case on which we developed the illustrative control scenarios found in Chapter 3 of this RIA. The sections below provide this projected air quality data in map and tabular form and then provides the key insights into the base case air quality modeling. Readers interested in documentation concerning both the base-case emissions estimates and CMAQ air quality modeling used to develop these estimates should consult Chapter 3.

2.4.1 Results

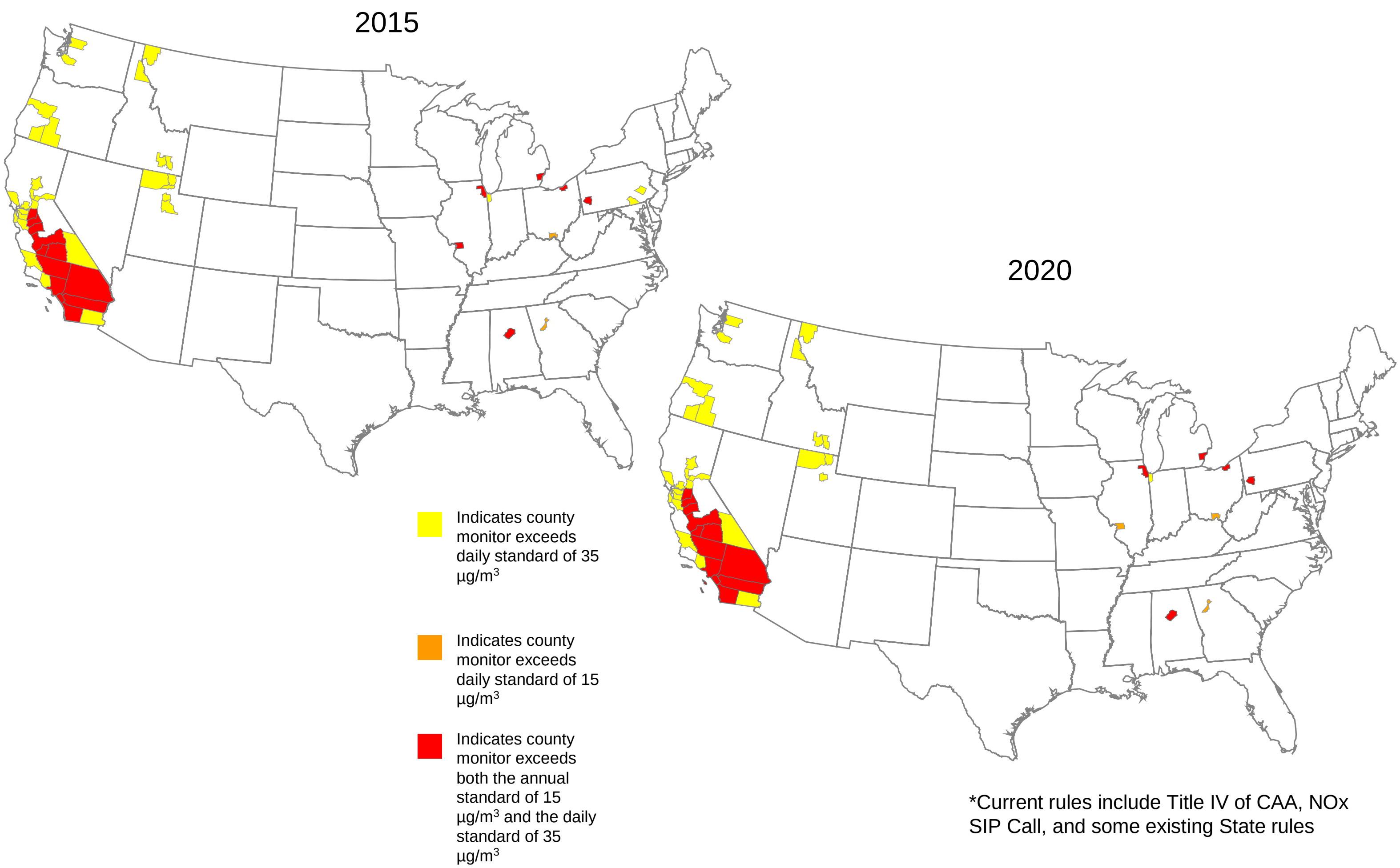
Figure 2-7 below illustrates the projected regulatory base case non-attainment with the revised standard of 15/35. The map on the left shows projected non-attainment in 2015. The map on the right shows projected non-attainment in 2020. Figure 2-8 illustrates the air quality increment by which counties are projected to violate the revised daily standard of 35 $\mu g/m^3$. Table 2-9 below summarizes the number of counties projected to not attain the standard in 2015 and 2020.

Counties Projected to Exceed Revised Standards in 2015 and 2020

	Annual and Daily	*Annual Alone*	*Daily Alone*
2015	2	18	32
2020	3	17	28

Figure 2-7. Counties projected to Violate the Revised PM2.5 Standards of 15/35 in 2015 and 2020

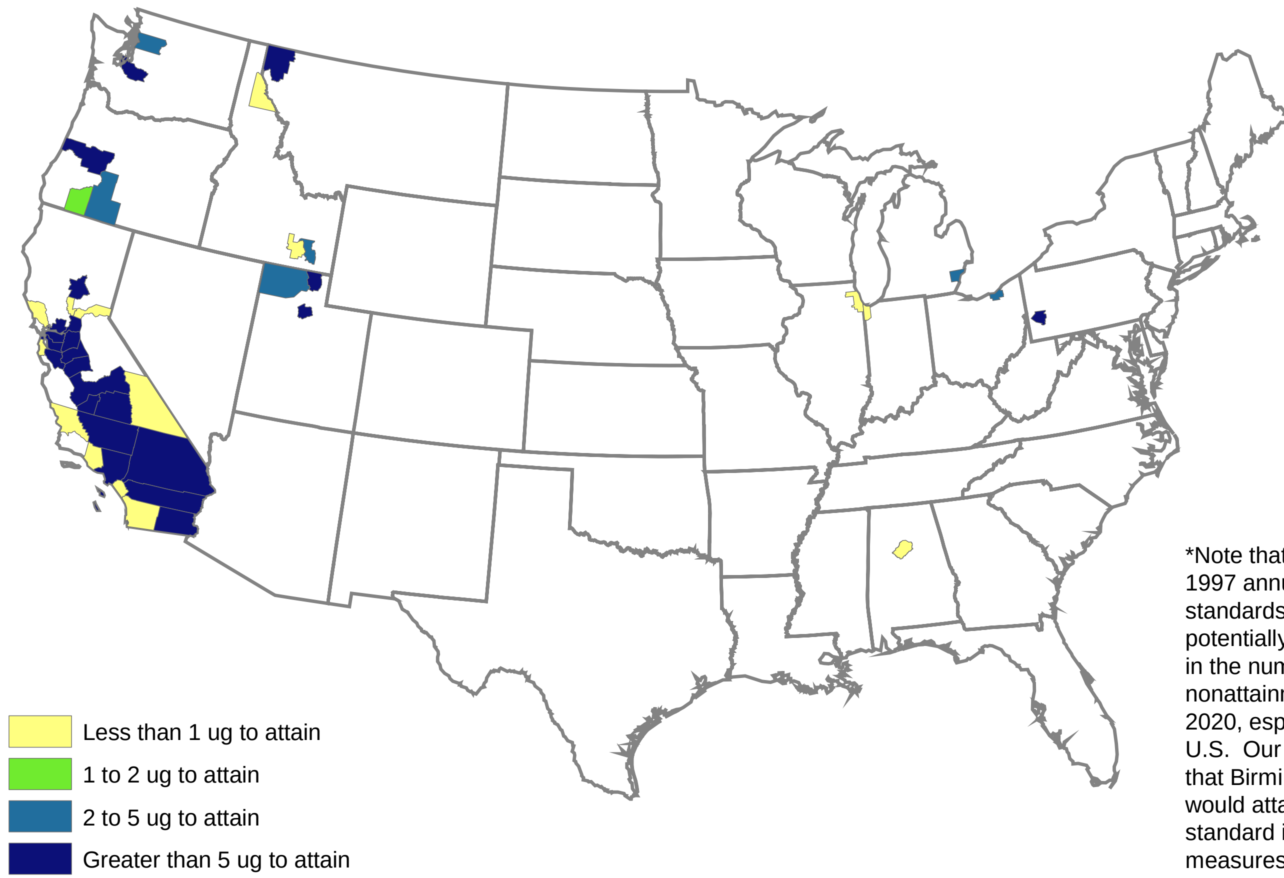
With CAIR/CAMR/CAVR and Some Current Rules* Absent Additional Local Controls



*Current rules include Title IV of CAA, NOx SIP Call, and some existing State rules

Figure 2-8. Projected Reduction in Daily Design Value Needed to Attain the Revised Daily Standard of 35 µg/m³ in 2020

*Incremental to baseline with CAIR/CAMR/CAVR and Mobile Source Rules without additional local controls for attainment of the current standards**



*Note that attainment with the 1997 annual and daily standards by 2020 would potentially result in reductions in the number of nonattainment counties in 2020, especially in the Eastern U.S. Our modeling suggests that Birmingham and Chicago would attain the revised daily standard in 2020 with measures needed to attain the 1997 standards.

2.4.2 Major Insights

A few key observations may be gleaned from the baseline air quality modeling:

- In total, EPA projects that in 2015 52 counties will not attain some combination of the current annual standard of 15 $\mu g/m^3$ and the revised daily standard of 35 $\mu g/m^3$.
- More western than eastern counties are projected to not attain the revised daily standard.
- Compared to the western US outside of California, more eastern counties are projected to violate both the annual standard of 15 $\mu g/m^3$and revised daily standard of 35 $\mu g/m^3$.
- Western counties located outside of California are projected to not attain the revised daily standard of 35 $\mu g/m^3$, but to attain the current annual standard of 15 $\mu g/m^3$.
- Most counties in southern California are projected to not attain either the revised daily standard 35 $\mu g/m^3$or the current annual standard of 15$\mu g/m^3$.
- Utah County, located south of Salt Lake City, and York County, located to the west of Philadelphia, are projected to attain the revised standard in 2020, but not 2015.

2.5 References

Frank, N.H., Retained Nitrate, Hydrated Sulfates, and Carbonaceous Mass in Federal Reference Method Fine Particulate Matter for Six Eastern U.S. Cities, *J. Air & Waste Manage. Assoc***. 2006***, 56,* 500-511.

Chapter 3: Control Analysis

Synopsis

This chapter documents the emission control measures we applied to simulate attainment with the revised $PM_{2.5}$ daily standard of 35µg/m^3 and alternative more stringent annual standard of 14 µg/m^3 and daily standard of 35 µg/m^3. Section 3.1 describes the decision rules we followed to select cost-effective emission controls to simulate attainment in each projected nonattainment area. Section 3.2 outlines the quality-assurance process our database of stationary source emission controls underwent before we selected them in our control strategies. Section 3.3 describes the sources of our control measures data and summarizes the emission reductions we simulated in each projected nonattainment area.

3.1 Emission Control Strategy Followed in this $PM_{2.5}$ National Ambient Air Quality Regulatory Impact Analysis

3.1.1 Overview of the Control Selection Process

We followed a three-step process to simulate attainment in all areas of the country with the 1997, revised and more stringent alternative standards. First, as we describe below in some detail, we identified cost-effective controls to apply in each projected non-attainment area and then simulated the resulting air quality change in an air quality model. Second, for those areas that we did not simulate attainment with the 1997, revised or more stringent alternative standards, we simulated the application of "supplemental" carbonaceous particle controls to the air quality model results to estimate the change in air quality. Third, and finally, if we did not simulate attainment after applying supplemental emission controls, we made a final determination of attainment or non-attainment by weighing the available monitor, modeling and design value data. These steps are referred to as "modeled," "supplemental," and "extrapolated" controls, or emission reductions (and associated costs) throughout the RIA. The emission controls discussion in this chapter focuses entirely with this first step of the three-step analysis, or "modeled" controls. Chapter 4 presents our analysis of the supplemental controls and the final attainment determinations (e.g. extrapolated emission reductions).

To select controls in the modeling step of the analysis, below we describe the method used to determine the geographic scope and cost-effectiveness of the emission controls we would select to simulate attainment in the air quality model with the current standard and each alternative. First, we established a hierarchy that governed the geographic scope of the controls that we would consider for each standard and standard alternative; generally, the tighter the $PM_{2.5}$ NAAQS, the broader the geographic scope we considered when simulating the application of emission controls. Second, we selected emission controls that were most cost-effective on a per-microgram basis—that is, controls that produced the greatest air quality benefit at the least cost. Third, we selected controls in most areas whose incremental cost remained below an urban-area specific benefit per ton threshold.[1] However, in an effort to reach attainment in California and Salt Lake City, Utah, we applied controls that exceeded the benefit per ton threshold. The subsections below describe how we implemented this process. We should note that a separate methodology was used for selecting and applying mobile source emission control strategies and EGU SO_2 control strategies, as described below.

3.1.2 Step One: Establish a Hierarchy of Emission Controls

To simulate attainment with the revised daily standard of 35µg/m^3, our approach first considered currently available known controls (i.e., known and demonstrated in the U.S. as of 2006), applied to the local projected nonattainment county and immediate surrounding counties. For example, Detroit is projected to not attain the revised standard in 2020. Our control strategy analysis includes the counties considered as part of the Detroit Metropolitan Statistical Area (MSA), as defined by the U.S. Census Bureau. After exhausting the controls available for the MSA (up to the limits set by our control strategy selection process discussed in Section 3.2.3), we then considered cost-effective controls available for surrounding counties of the MSA that touch the geographic border and may have an influence on the MSA attainment strategy. In some cases, a local control strategy did not provide enough emission reductions to attain the target PM concentration. In that case, we explored emission controls among a broader set of counties within the state containing the projected nonattainment area that focused on a key pollutant/sector. Examples include a program to reduce directly emitted $PM_{2.5}$ from non-EGU point sources.

In addition, for the more stringent alternative that would tighten the annual standard to 14 µg/m^3, we considered the use of regional control programs. We simulated the implementation of such a program across a multi-state area to facilitate region-wide attainment with a more stringent annual standard. As chapter two describes, monitored $PM_{2.5}$ speciation data indicates that in the industrial Midwest and eastern United States a substantial fraction of total $PM_{2.5}$ mass is composed of sulfates; these sulfates are formed on a secondary basis from SO_2 emitted from a variety of industrial sources. Both programs are described more fully below and in the case of the analysis of the more stringent alternative, they were applied prior to application of controls at the local level. For this reason, we considered both a control program implemented on a regional basis to control SO_2 at EGUs and another regional control program to control SO_2 emissions from industrial point sources. Note that for mobile source control measures, control costs were not available at the time that we began making decisions on the controls to apply. Therefore, we used the following approach for selecting mobile source controls:

- For the baseline of analysis (i.e., assessing how areas will comply with the current standard of 15/65), we applied all mobile source national rules to applicable sources

[1] We developed benefit per ton thresholds to account for the natural variability in the propensity of each precursor to form $PM_{2.5}$ in several urban areas. For example, sulfates contribute a larger fraction of $PM_{2.5}$ mass in the East than these particles do in the West; conversely, nitrates contribute a larger fraction of $PM_{2.5}$ mass in the West than they do in the East. Thus, the benefit per ton threshold for sulfates will be larger in the East than it will be in the West, and vice-versa. We intended these thresholds to roughly emulate the same decision process that local planners would follow—that, other things being equal, planners will select controls that produce the highest expected benefit in their urban area. Clearly, to the extent that planners have exhausted all available controls, these thresholds are moot. For example, due to the magnitude of the non-attainment problem in California, we selected emission controls whose costs exceeded the benefit per-ton threshold.

nationwide in 2015 because of the higher likelihood that they will be implemented in the near future, and despite the fact that some of these rules (e.g., the small nonroad engine rule) are primarily focused on VOC emission control and may have only a small impact on ambient PM.

- We applied mobile source local measures to applicable sources only in geographic areas where additional reductions were needed after the application of stationary source controls and the application of mobile source national rules

Because we used separate steps for selecting stationary and mobile source control measures, we did not necessarily apply the most cost effective set of control measures for each area. We anticipate that States would choose control measures in a more integrated fashion and there may be occasions in which States would choose mobile control measures prior to the application of certain stationary source controls.

Identification of Currently Available Known Stationary Source Controls Technologies. We used the AirControlNet tool (ACN) to identify and rank stationary source controls. ACN overlays a detailed control measures database onto EPA emissions inventories to compute source and pollutant-specific emission reductions. For this analysis, we linked ACN to the emissions inventory for 2020 to identify potential stationary source controls available in each county of the country. We then used the Least Cost Module of ACN to list control measures in rank order of annualized cost-effectiveness (cost-per-ton reduction) for each pollutant. The Least Cost Module lists the pollutant, sector and source category associated with controllable emissions as well as the control technology, the maximum tons of emission reduction that can be achieved with this technology at a specific plant and stack, and cost information (total average annualized cost and average cost per ton).[2]

Based on updated information, we placed limits on our selection of controls from the ACN database (e.g. excluding controls on point sources emitting less than 5 tons per year), as described in Section 3.2.2. We also constrained our controls of $PM_{2.5}$ precursors based on benefit per ton thresholds that vary by projected non-attainment area. The benefit per ton estimates differ by projected non-attainment county due to variability in the exposed population and the types of $PM_{2.5}$ precursors present in the atmosphere in these areas. For instance, counties with higher population levels have a greater number of people exposed to $PM_{2.5}$ and hence have a higher benefit per ton of emission reduced than in areas with lower population levels because the larger incidence in estimated mortality and morbidity produces a larger estimated benefit of reducing a given ton of precursor in that area. The type of precursors reduced—carbonaceous particles, NOx, SO_2, NH_3—in a given area also affect the estimated benefit per ton because of inherent differences in atmospheric chemistry among precursors. Each precursor has a different propensity to form $PM_{2.5}$ that can vary by geographical area.

[2] Controllable emissions refers to the maximum level of emissions that can be controlled given the control efficiency of technologies available in ACN. Total emissions in the inventory are greater than controllable emissions because technologies are able to control fewer than one hundred percent of all emissions.

In some areas, the benefit per ton threshold is $20,000 while in other areas with higher population levels or for precursors with a greater contribution to ambient $PM_{2.5}$, the benefit per ton threshold is $100,000 – $300,000. This approach follows principles of cost-benefit analysis. It also attempts to emulate what State Implementation Plan (SIP) planners might face when developing a control strategy for their area. SIP planners are not likely to choose control strategies whose estimated costs that far outweigh the estimated benefits. In situations where we exhausted all controls that pass the benefit-cost test, we lifted this restriction, and controls with costs per ton exceed benefits per ton were included in the control strategy. Table 3-1 below summarizes the benefit per ton thresholds that we utilized.

Table 3-1: Benefit per Ton Estimates[1, 2]

State	Emissions Sector	Pollutant	$Benefit/ton
Alabama Georgia	NonEGU	SO2	$130,000
	Area	PM2.5	$110,000
	EGU & NonEGU	PM2.5	$210,000
Illinois Indiana Michigan Missouri Ohio West Virginia	NonEGU	SO2	$22,000
	Area	PM2.5	$85,000
	EGU & NonEGU	PM2.5	$180,000
Pennsylvania	NonEGU	SO2	$35,000
	Area	PM2.5	$170,000
	EGU & NonEGU	PM2.5	$210,000
California Idaho Montana Oregon Utah Washington	NonEGU	SO2	$370,000
	EGU	Nox	$310,000
	NonEGU	Nox	$33,000
	Area	PM2.5	$29,000
	EGU & NonEGU	PM2.5	$87,000

[1] These estimates are used as general approximations of the benefits/ton of emissions for the areas based on extrapolated benefit values in RSM to inform the analysis of least-cost control strategies.

[2] These estimates should not be construed as the true value of benefits for a given area. The benefit-cost analysis conducts a complex and detailed analysis of the benefits attributable to each area based on results of air quality modeling, population demographics, and other factors specific to that area.

Recall from Section 1 that the control strategies provided in this analysis are illustrative and not intended to be specific strategies that EPA recommends for each nonattainment area. Moreover, we expect local areas to select a broader array of mobile source controls than we were able to model for the RIA. There are myriad combinations of controls and levels of reduction that can be imposed to achieve the targeted $PM_{2.5}$ concentration, and each SIP planning body is anticipated to consider a wide variety of issues, including cost and level of PM reduction to achieve, to design strategies that attain the PM NAAQS.

3.1.3 Step Two: Identify Cost-Effective Controls

At proposal, the EPA also introduced the Response Surface Model (RSM), which generates screening-level estimates of air quality changes resulting from a simulated change in pollutant emissions.[3] EPA designed the RSM as a screening tool that would allow EPA, States, and regional planning bodies to consider information on the relative effectiveness of pollutant reductions on design values (annual and daily in an area) without the time and expense of running a more complete and complex air quality model, such as CMAQ. In the Interim RIA, EPA used the RSM to assess the air quality impact of alternative sets of control strategies for five different areas of the country, including: Atlanta, Chicago, Cleveland, Salt Lake City, and Seattle. In Appendix A of the Interim RIA, we presented stacked bar charts of air quality impact at the violating urban area monitor associated with reductions in $PM_{2.5}$ precursors from each of several industrial and mobile source sectors. Below we reproduced one such stacked bar chart for Atlanta as an example.

The figure below illustrates the air quality impact associated with a 30% reduction of emissions in each industrial and mobile sector in the Fulton county area. The first bar chart illustrates the reductions in $PM_{2.5}$ resulting from local-area emission reductions, while the second bar illustrates the changes resulting from regional emission reductions. The resulting changes in concentrations of $PM_{2.5}$ are 1.536 $\mu g/m^3$ due to local emission reductions and 1.77 $\mu g/m^3$ due to the regional emission reductions. Each segment of the stacked bar chart provides the relative contribution of each sector and pollutant to the resulting reduction in $PM_{2.5}$. Dividing the RSM-estimated micrograms reduced by the tons of $PM_{2.5}$ precursor reduced the yields an approximate *µg air quality impact per ton reduced* for each sector and pollutant at the violating monitor. For example, in the figure below, we see the 30% reduction of locally-emitted carbon (i.e., directly emitted $PM_{2.5}$) from the area source sector has the largest impact on PM concentrations as indicated by the largest portion in red on the stacked bar for Fulton county. In total, a 30% reduction in area source carbon is equal to approximately 2,600 tons; this reduction produces a reduction in $PM_{2.5}$ concentration of 0.637 $\mu g/m^3$. Dividing the PM2.5 reduction by the tonnage reduction yields a µg-per-ton estimate for locally-emitted area source carbon in Fulton County, Georgia of about 2.47×10^{-04} µg/ton.

By calculating a microgram-per-ton estimate for each precursor and industrial source in a given urban area, EPA was able to determine which combination of precursor and industrial source was most effective to control when combined with cost per ton information from ACN. The resulting µg per ton estimates from the model runs for stationary sources were used to identify the most cost effective measures and are provided in Appendix C. Note that these estimates are only used in a relative sense to rank the relative effectiveness of controlling different precursors and industrial sources. As described previously, a different approach was used to decide where mobile source measures were applied.

[3] Additional information on the RSM model may be found in Chapter 1 of this RIA.

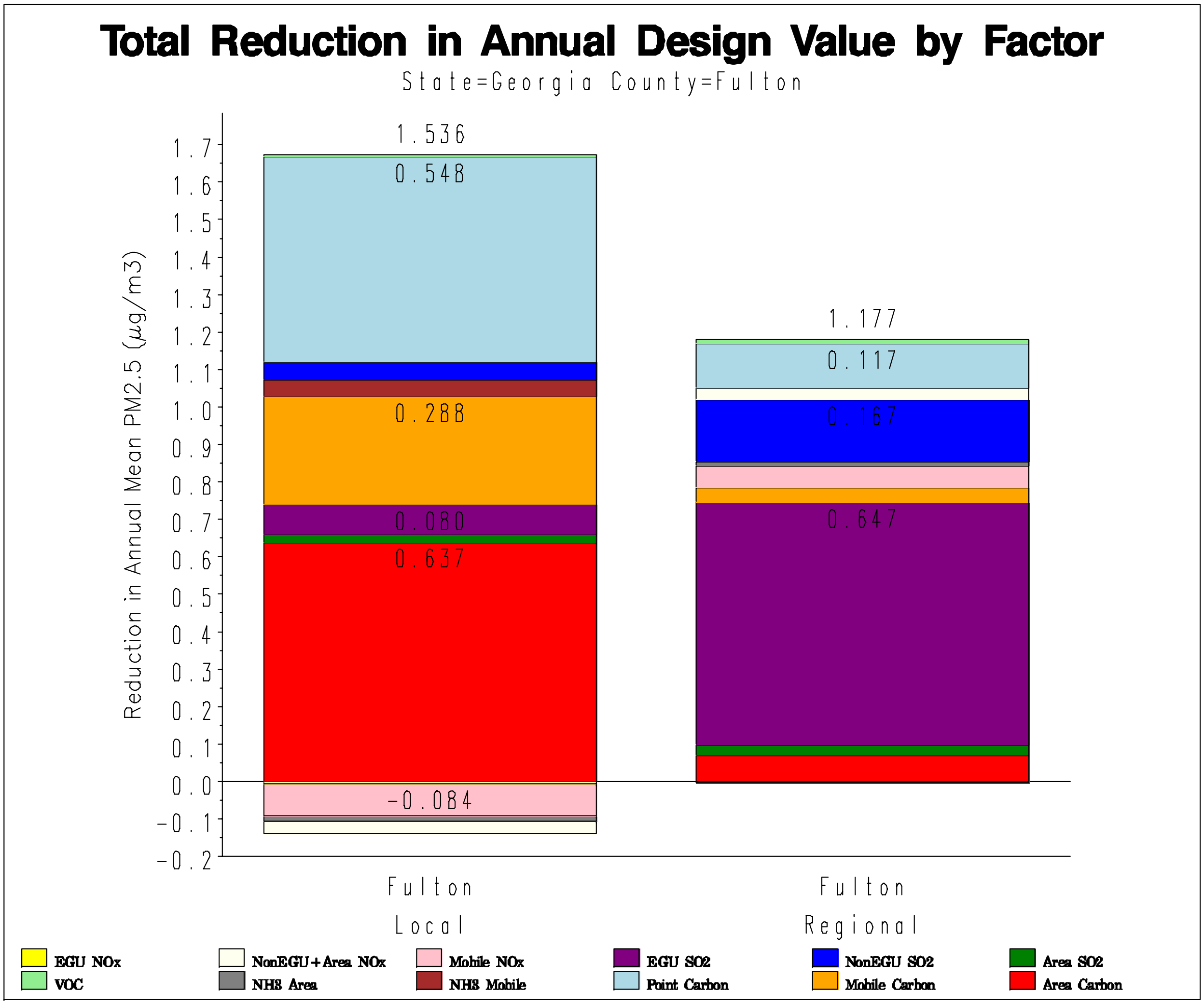


Figure 3-1. Example of Emissions and PM Concentrations from the Response Surface Model: Contributions from each Pollutant/Sector Combination to Total Annual $PM_{2.5}$ in Fulton County, Georgia (Given a 30% emission reduction in each sector)

In our analysis of cost-effective control strategies, we combined air quality effectiveness data from the RSM—that is, the air quality improvement per reduction in $PM_{2.5}$ precursor— with cost information from the ACN tool. By using the two models in this way we were able to develop an emission control strategy that achieved the targeted PM reductions at the lowest cost. We combined the output from the ACN and the RSM models to derive a *cost per µg* estimate for each geographic area of analysis and for each sector and pollutant combination (i.e., direct $PM_{2.5}$ in the non-EGU point source sector). The following figure displays the pollutant and sector combinations provided as outputs by the Least Cost Module of ACN and included in the calculation of cost per µg. As mentioned previously in this chapter, this approach was used for selecting stationary source controls only. Mobile source controls were applied according to the approach described in Section 3.1.2.

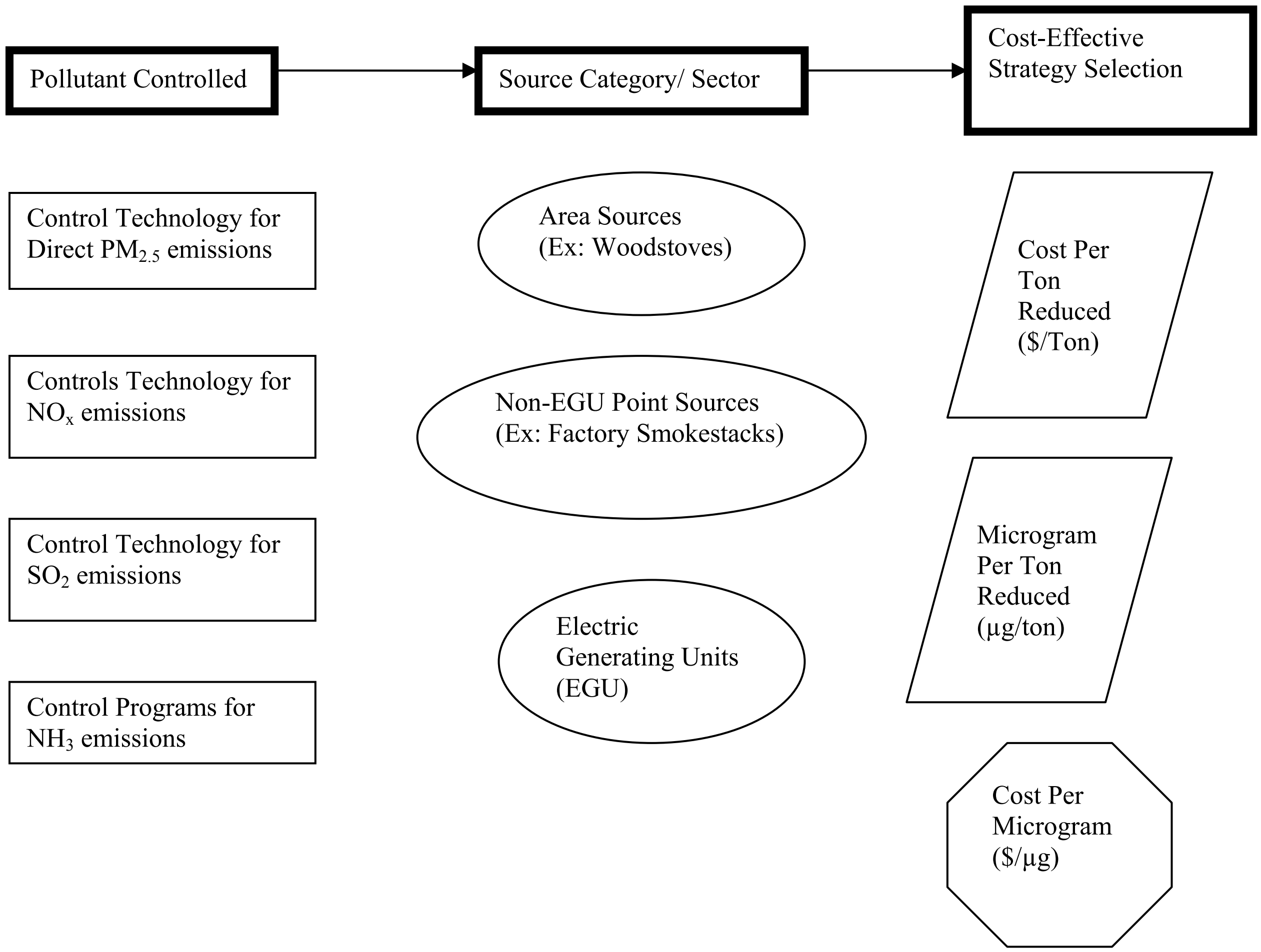


Figure 3-2. Process for Selecting Cost-effective Emission Controls

We used the RSM to assess the cost per microgram of $PM_{2.5}$ reduction for all sectors, including point, area, mobile and EGU's. Calculated values of cost per microgram for stationary sources used in the analysis are presented in Appendix C. To develop the cost per microgram estimates detailed above, EPA used a variety of emission control databases. We used AirControlNet (ACN) to identify $PM_{2.5}$ precursor control measures for the point and area stationary source sector. The ACN tool also provided certain controls for EGUs (limited to pollutants and technologies that are not already considered as part of the CAIR rule). A summary of the control measures in the ACN tool are discussed below in Section 3.2. To identify mobile source control strategies we used a suite of mobile source sector models, including MOBILE6, NONROAD, NMIM and control strategy information from ongoing mobile source studies.

The additional information provided by the RSM has greatly improved our ability to find efficient and cost-effective control strategies. By applying controls that are cost-effective and efficient, we are targeting the pollutants and sectors that are likely to have the largest impact on PM concentrations at the lowest cost. Prior to having information from the RSM on the µg per ton that is anticipated from the more complex air quality models, strategies were developed based on available control technologies, costs, and expert judgment of the sources and pollutants in an area that could be required to control under a SIP development plan. Therefore, it is expected that the analytical approach employed for this RIA will produce control strategies that achieve the targeted reduction in PM at a far lower cost than in prior regulatory analyses of the

PM NAAQS. Furthermore, we expect local areas to employ a broader suite of cost-effective mobile source control measures than we were able to model with RSM, which should further contribute to these lower costs. It should also be noted that a complete evaluation of air quality changes given the selected control technologies is still necessary to account for more complex issues of meteorology, layers of air quality in the atmosphere with air chemistry, and terrain.

For the alternative 14 $\mu g/m^3$ annual and 35 $\mu g/m^3$ daily alternative standard, EPA also modeled a regional SO_2 program for the electric utility sector using the Integrated Planning Model (IPM). The models and data used and results of analyses conducted for the mobile sector and a regional EGU program are discussed further later in this chapter. EPA developed this augmented EGU approach to illustrate the impacts (costs and benefits) of additional EGU controls. If EPA were to study and investigate additional EGU emission reductions in a rulemaking under an alternative standard of 14/35, the Agency would need to go through the regulatory process and perform more complex technical analysis of the merits of additional EGU reductions beyond what is anticipated under CAIR.

Applying Selected Controls to Simulate Attainment

Once the full set of control technologies available for analysis was established along with the cost per µg associated with each pollutant/sector category, we employed a series of database queries to derive the final set of stationary source controls selected for analysis.

We selected stationary source controls from the database by following two steps: first, we selected the pollutant/sector combination with the lowest cost per µg, second, we selected controls with the lowest cost per ton until the targeted $PM_{2.5}$ reduction is achieved or until cost per ton exceeds benefits per ton within that pollutant and sector. If we did not achieve the targeted reduction within pollutant/sector combination chosen, we then selected emission controls from the pollutant/sector combination with the next lowest cost per µg. Finally, if we did not achieve the targeted reduction within the local MSA, we then ranked the cost per µg in counties surrounding the violating county and selected those controls with the lowest estimated cost per ton until the area attained the targeted reduction. If local known controls in the MSA and surrounding area are not enough to bring the area into attainment, then we considered developmental emission controls, which are discussed further in Section 3.3 below. Next, we considered the need for local mobile source programs in the analysis of attainment. To the extent that we did not simulate full attainment by using known and developmental controls, we made a final determination of attainment by weighting the empirical monitoring, modeling and emissions inventory data in an application of "supplemental" controls and "extrapolated" reductions. See Chapter 4 for further discussion of this process.

3.2 Quality Assurance of AirControlNET Control Measures

3.2.1 Description of AirControlNET and Overview of Quality Assurance Process

Before developing the cost per microgram estimates described above, we first revised the controls in the AirControlNET (ACN) tool. As discussed above, we used (ACN) as the source of our point and area source control data. AirControlNET is a desktop-based computer program that overlays a detailed control measures database on EPA emissions inventories to compute source-and pollutant-specific emissions reductions and associated costs at various geographic levels (EPA, 2006). Controls found in ACN are largely well-demonstrated add-on (or "known") control measures for which there is reliable documentation of their control efficiency and costs based on Alternative Control Techniques (ACTs), Control Technique Guidelines (CTGs), and other technical documents prepared by EPA and other entities. ACN contains an extensive set of control measures for achieving direct $PM_{2.5}$ and precursor emission reductions from point and area sources, and a small set of control measures for mobile (onroad and nonroad) sources. The current version of ACN has some control measures for ammonia and area source SO_2 emissions and has some additional area source PM controls as a result of updates made after the interim RIA was completed. These changes are discussed in more detail later in this section.

ACN contains a least-cost module that can generate a list of control measures in rank order of average annualized cost-effectiveness (average cost-per-ton reduction) for each pollutant. Controls applied for a specific pollutant may also result in changes in emissions of other pollutants. These changes are also estimated but are not part of the rank-ordering carried out in the least-cost module. This module was utilized extensively in producing analyses for some of the control strategies listed below.

Types of Stationary Source Controls in AirControlNET

Controls discussed here are taken from ACN and consist primarily of controls already in use (i.e., controls that some sources have already employed and demonstrated to be viable) that illustrate measures that could be chosen by States or local areas controls already in use, and are intended to be illustrative of measures that could be chosen by states or local areas today, with little uncertainty about availability and applicability of controls. Measures such as material substitution, source minimization, work practices, and fuel switching are considered to a lesser degree. Technologies emerging now, or to be developed in the future, may play a key role in attaining the new standards and are discussed below.

AirControlNET contains a variety of control measures available for primary $PM_{2.5}$ and organic and elemental carbon (OC and EC), $PM_{2.5}$ precursors (SO_2, NO_x, NH_3), and volatile organic compounds (VOC). For purposes of brevity, we do not include an exhaustive list of these controls. Readers interested in this detail should consult the AirControlNET control measures documentation report.

All annualized cost/ton estimates for each non-EGU point and area source control measures control measure are in average annualized cost/ton terms. If marginal cost/ton estimates were available for application of these measures, they would likely be higher than the average cost/ton estimates given that pollution control devices typically have costs that slope upwards in an increasing manner as available pollution reductions become fewer. Hence, a control strategy analysis may show fewer of these controls selected using marginal costs as a basis, all other things being equal.

3.2.2 Quality Assurance for Point Source Data in AirControlNET

The interim RIA included point and mobile source controls with very high average annualized cost per ton estimates (some with costs of more than $1 million/ton of emission reduction). Thus, it was difficult to conclude that the strategies we were analyzing for the interim RIA using AirControlNET were truly least-cost for the areas covered. As a result, we took several steps to augment emission control information .

First, we populated the baseline emission inventory used for the control strategy analysis with updated data on such control measures already on or planned for mobile sources. This allowed us to provide more accurate and reasonable estimates of costs for this final RIA. These updates to the inventory are described in more detail in Chapter 2 of this RIA.

Next, we reviewed the applicability of PM control measures to point sources within the ACN tool and made changes if appropriate. In many instances this led to our reducing the applicability of PM control measures to certain sources, including small emitting sources.

These aggregate changes can be summarized as follows:

- No controls to be placed on sources with 5 tons/year of PM emissions or fewer. This recommendation is based on a finding that most point sources with such PM emissions already have PM controls on them and further control is not cost-effective.

- No controls to be placed on direct PM point sources with 50 tons/year of direct PM emissions or fewer. This recommendation is based on a finding that most point sources with emissions of this level or fewer had PM controls already on them. This led to fewer applications of fabric filter controls**,** the major control that had the very high cost/ton estimates alluded to earlier in this section

- No fugitive dust controls or other PM_{10} controls to be applied except in a case where there is a critical need or where such sources are major contributors to $PM_{2.5}$ concentrations. We applied such controls only in California where the extent of nonattainment was so high that we applied every known control available. This recommendation is based on the fact that such controls provide minimal reduction in $PM_{2.5}$ based on CMAQ and other modeling results.

- No controls to be placed on SO_2 point sources with 50 tons/year of emissions or less. This recommendation is based on a finding that most point sources with emissions of this level or less had SO_2 controls already on them,

- Replace the cost equations for cement kiln SO_2 controls with cost/ton estimates for specific controls. This recommendation is based on a finding that these equations in AirControlNET may not be representative enough to continue using in control strategy analyses such as those for this RIA,

- Augment the NH_3 controls in AirControlNET with an ‘emerging’ but tested hog control technology. This addition to AirControlNET is categorized as a “developmental” control (discussed in section 3.3.2). Data on this technology was collected as part of the analyses conducted in support the agreement reached between North Carolina pork producers (Smithfield Foods, Premium Standard Farms, and Frontline Farmers) and the N.C. State's Attorney General. The objective was to identify alternative pork producing approaches to lagoon and sprayfield systems which could reduce the impact on multiple environmental mediums including NH_3 emissions. Similar data on dairy controls were analyzed in California's San Joaquin Valley, not related to the N.C. agreement, were also used to augment current AirControlNET controls.

Third, research identified control measures for pollutants and source categories for which no measures had been previously available (such as SO_2 emissions from area sources). As a result we added a new control measure for area source SO_2 emissions from home heating oil use based on data from NESCAUM study completed in December 2005 (NESCAUM, 2005). This measure is a switch from high-sulfur home heating oil (approximately 2,500 ppm sulfur content) to lower-sulfur home heating oil (500 ppm sulfur content). This measure will lead to an estimated 75% reduction in SO_2 emissions and a co-benefit of 80% reduction in direct PM emissions at an estimated average annualized cost of $2,350/ton of SO_2 emission reduction (1999$). As a result of our research, we also identified a control measure for reduction of PM emissions from commercial cooking facilities (mostly restaurants) in response to this review. This measure is essentially a small electrostatic precipitator that can be applied in some restaurants (particularly larger ones). It can yield up to 99% reduction in PM at an average annualized cost of $7,000/ton (1999$) (Sorrels, 2006).

Finally, we reviewed control measures in ACN to determine if they were consistent with control measures data collected by Regional Planning Organizations (RPOs), organizations such as STAPPA/ALAPCO, States such as California (reports prepared by the California Air Resources Board, or CARB) or local agencies such as the South Coast Air Quality Management District (SCAQMD). Our review of other control measure data sets concluded that there were very little data being used by these bodies that was not already in ACN or that data on control measures used by these bodies not found in ACN were not sufficient to be included in the software tool. In fact, LADCO lists AirControlNET 3.2, a previous version of the software tool, as a reference in a White Paper prepared in April 2005 (MACTEC Engineering and Consulting, Inc., 2005).

The results of this review are available in a memo prepared by EPA and can be found in the docket. The analyses done for non-EGU sources and included in this final RIA reflect the incorporation of the changes that were recommended.

3.3 Sources of Emission Control Estimates

3.3.1 Non-EGU Point and Area Source Controls

We used the AirControlNET (ACN) tool to generate estimates of control cost to non-EGU point and area sources. We supplemented the controls in ACN with additional information regarding PM and precursor controls whose cost and control efficiency is less well characterized in comparison to existing control measures in the database.

PM Emissions Control Technologies[4]

This section summarizes an array of measures available to control emissions of PM from EGU, non-EGU point, and area source categories. Most of the control measures available are add-on (or end of tailpipe) technologies, but some other technologies and techniques that are not add-on in nature can reduce PM emissions[5].

PM Control Measures for Utility and Non-EGU Point Sources. Most control measures on utility and non-EGU point sources are add-on technologies. These technologies include: fabric filters (baghouses), ESPs, and wet PM scrubbers. Fabric filters collect particles with sizes ranging from below 1 micrometer to several hundred micrometers in diameter at efficiencies in excess of 99%, and this device is used where high-efficiency particle collection is required. 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 passes up (usually) along the surface of the bags than radially through the fabric. Particles are retained on the upstream face of the bags, and the cleaned gas stream is vented to the atmosphere. The filter is operated cyclically, alternating between relatively long periods of filtering and short periods of cleaning. Dust that accumulates on the bags is removed from the fabric surface when cleaning and deposited in a hopper for subsequent disposal.

ESPs use electrical forces to move particles out of a 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 particles are on the collector plates, they must be removed without reentraining 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. This removal of collected particles is typical of a "dry" ESP. A "wet" ESP operates by having a water flow applied intermittently or continuously to wash the collected particles for disposal. The advantage of wet ESPs is that there are no problems with rapping reentrainment or with back coronas. The disadvantage is that the collected slurry must be handled more carefully than a dry product, adding to the expense of disposal. ESPs capture particles with sizes ranging from below 1 micrometer to several hundred micrometers in diameter at efficiencies from 95 to up to 99% and higher.

Wet PM scrubbers remove PM and acid gases 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. Collection efficiencies for wet scrubbers vary by scrubber type, and with the PM size distribution of the waste gas stream. In general, collection efficiency decreases

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[4] The descriptions of add-on technologies throughout this section are taken from the EPA Air Pollution Control Cost Manual, Sixth Edition. This is found on the Internet at http://epa.gov/ttn/catc/products.html#cccinfo.

[5] It should be noted that in addition to the controls discussed in this section, state and local authorities may also consider seasonal local controls to address high daily PM concentrations that are infrequent or seasonal in nature as part of State Implementation Plans to meet the standard. Seasonal controls are considered in this analysis only to the extent that the emissions and controls are seasonal in themselves (e.g. woodstove emissions and controls are applied for the Winter season). We are not able to assess other viable seasonal controls available to local authorities due to the difficulty of modeling such programs in a national-scale analysis.

as the PM size decreases. Collection efficiencies range from in excess of 99% for venturi scrubbers to 40%-60% for simple spray towers. Wet scrubbers are generally smaller and more compact than fabric filters or ESPs, and have lower capital cost and comparable operation and maintenance (O&M) costs. Wet scrubbers, however, operate with a higher pressure drop than either fabric filters or ESPs, thus leading to higher energy costs. In addition, they are limited to lower waste gas flow rates and operating temperatures than fabric filters or ESPs, and also generate sludge that requires additional treatment or disposal. This final RIA only applies wet scrubbers to fluid catalytic cracking units (FCCUs) at petroleum refineries.

Virtually all utility boiler and non-EGU point sources have some type of add-on PM control measure installed to capture $PM_{2.5}$ emissions. For example, as of 2004 84% of all coal-fired EGUs in the US have an ESP installed in the U.S.[6] Fourteen percent of coal-fired EGUs have a fabric filter installed on them, and the remaining units have some type of wet PM scrubber installed.

In addition, we also examined additional add-on control measures specifically for steel mills. Virtually all steel mills have some type of PM control measure, but there is additional equipment that could be installed to reduce emissions further. Capture hoods that route PM emissions from a blast furnace casthouse to a fabric filter can provide 80% to 90% additional emission reductions from a steel mill. Other capture and control systems at blast oxygen furnaces (BOFs) can also provide 80% to 90% additional reductions as well.

This final RIA also selects/uses/presents control measures that are upgrades to existing control measures or are improvements to how existing control measures operate due to increases in monitoring. Such controls can lead to small reductions in PM (5% to 7%). We also include control measures to upgrade ESPs by adding enough collector plates to be equivalent to one or two new fields to increase the collector area and hence increase the control efficiency of the device. Upgrading can lead to an additional 67% emissions reduction in addition to what the ESP provides already for PM reductions.

Finally, we also use/select coal washing as a way to reduce PM emissions from EGU operations. This measure can yield up to 35% reduction in PM. The following table summarizes these point source measures by the sector they apply to.

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[6] Spreadsheet files that are input to the Integrated Planning Model (IPM) for analysis applied to a 2020 inventory. Files obtained from E. H. Pechan and Associates, May 2006.

Table 3-2: Example PM Control Measures for Utility Boilers and Non-EGU Point Sources Applied in Modeled Control Strategy Analyses[a]

Control Measure	*Sector(s) to which Control Measure Can Apply*	*Control Efficiency (percent)*	*Average Annualized Cost/Ton*
ESPs—wet or dry[b]	Industrial Boilers, Iron and Steel Mills, Pulp and Paper Mills	95 to 99.9	$1,000–$20,000
ESP Upgrades (Adding enough collector plates to be equivalent to one or two new fields)	Utility Boilers	44 to 67	$3,000–15,000
Fabric Filters[b]	Industrial Boilers, Iron and Steel Mills, Pulp and Paper Mills	98 to 99.9	$2,000–$100,000
Secondary Capture and Control Systems—Capture Hoods for Blast Oxygen Furnaces	Coke Ovens	80 to 90	$5,000
Coal Washing	Utility Boilers (coal-fired only)	35	$2,500–9,000
CEM Upgrade and Increased Monitoring Frequency	Sectors with Utility Boilers and Non-EGUs with an ESP	5 to 7	$600–$5,000

[a] This table presents a sample of PM control measures applied in our "modeled" assessment of attainment. In a limited number of areas, the modeling of control strategies results in areas that do not fully comply with the proposed standards, (i.e. areas of residual nonattainment). In areas of residual nonattainment, we conducted further analysis using supplemental controls and extrapolated reductions (discussed fully in Chapter 4).

[b] AirControlNET contains equations to estimate capital and annualized costs for ESP and FF installation and operation. The annualized cost/ton estimates presented here for these control measures are outputs from our modeling, not inputs. They also reflect applications of control where there is no PM control measure currently operating except if the control measure is an upgrade (e.g. ESP upgrades).

A full listing of PM control measures for utility and non-EGU point sources can be found in Appendix E.

PM Control Measures for Area Sources. Specific controls exist for stationary area sources (e.g., restaurants) and for emissions from agricultural operations (e.g., fugitive dust emissions). Area source PM controls at stationary sources include catalytic oxidizers on conveyorized charbroilers at restaurants that can reduce PM emissions by more than 80%, replacement of older woodstoves with those that are compliant with the New Source Performance Standard (NSPS) for residential wood combustion, which can lead to up to 98% reduction of PM,[7] education and advisory programs to help users to operate woodstoves more efficiently and with fewer emissions (up to 50% reduction in PM), and replacement of older woodstoves with new woodstoves when property is sold or changes hands (up to a 46% reduction in PM over time).

[7] This control measure is largely meant to simulate the effects of a woodstove changeout program as applied to Libby, MT per the efforts of the U.S. EPA and several co-sponsors. For more information, refer to http://www.epa.gov/woodstoves/how-to-guide.html.

Applying diesel particulate filters to existing diesel-fueled compression-ignition (C-I) engines can achieve up to a 90% reduction in fine PM. This measure is likely to be applied to new C-I engines as part of a NSPS that will be implemented beginning in 2006.

Area source PM controls at other area sources include controls or techniques that are primarily designed toward PM_{10} reductions such as dust control plans for construction sites, soil conservation plans for farm tilling, watering of beef cattle feedlots, the use of wood waste chipping for landfill disposal instead of open burning of wood waste. While these controls are geared towards reducing PM_{10}, they also yield reductions of $PM_{2.5}$ at the same or lower percentages compared to PM_{10}. Reductions in fine PM from these measures can range from 25 to up to 100 tons.

Table 3-3: Example PM Control Measures for Area Sources Applied in Modeled Partial Attainment Control Strategy Analyses[a, b]

Control Measures	*Sectors to which These Control Measures Can Apply*	*Control Efficiency (percent)*	*Average Annualized Cost/ton*
Catalytic oxidizers for conveyorized charbroilers	Restaurants	83	$1,300
Changeout of older woodstoves for new ones by a woodstove changeout campaign or on sale of property, or an education and advisory program for woodstove users	Residential wood combustion sources	46 to near 100	$1,900
Dust control plans[c]	Construction activities	63	N/A[d]
Soil conservation plans[c]	Agricultural tilling	12	N/A[d]
Watering[c]	Beef cattle feedlots	50	N/A[d]
Replace open burning of wood waste with chipping for landfill disposal	Residential waste sources	Near 100	$3,500

[a] This table presents a sample of PM control measures applied in our “modeled” assessment of attainment. In a limited number of areas, the modeling of control strategies results in areas that do not fully comply with the proposed standards, (i.e. areas of residual nonattainment). In areas of residual nonattainment, we conducted further analysis using supplemental controls and extrapolated reductions (discussed fully in Chapter 4).

[b] The estimates for these control measures reflect applications of control where there is no PM area source control measure currently operating.

[c] Given that the available evidence regarding adverse health effects associated with exposure to thoracic coarse particles is strongest with respect to urban and industrial ambient mixes of those particles, EPA encourages States to focus control programs on urban and industrial sources to the extent that those sources are contributing to air quality violations. The information here is provided for illustrative purposes only and should not be used to justify control requirements until additional information is available.

[d] These control technologies are primarily selected for control of PM10 emissions, but may also have some impact on PM2.5. In the analysis of the revised and alternative standards, the costs of controls for PM10 are attributable to a program presumed to be implemented by 2020 to meet the PM10 standards, and therefore, are not assigned a cost to the PM2.5 standards.

SO_2 Emissions Control Measures

This section describes available technologies for controlling emissions of SO_2 for industrial, commercial, and institutional (ICI) boilers[8] and other source categories. In general, Flue Gas Desulfurization (FGD) scrubbers are applied most commonly as the control technology for utility boilers and many non-EGU point and SO_2 sources because of their possible application to most any combustion source application. While all controls presented in this analysis are considered generally technically feasible for each class of sources, source-specific cases may exist where a control technology is in fact not technically feasible.

SO_2 Control Technology for Point Sources. FGD scrubbers can achieve 90% control of SO_2 for non-EGU point sources and 95 percent for utility boilers. This control is the predominant technology available in our database for most of the source categories covered by utility boilers and non-EGU point sources. Spray dryer absorbers (SDA) are another commonly selected technology, and they can achieve up to 90% control of SO_2. For specific source categories, other types of control technologies are available that are more specific to the sources controlled. The following table lists these technologies. For more information on these technologies, please refer to the AirControlNET 4.1 control measures documentation report.[9]

Table 3-4: Example SO_2 Control Measures for Non-EGU Point Sources Applied in Modeled Control Strategy Analyses[a]

Control Measure	*Sectors to which These Control Measures Can Be Applied*	*Control Efficiency (percent)*	*Average Annualized Cost/ton*
FGD scrubbers and SDA	ICI boilers—all fuel types, kraft pulp mills, Portland cement plants (all fuel types)	90—FGD scrubbers or SDA	\$800-\$8,000—FGD \$900 – 7,000—SDA
Increase percentage sulfur conversion to meet sulfuric acid NSPS (99.7% reduction)	Sulfur recovery plants	75 to 95	\$4,000
Sulfur recovery and/or tail gas treatment	Sulfuric Acid Plants	95	\$3,000 – 6,000
Vacuum carbonate + sulfur recovery plant	Coke ovens	82	\$5,000

Source: AirControlNET 4.1 control measures documentation report (May 2006). The estimates for these control measures reflect applications of control where there is no SO_2 control measure currently operating.

[a] This table presents a sample of PM control measures applied in our "modeled" assessment of attainment. In a limited number of areas, the modeling of control strategies results in areas that do not fully comply with the proposed standards, or areas of residual nonattainment. In areas of residual nonattainment, we conducted further analysis using supplemental controls and extrapolated reductions (discussed fully in Chapter 4).

[8] The terms "ICI boiler" and "industrial boiler" are used interchangeably in this RIA.
[9] For a complete description of AirControlNET control technologies see AirControlNET 4.1 control measures documentation report, prepared by E.H. Pechan and Associates. May 2006.

SO_2 Control Technology for Area Sources. Fuel switching from high to low-sulfur fuels is the predominant control measure available for SO_2 area sources. For home heating oil users, our analyses include switching from a high-sulfur oil (approximately 2,500 parts per million (ppm) sulfur content) to a low-sulfur oil (approximately 500 ppm sulfur). A similar control measure is available for oil-fired industrial boilers. More information on the industrial boiler fuel-switching measure is available later in this chapter. For more information on these measures, please refer to the AirControlNET 4.1 control measures documentation report.

NO_x Emissions Control Measures

This section describes available measures for controlling emissions of NO_x from non-EGU point sources. In general, low-NO_x burners (LNB) are often applied as a control technology for industrial boilers and many other non-EGU sources because of their possible application to almost any industrial boiler and other combustion source application. While all controls presented in this analysis are considered generally technically feasible for each class of sources, source-specific cases may exist where a control technology is in fact not technically feasible.

NO_x Control Measures for Non-EGU Point Sources. Several types of NO_x control technologies exist for non-EGU sources : SCR, selective noncatalytic reduction (SNCR), natural gas reburn (NGR), coal reburn, and low-NO_x burners. The two control measures chosen most often were LNB and SCR because of their breadth of application. In some cases, LNB accompanied by flue gas recirculation (FGR) is applicable, such as when fuel-borne NO_x emissions are expected to be of greater importance than thermal NO_x emissions. When circumstances suggest that combustion controls do not make sense as a control technology (e.g., sintering processes, coke oven batteries, sulfur recovery plants), SNCR or SCR may be an appropriate choice. Finally, SCR can be applied along with a combustion control such as LNB with overfire air (OFA) to further reduce NO_x emissions. All of these control measures are available for application on industrial boilers.

Besides industrial boilers, other non-EGU source categories covered in this final RIA include petroleum refineries, kraft pulp mills, cement kilns, stationary internal combustion engines, glass manufacturing, combustion turbines, and incinerators. NO_x control measures available for petroleum refineries, particularly process heaters at these plants, include LNB, SNCR, FGR, and SCR along with combinations of these technologies. NO_x control measures available for kraft pulp mills include those available to industrial boilers, namely LNB, SCR, SNCR, along with water injection (WI). NO_x control measures available for cement kilns include those available to industrial boilers, namely LNB, SCR, and SNCR. In addition, mid-kiln firing (MKF), ammonia-based SNCR, and biosolids injection can be used on cement kilns where appropriate. Non-selective catalytic reduction (NSCR) can be used on stationary internal combustion engines. OXY-Firing, a technique to modify combustion at glass manufacturing plants, can be used to reduce NO_x at such plants. LNB, SCR, and SCR + steam injection (SI) are available measures for combustion turbines. Finally, SNCR is an available control technology at incinerators. Table 3-4 lists the control measures available for these categories. For more information on these measures, please refer to the AirControlNET 4.1 control measures documentation report.

Table 3-5: Example NO_x Control Measures for Non-EGU Source Categories

Control Measures	*Sectors to Which These Control Measures Apply*	*Control Efficiency (percent)*	*Average Annualized Cost/ton*
LNB	Industrial boilers—all fuel types, Petroleum refineries, Cement manufacturing, Pulp and Paper mills	25 to 50%	$200 to $1,000
LNB + FGR	Petroleum refineries	55	$4,000
SNCR (urea-based or not)	Industrial boilers—all fuel types, Petroleum refineries, Cement manufacturing, pulp and paper mills, incinerators	45 to 75	$1,000 to $2,000
SCR	Industrial boilers—all fuel types, Petroleum refineries, Cement manufacturing, pulp and paper mills, Combustion turbines	80 to 90	$2,000 to 7,000
OXY-Firing	Glass manufacturing	85	$2,500 to 6,000
NSCR	Stationary internal combustion engines	90	500
MKF	Cement manufacturing—dry	25	–$460 to 720
Biosolids Injection	Cement manufacturing—dry	23	$300
SCR + SI	Industrial boilers—all fuel types	95	$2,700

Source: AirControlNET 4.1 control measures documentation report (May 2006). Note: a negative sign indicates a cost savings from application of a control measure. The estimates for these control measures reflect applications of control where there is no NOx control measure currently operating except for post-combustion controls such as SCR and SNCR. For these measures, the costs presume that a NOx combustion control (such as LNB) is already operating on the unit to which the SCR or SNCR is applied.

3.3.2 Developmental Emission Controls

During the planning and scoping stage of this analysis we determined that the number and effectiveness of emission controls in the AirControlNET database was likely insufficient to simulate attainment in all areas. For this reason, we investigated the existence of new and developing control measures that would complement those in the AirControlNET database; as previously noted, AirControlNET contains well-documented controls that have seen broad application and for this reason would not include more speculative and nascent control technologies. Due to the increased uncertainty of these developmental controls, we chose to apply them after first considering the AirControlNET control measures. Application of developmental controls is limited to only those areas in which we were not able to model attainment with local known controls on point and area sources, and local programs for mobile sources. Chapter 6 provides details of when developmental controls are applied and the cost of application.

The developmental controls generally fall into three categories. Developmental controls in this RIA are:

1. *Adaptations of existing controls to a new source*. In particular cases we used engineering judgment to transfer a well-characterized control from one source type to another.
2. *Modifications of existing controls to incorporate new information*. Certain controls such as wood stove change-outs in AirControlNET incorporate assumptions regarding the extent to which a nonattainment county will adopt that control. For some counties that we projected to be in significant nonattainment, we adjusted these assumptions so that the county will adopt the control at a much higher rate.
3. *Adoptions of state-level strategies*. States such as California have generated comprehensive analyses of sector-based emission reductions programs. In this RIA we have adapted the control measures and costs found in these strategies.

Table 3-5 below summarizes each control by providing the pollutant it controls, its control efficiency, total possible emission reductions, cost per ton, and information regarding its derivation.

Table 3-6: Developmental Emission Control Measures Applied in Modeled Attainment Strategies for the PM NAAQS RIA

Control Measure	*Primary Pollutant Controlled*	*Control Efficiency*	*Average Cost per Ton*	*Notes*
Adaptation of Existing Control Technology				
Fuel switching for industrial boilers	SO_2	80%	$2,300	This control transfers a home-heating oil fuel control to industrial boilers by substituting “red dye” distillate oil for high-sulfur fuel. Distillate has 500 ppm versus 2,500 to 3,000 ppm for high-sulfur diesel.
Emerging animal feeding operation control technologies (swine)	NH_3	70%	≤$10,000	This control is a solids separation-tangential flow separator combined with a fan separation system.
Emerging animal feeding operation control technologies (dairy)	NH_3	55%	≤$10,000	Efficiency and cost estimates derived from technologies assessed by San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel and those recommended to the San Joaquin Valley Air Pollution Control Officer by the Dairy Permitting Advisory Group.
Stationary Internal Combustion Engine Controls	$PM_{2.5}$	90%	$9,000	Applies diesel particulate filter retrofits to stationary internal combustion engines.
Modification and Improvement to Existing Control Technology				
Wood Stove Change-out	$PM_{2.5}$	Up to 100%	$2,000	Increasing the assumed adoption rate can take place by increasing the rate of housing stock turnover and assuming NSPS-compliant wood stoves are installed in place of older conventional wood stoves at the time of turnover.
Adoption of State Emission Reduction Strategies				
California Goods Movement Initiative	$PM_{2.5}$	80%	$50,000	Control efficiencies and costs derived from California analysis
Substitution of land-filling for open burning of land clearing debris	$PM_{2.5}$	50 to 100%	$3,500	Uses state-level emission reduction and control cost data

Below we provide additional information regarding each of these developmental controls.

Fuel Switching for Industrial Boilers

Overview: This control is an adaptation of the residential home heating oil fuel switching control currently in AirControlNET. The home heating oil control substitutes lower sulfur "red dye" distillate fuel for higher sulfur diesel fuel. Where red dye distillate has a sulfur content of approximately 500 ppm, higher sulfur diesel fuel has as sulfur content of between 2,500 and 3,000 ppm. This reduced sulfur content will reduce SO_2 emissions, which will in turn reduce the formation of $PM_{2.5}$.

Control Efficiency and Cost: We have adopted the AirControlNET control efficiency and cost for this control for two reasons: (1) we do not believe that the control efficiency will change when red dye distillate is burned at industrial boilers; (2) we do not anticipate that boilers would incur a cost for red dye distillate fuel that is different from the cost borne by users of residential home heating oil.[10] We estimate that the control efficiency for this control is 80% and that the average annualized cost is approximately $2,300 a ton of SO_2 abated.

Major Uncertainties: For this control we assume that the control efficiency and cost are identical to the AirControlNET residential fuel switching control. If industrial boilers are not capable of using this fuel, or if this source faces significantly higher costs for this fuel than residential users, then our estimates of emission control and cost will be too incorrect.

Emerging animal feeding operation control technologies (Swine)

Overview: The system is one the 'Environmentally Superior Technologies' that was tested and analyzed for North Carolina swine operations as part of the agreement between North Carolina State's Attorney General and Smithfield Foods as well as Premium Standard Farms and Frontline Farmers. The system treats waste from finishing barns. Manure flushed from the barns flows first to a collection pit, then to an above-ground feed tank, then to a separator on a raised platform. The liquid that flows through the separator screen flows to a second feed tank, then to two tangential flow gravity settling tanks sited parallel to each other. Tangential flow in the first tank causes solids to concentrate in the center of the tank and settle to the bottom. This settled slurry is then pumped to the second tank for sludge thickening. Once an hour the settled slurry from the second tangential flow settling tank is pumped back to the tank that feeds the separator, where the settled slurry is combined with the flushed manure that is being pumped to the separator. Effluent gravity runs to a stabilization and treatment pond which is the source of the recycled liquid used for flushing the barns.

Control Efficiency and Cost: Based on tests performed on a single site in North Carolina. The system demonstrated an NH_3 emission control efficiency of 71.8 percent from barns and water holding structures during cold months and 66 percent reduction efficiency during warm months from the same structures in North Carolina. These efficiencies average 68.9 percent for the year. According the Agreement report, the costs are

[10] U.S. Environmental Protection Agency. AirControlNET 4.1 Control Measure Documentation Report. Prepared by E. H. Pechan and Associates. May 2006.

estimated at $114.56 per 1000 lbs. steady state live weight at a 4,320 head finishing farm. EPA used this cost number to estimate costs on a farm and state level in order to then estimate the per source cost adjusted to 1999 dollars. It should be noted that, in order to minimize the manipulation of results from the reports provided as part of the Agreement between the North Carolina Attorney General, Smithfield Foods, et al., costs are as reported by the Agreement and, therefore, are at an eight percent discount rate (10 years) as opposed to the seven percent rate used for other control technologies.

Major Uncertainties: The control efficiency information is based on tests at a single North Carolina hog operation. Although the Agreement report did not provide any uncertainty analysis on its results, it stated that its test results were within a range of possible values and, therefore, could be higher or lower than reported. Furthermore, the values reported above are likely to vary by region, type of swine operation, and type of manure management system both within North Carolina and nationally. It is expected that the NAEMS will provide a more scientific assessment of emissions from animal operations and how those emissions differ according to various factors, including type and size of animal, type of housing and manure management systems, geography, time of day, and seasonality. Taking into account the limited control and cost information available for this technology, and the yet undertermined need for control of these emissions, the information here is provided for illustrative purposes and should not be used to determine control costs or justify control requirements until additional information is available.

The cost information is based on converting an existing lagoon and spray field system to a system based on the proposed technology. As a result, costs may be different for converting a deep pit system in the Midwest or other systems in different geographic areas. In addition, costs are presented per 1000 lbs. of steady state live weight on a 4,320 head finishing farm, which is not the standard size of all hog operations in the U.S. Therefore, EPA recognizes that costs could vary depending on the season, size of an operation, the system in place to raise hogs, the growing phase of the hogs in each operation, and the number of hogs per operation, as well as the geographic location of the operation.

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Emerging animal feeding operation control technologies (Dairy)

Overview: In 2006, the Dairy Permitting Advisory Group recommended a set of Best Available Control Technologies for Dairy operations in the San Joaquin Valley, CA (a PM2.5 nonattainment area) to the San Joaquin Valley Air Pollution Control Officer. These recommendations were presented in their final report released in January of the same year. In December of 2005, the San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel prepared a similar report assessing dairy technologies in the San Joaquin Valley, CA. The dairy technologies assessed for efficiency and cost for the PM NAAQS are based on information provided in these San Joaquin Valley documents and consist of solids separations/nutrient removal systems, a phototrophic lagoon processing system, a liquid manure injection and spreading system, and a man-made wetlands system for N removal..

Control Efficiency and Cost: The control efficiency is estimated at 55 percent and represents an average or expected value from six technologies in the aforementioned reports that contained both cost and efficiency data. Costs are averaged from the same six technologies and, similar to the hog control costs, are estimated on a farm ($64,428 per farm) and state level in order to then estimate the cost per source in 1999 dollars. In order to maintain a consistency with the hog technologies, these costs were annualized at an eight percent discount rate for ten years.

Major Uncertainties: Similar to the hog technologies, these emerging dairy manure control technologies are expected to vary in efficiency and cost by region, season, head count, and operation size. Furthermore, the values used for cost and emission reduction efficiency are not based on one specific control technology. Instead, these values are averages derived from a range of estimates of different systems with each system likely to have a degree of uncertainty with its numbers. It is likely that the level of uncertainty with the dairy controls' cost and efficiency numbers is greater than that of the hog controls. Taking into account the limited control and cost information available for this technology, and the yet undertermined need for control of these emissions, the information here is provided for illustrative purposes and should not be used to determine control costs or justify control requirements until additional information is available.

Stationary Internal Combustion Engine Controls

Overview: This control incorporates directly-emitted $PM_{2.5}$ reductions from stationary internal combustion engines that will be affected by the compression-ignition internal combustion engine new source performance standard (NSPS). The expected impacts from this NSPS are not accounted for in our future year emission inventories since this NSPS was not promulgated until June 28, 2006 (after proposal of the $PM_{2.5}$ standard). Because this rule was recently promulgated, control technology data such as control efficiency and costs were not part of the AirControlNET control measures database. Diesel particulate filters (DPF) are likely to be the control technology required for these engines to meet the NSPS requirements. The control is applied here as a retrofit to existing stationary internal combustion engines in our inventory.

Control Efficiency and Cost: We have taken the control efficiency and cost data from technical support documents prepared for the U.S. EPA as part of analyses undertaken for the final NSPS.[11] The control efficiency for $PM_{2.5}$ reductions from applying DPF is 90 percent at an average cost of $9,000/ton.

[11] U.S. Environmental Protection Agency. "Emission Reduction Associated with NSPS for Stationary CI ICE." Prepared by Alpha-Gamma, Inc. June 3, 2005, and U.S. Environmental Protection Agency. "Cost per Ton for NSPS for Stationary CI ICE." Prepared by Alpha-Gamma, Inc. June 9, 2005.

Major Uncertainties: The analysis assumes that all affected engines will be using ultra-low sulfur fuel (ULSD) in the analysis year of 2020. To the extent that these existing engines are not using ULSD, the level of control is likely to be lower than estimated in this RIA since DPFs will clog if the engine being controlled uses a higher-sulfur fuel than ULSD (15 ppm sulfur) and thus yield lower reductions of $PM_{2.5}$.

Wood Stove Change-out

Overview: The existing wood stove change-out control in AirControlNET assumes that 10% of residents in a non-attainment area will elect to replace their older wood-burning stoves with NSPS-compliant wood stoves. Planners in non-attainment areas that we project to be in severe non-attainment with the proposed daily standard may elect to require residents to install these stoves at a higher rate. For this reason, we modified the AirControlNET wood stove control to incorporate a higher rate of change-out and thus a higher control efficiency of directly-emitted $PM_{2.5}$. There are two variants to this developmental control. The first variant assumes that stoves must be replaced as the housing stock turns over; owners must replace their non-NSPS stoves with NSPS-compliant stoves when they sell their home. The second variant assumes that projected non-attainment areas would require all home owners to replace their non-NSPS stoves with NSPS-compliant stoves within a certain time frame. The chief difference between these two controls is in the implementation time frame; areas projected to be in severe non-attainment with the proposed daily standard are more likely to implement the more ambitious wood stove control.

Control Efficiency and Cost: The housing-stock turnover variant of this wood stove control derives its control efficiency by multiplying estimates of annual housing stock turn-over, which is about 4.7%, by the $PM_{2.5}$ control efficiency of a the control technology, which is 100%.[12] Thus, for a given county, PM2.5 emissions would be reduced by 4.7% per year, or about 47% over ten years and about 71% over 15 years. The cost per ton of $PM_{2.5}$ abated from this control measure would be approximately $2,000 a ton, which is the estimate found in AirControlNET.

The more ambitious wood stove change-out variant assumes that 100% of non-NSPS compliant wood stoves would be replaced with NSPS compliant wood stoves in a give year. For this reason, the control efficiency would be 100%. The estimated average cost per ton of $PM_{2.5}$ abated from this control measure would be approximately $2,000 a ton, which is the estimate found in AirControlNET.

Major Uncertainties: To the extent that residents in non-attainment areas do not adopt this control at the rate we assume, then our estimate of emission reduction will be too high.

California Goods Movement Emission Reduction Plan

[12] Reference: National Association of Realtors; U.S. Environmental Protection Agency. AirControlNET 4.1 Control Measure Documentation Report. Prepared by E. H. Pechan and Associates. May 2006.

Overview: California recently developed a strategy to reduce $PM_{2.5}$, SO_2 and NOx emissions from ships, harbor craft, cargo handling equipment, trucks and trains.[13] This strategy includes a comprehensive analysis of the emissions reductions and costs associated with this plan. To avoid double-counting emission reductions that may already be achieved by national mobile source rules (the recent non-road rule, the upcoming diesel locomotive rule, etc.), we elected to adopt the ship and harbor craft reductions only; these emission reductions were able to be "unbundled " from the national mobile source rules.

Control Efficiency and Cost: In its report California provides a list of control measures for ships and harbor craft, the annual emission reductions associated with these controls, as well as a gross estimate of the annualized cost of these controls at 5-year intervals. To develop a control efficiency for these controls, we simply divided the reduction in precursor emissions by the total emissions. We then multiplied this efficiency by the appropriate source category classification code in the EPA emissions inventory to derive a total emission reduction. It was not possible to simply use the total emission reduction from the California report because of differences in the way in which California and US EPA classify port emissions. To estimate control cost, we divided the total annualized cost by the total emission reductions and multiplied this average cost per-ton estimate by the controllable emissions in the National Emissions Inventory (NEI).

Major Uncertainties: The principal source of uncertainty with this control is the process by which we estimated emission reductions in the US EPA emissions inventory. The California report apportions emission reductions at a finer resolution than the NEI. Where California applied controls to ships and harbor craft, the NEI lists a single source category classification for all mobile source marine vessel diesel emissions.

Substitution of Chipping and Shredding and Land-Filling for Open Burning

Overview: Several states have enacted ordinances that require residents to either landfill or chip and shred yard waste instead of burning it. This substitution can substantially reduce directly-emitted $PM_{2.5}$.

Control Efficiency and Cost: Efficiency is near 100% because burning would not occur. Emissions and emissions factors based on Documentation for the Draft 2002 Nonpoint Source National Emissions Inventory for Criteria and Hazardous Air Pollutants (March 2005 Version) , pp A-105 and A-106. Landfill tipping fees estimate as $30/ton (1999 dollars) based upon national average in National Sold Waste Management Associations 2005 Tipping Fee Survey. Overall estimate of emissions of 0.68 tons per acre and cost of $2400 per acre results in estimate of about $3,500/ton.

Major Uncertainties: Landfill costs based upon limited cost information. Average landfill costs, and average debris/acre, may not well represent costs in some locations. Significant uncertainties exist in emissions factors for open burning.

[13] The analysis can be found at: http://www.arb.ca.gov/planning/gmerp/march21plan/march22_plan.pdf.

3.3.3 Mobile Source Control Information

To estimate emission reductions that could be obtained for mobile sources as part of our illustrative attainment strategies, we identified a set of viable onroad and nonroad mobile source control options and compiled emission reduction and cost information for each. Mobile source control options included in the RIA can be broken into two categories, with important differences between them. The first category includes federal rules that are likely to be developed and implemented in a timeframe such that emission reduction impacts would be relevant to this RIA. These "national rules" are in various stages of conceptual or regulatory development, and EPA has not conducted full-scale analyses on these rules' cumulative costs or emissions impacts. Ideally, such calculations would be included in the baseline values used in an analysis. Given the timeline of this RIA and the rules in question, however, and assuming these rules are likely to be in effect during the years of analysis, it makes sense to include *approximations* of their effects as part of our illustrative control strategies. These estimates are based on highly preliminary analyses and should not be construed as the product of in-depth analysis on the rules.

The federal rules incorporated into this analysis were applied nationally, regardless of an area's attainment status. The rules analyzed affect the following sources:

- Diesel Locomotives
- Diesel Marine Vessels
- Ocean Going Vessels
- Ocean Going Vessels (residual fuel)
- Small Nonroad Gasoline Engines

The recent proposal to reduce mobile source air toxics (71 FR 15804, March 29, 2006) discusses data showing that direct PM2.5 emissions from gasoline vehicles are elevated at cold temperatures. The proposed vehicle hydrocarbon standards contained in the March 29, 2006 action would reduce these elevated PM emissions. This RIA does not include the effects of this proposed rule because we do not currently have the data to model the impacts of elevated cold-temperature PM emissions across the entire in-use fleet. As a result, these emissions are not included in our baseline emission inventories. We are currently analyzing the data from a large collaborative test program with industry, and our next emissions model (MOVES) will include cold temperature effects for PM.

Because these mobile source national rules were applied across the country as part of the analysis of meeting the current standard of 15/65, they were not applied as an incremental control for the analysis of meeting the revised and alternative standards. Therefore, the cost for implementation of these national mobile source rules is discussed in Appendix A with the discussion of costs for the current standard.

The second set of strategies are referred to as "local measures," and are those control strategies that are likely to be employed at the state or local level to achieve emissions reductions. Many of these programs are already in place in various areas around the country. It should be emphasized that this list is in no way an exhaustive catalog of steps that state and local authorities can take to reduce mobile source emissions. Instead, it represents a smaller sample of measures that we find to be cost-effective and analytically quantifiable for purposes of this RIA. State and local governments may very well identify and implement numerous other local mobile measures that also serve to cost-effectively reduce emissions of direct PM or its precursors. Due to analytical and time constraints, local mobile measures were utilized only in certain areas once other measures had been exhausted. The local measures employed in this analysis as follows:

- Diesel Retrofits and Retirement
- Reduction of Idling Emissions
- Intermodal Transfer
- Best Workplaces for Commuters (BWC)

It should be emphasized that, with regard to lowering direct PM and precursor emissions reductions from the mobile sector, many of the most significant and cost-effective reductions will come from EPA national mobile source rules that have already been developed and are currently being implemented. As noted in Chapter 2, these rules, which include the Clean Air Nonroad Diesel Rule, the Light-Duty Vehicle Tier 2 Rule, and the Heavy Duty Diesel Rule, will produce substantial reductions in directly emitted $PM_{2.5}$, SO_2, and NO_x at the following levels:

Table 3-7. National Emission Reductions in Base Case Emission Projections (thousands of tons per year)

Rule	*Year*	*NOx*	*PM2.5*
Clean Air Nonroad Diesel Rule	2015	195	53
	2020	445	86
Light Duty Vehicle Tier 2 Rule	2015	1,800	28
	2020	2,200	31
Heavy Duty Diesel Rule	2015	1,300	61
	2020	1,800	82

These rules are included in the base case emissions projections for this analysis, and will significantly reduce the target reductions many states will set during implementation of the revised $PM_{2.5}$ NAAQS.

In the remainder of this section, we first provide information on the national rules, and second on the chosen local measures. Note that where "PM" is indicated, the term encompasses PM_{10} and $PM_{2.5}$ emissions. For all percent reductions in the tables below, the values refer to reductions from the projected base case in the noted year (i.e., 2015 or 2020).

<u>National Rules</u>

Diesel Locomotives

EPA is developing a proposal for more stringent locomotive engine emission standards that are modeled after the Clean Air Nonroad Diesel Engines Program, likely to be issued in early 2007. Such standards would require the use of advanced emission-control technologies similar to those already upcoming for heavy-duty diesel trucks and buses. Based on such a standard for diesel locomotives, we used the following emission reductions for the years included in this analysis:

Table 3-8: National Emission Reduction Estimates for Diesel Locomotives

National Emission Reduction Estimates for Diesel Locomotives in 2020

	2015	*2020*
PM	35%	60%
NO_x	5%	10%

These estimates are based on control of both new locomotives and in-use locomotives at the time of rebuild:

- New locomotives, 90% control efficiency in PM and NOx beginning in 2012
- Tier 2 locomotives: 90% control efficiency in PM at rebuild beginning in 2012
- Tier 0 and Tier 1 locomotives: 50% reduction in PM beginning in 2010

Diesel Marine Vessels, Category 1 and 2

Similar to diesel locomotives, EPA is developing a proposal for more stringent emission standards for all new commercial, recreational, and auxiliary marine diesel engines except the very large engines used for propulsion on deep-sea vessels, likely to be issued in early 2007. These standards, which are modeled after the Clean Air Nonroad Diesel engines program, would require the use of advanced emission-control technologies. For Diesel Marine Engines, Category 1 and 2, we estimated a 90 percent reduction in NOx and PM from all new engines, beginning in 2012.

Table 3-9: National Emission Reduction Estimates for Diesel Marine Engines

National Emission Reduction Estimates for New Diesel Category 1 and 2 Marine Engines

	2015	*2020*
PM	16%	44%
NO_x	11%	35%

Ocean Going Vessels

Current negotiations at the International Maritime Organization offer the potential for additional reductions in PM and NOx from what are sometimes called category 3 marine engines. Category 3 marine diesel engines are very large engines (≥30 liters displacement per cylinder) used for propulsion power on ocean-going vessels. Because of the uncertainty as to the outcome of this program, we considered two possible scenarios: one scenario where new engine NOx and PM are reduced by 50%, and one scenario where they are both reduced by 90%. We estimated both of these scenarios could begin in 2012. Because of the very long turn-over rates for these products, the reductions take a long time to impact the fleet. The numbers in the tables below are reductions in the entire fleet of vessels.

Table 3-10: National Emission Reduction Estimates for Ocean Going Vessels

90% Reduction in New Engine PM and NO_x			*50% Reduction in New Engine PM and NO_x*		
	2015	*2020*		*2015*	*2020*
PM	10%	30%	PM	5%	15%
NO_x	10%	3%	NO_x	5%	15%

Residual Fuel in Ocean Going Vessels

EPA is an active participant in the International Maritime Organization (IMO), and has analyzed one IMO treaty annex which allows signatories to the treaty to declare a "Sulphur Emission Control Area" (SECA). The sulfur cap for a SECA is 15,000 ppm sulfur fuel (or an equivalent reduction in the engine's SOx emissions using a scrubber). Although the U.S. has not ratified this particular treaty, we think it is reasonable to project that we may be in a position of having a SECA in place for all of the U.S. coasts by 2015; this is the basis for the 2015 SOx emission reduction identified in the table below. At least one state has encouraged further development of SECAs as part of its efforts to address nonattainment concerns. IMO is also starting another round of discussions of future standards for ocean-going vessels. We believe it is possible a lower sulfur cap may result from that discussion, allowing for lower SECAs to be enforced. That is the basis for the 2020 SOx emission reduction in the table below.

Table 3-11: National Emission Reduction Estimates for Residual Fuel in Ocean Going Vessels

Emission Reductions from Ocean-going Marine Vessels fueled with Residual Fuel		
	2015	*2020*
SO_x	45%	95%

Small Nonroad Gasoline Engines

EPA is developing a proposal to reduce emissions from certain small nonroad gasoline engines, likely to be issued by the end of 2006. This rule will include reductions from three categories of equipment:

- Small Spark-Ignition Non-handheld Category I
- Small Spark-Ignition Non-handheld Category II
- Gasoline Recreational Marine

Non-handheld spark-ignition equipment includes lawnmowers, generator sets, and riding mowers. Handheld spark-ignition equipment includes trimmers, edgers, brush cutters, leaf blowers, leaf vacuums, chain saws, augers, and tillers. Small engines, those below 225 cc of displacement, are called "Category I." Larger engines, those with displacement greater than or equal to 225 cc, are called "Category II." Gasoline recreational marine engines include outboard motors, personal watercraft, and sterndrive and inboard engines.

Below are the values we applied for reductions from control of these small nonroad gasoline engines.

Table 3-12: National Emission Reduction Estimates for Small Nonroad Gasoline Engines

Emission Reductions for Small Nonroad Gasoline Engines

	Year: 2015			*Year: 2020*		
Category	*VOC*	*NO_x*	*PM*	*VOC*	*NO_x*	*PM*
Small Gasoline, Nonhandheld Class I	45%	25%		50%	25%	
Small Gasoline, Nonhandheld Class II	30%	35%		40%	40%	
Gasoline Recreational Marine						
– Outboard Marine Engines	20%	10%	25%	45%	15%	50%
– Personal Watercraft Engines	40%	–10%	50%	65%	–20%	80%
– Sterndrive/Inboard Marine Engines	10%	30%		25%	45%	

<u>Local Measures</u>

Diesel Retrofits and Vehicle Replacement

Retrofitting heavy-duty diesel vehicles and equipment manufactured before stricter standards are in place – in 2007 for highway engines and in 2008 for most nonroad equipment – can provide PM, NO_x, HC, and CO benefits. The term "retrofit" can mean any number of modifications or technological add-ons; the specific retrofit strategies included in the RIA retrofit measure are:

- Installation of emissions after-treatment devices:
  - diesel oxidation catalysts ("DOCs")
  - diesel particulate filters ("DPFs")
- Rebuilding nonroad engines ("rebuild")
- Early replacement and retirement of onroad vehicles ("replacement")

More in-depth information on retrofit technologies can be found at http://www.epa.gov/otaq/retrofit/retrofittech.htm.

We chose to focus on these strategies due to their potential for both substantial emissions reductions and for widespread application. Emissions reductions through retrofits vary significantly by strategy and by the type and age of the engine and its application. For this analysis, we first isolated the target vehicles: all heavy-duty engines (except for 5% of the nonroad fleet) that do not meet EPA's more stringent standards and are still expected to be operating in 2015 and 2020. Then we set two "cut-points:" we analyzed the emission reduction potential of retrofitting the first 50% of targeted vehicles (used only in the 15/65 control scenario), and then 100% of targeted vehicles (used in both the 15/35 and 14/35 scenarios). We expect that most areas will target less than 100% of their diesel engines for implementation of retrofit controls.

To estimate the potential emissions reductions from this measure, we applied a mix of four retrofit strategies (DOCs, DPFs, rebuild, replacement) for the 2015 and 2020 inventories of:

- Heavy-duty highway trucks class 5 & above and all buses, Model Year 1990-2006
- All nonroad engines, Model Year 1988-2007, except for locomotive, marine, pleasure craft, & aircraft engines

Eliminating Long Duration Truck Idling

Emissions from virtually all long duration truck idling that lasts for longer than 15 minutes – from heavy-duty diesel class 8a and 8b trucks, can be eliminated with two strategies:

- Truck stop & terminal electrification (TSE)
- Mobile idle reduction technologies (MIRTs) such as auxiliary power units, generator sets, and direct-fired heaters

A number of State and local governments have already taken steps to reduce emissions from idling, and we expect this trend to continue. A discussion of alternatives to long-duration idling can be found at EPA's website for the SmartWay Transport partnership, at http://www.epa.gov/smartway/idlingalternatives.htm. For the two measures listed above, our analysis limited the emission reductions to a 3.4 percent decrease in all pollutants to be consistent with the existing MOBILE 6.2 inventory assumptions.

Intermodal Transport

Intermodal transport refers to the transportation of goods through a combination of local truck and long-distance rail transport. Intermodal transport usually involves moving a container by truck (called drayage) to a rail facility where the container is moved from the truck to a rail car. The container is transported by rail for the majority of the trip, and then is usually transferred to another truck for final delivery. Intermodal transport is almost always a more fuel-efficient and less polluting way to transport goods on a ton-per-mile basis compared to truck-only transport. For the purposes of this RIA, we employ a 1% shift from truck-only transport to intermodal transport in 2015 and 2020.

For 2015, we estimated emissions reductions from this measure as follows:

- 1% decrease in all pollutants from all relevant highway truck SCC codes
- 0.4% corresponding increase in all pollutants from all locomotive and rail equipment SCC codes

For 2020, we estimated emissions reductions as follows:

- 1% decrease in all pollutants from all highway truck SCC codes
- 0.3% corresponding increase in all pollutants from all locomotive and rail equipment SCC codes

Best Workplaces for Commuters

Best Workplaces for Commuters (BWC) is an EPA program that recognizes and supports employers who provide incentives to employees to reduce light-duty vehicle emissions. Employers implement a wide range of incentives to affect change in employee commuting habits including transit subsidies, bike-friendly facilities, telecommuting policies, and preferred parking for vanpools and carpools. The BWC measure in this RIA reflects a mixed package of incentives, and reduces multiple pollutants (NO_x, VOC, SO_2, NH_3, PM 10, and PM 2.5).

We calculated that when employed, BWC would reduce light-duty gasoline emissions by 0.4% and 1% with a 10% and 25% program penetration rate, respectively. The lower program penetration level was used only in the 15/65 control scenario, while the higher level was used in both the 15/35 and 14/35 scenarios.

3.3.4 Electrical Generating Unit Emission Control Technologies

The Integrated Planning Model v2.1.9 (IPM) includes SO_2, NO_x, and mercury (Hg) emission control technology options for meeting existing and future federal, regional, and state, SO_2, NO_x and Hg emission limits. Table 3-12 summarizes the emission control technologies available in IPM.

Table 3-13. Summary of Emission Control Technology Retrofit Options Available in IPM

SO_2 Control Technology Options	*NO_x Control Technology Options*
Limestone Forced Oxidation (LSFO) Scrubber	Selective Catalytic Reduction (SCR) System
Magnesium Enhanced Lime (MEL) Scrubber	Selective Non-Catalytic Reduction (SNCR) System
Lime Spray Dryer (LSD) Scrubber	Combustion Controls

It is important to note that besides the emission control options listed in Table 3-11, IPM offers other compliance options for meeting emission limits. These include fuel switching, repowering, and adjustments in the dispatching of electric generating units.

Sulfur Dioxide Control Technologies
IPM includes three commercially available wet and semi-dry Flue Gas Desulfurization (FGD) technology options for removing SO2 produced by coal-fired power plants. The three types of FGD options or scrubbers - Limestone Forced Oxidation (LSFO), Magnesium Enhanced Lime (MEL), and Lime Spray Dryer (LSD) - are available to "unscrubbed" existing units, potential units, and "scrubbed" units with reported removal efficiencies of less than fifty percent.

Existing unscrubbed units that are selected to be retrofit by the model with scrubbers achieve removal efficiencies ranging from 90% to 96%, depending on the type of scrubber used. Detailed cost and performance derivations for each scrubber type are discussed in detail in the EPA's documentation of IPM (http://www.epa.gov/airmarkets/epa-ipm).

Nitrogen Oxides Control Technology
IPM includes two categories of NOx reduction technologies: combustion and post-combustion controls. Combustion controls reduce NOx emissions during the combustion process by regulating flame characteristics such as temperature and fuel-air mixing. Post-combustion controls operate downstream of the combustion process and remove NOx emissions from the flue gas. All the specific combustion and post-combustion technologies included in IPM are commercially available and currently in use in numerous power plants.

NOx Combustion Controls
Cost and performance of combustion controls are tailored to the boiler type, coal type, and combustion controls already in place and allow appropriate additional combustion controls to be exogenously applied to generating units based on the NOx emission limits they face. IPM includes two post-combustion retrofit control technologies for existing coal and oil/gas steam units: Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR).

NOx Post-combustion Controls
IPM includes two post-combustion retrofit control technologies for existing coal and oil/gas steam units: Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR). the performance assumptions for each NOx control technology.

Existing coal-fired units that are retrofit with SCR have a NOx removal efficiency of 90%, with a minimum controlled NOx emission rate of 0.06 lb/mmBtu in EPA Base Case 2004. Potential (new) coal-fired, combined cycle, and IGCC units are modeled to be constructed with SCR systems and designed to have emission rates ranging between 0.02 and 0.06 lb NOx/mmBtu.

Detailed cost and performance derivations for NOx controls are discussed in detail in the EPA's documentation of IPM (http://www.epa.gov/airmarkets/epa-ipm).

Direct $PM_{2.5}$ Controls Applied to EGUs

For certain EGUs it is possible to upgrade the existing $PM_{2.5}$ controls to increase their capture efficiency. EGUs generally employ three different $PM_{2.5}$ control devices. The first is an electrostaic precipitator (ESP), which is the predominant PM control technology available at

EGUs. Second is the fabric filter and third is the wet $PM_{2.5}$ scrubber.[14,15] EPA's National Electric Energy System Database (NEEDS) indicates that as of 2004, 84% of all coal-fired EGUs have an ESP in operation, about 14% of EGUs have a fabric filter and roughly 2% have wet $PM_{2.5}$ scrubbers.[16] Upgrading an existing ESP appears to be cost effective because it increases control efficiency at a potentially small expense. Given the large proportion of EGUs that currently use an ESP, EPA believed it would be possible to control EGUs contributing to downwind nonattainment in projected nonattainment areas.

The most common way to upgrade an ESP is to increase the specific collector area (SCA), which is an important variable in characterizing ESP performance. One of the most common routes by which to increase SCA is to simply increase the collector plate area by adding additional collector plates. The ESP modifications considered as control measures in this RIA include adding enough collection plate area to be equivalent to one or two new fields. The $PM_{2.5}$ reductions from adding 1 plate are about 44%, and about 67% from adding 2 plates. These levels will vary depending on how much SCA resides in each field. If an ESP designer has installed a large number of fields, with a relatively low amount of surface area in each field, the additional $PM_{2.5}$ reductions obtained by adding additional fields would be relatively low.

Another method for adding more surface area to an ESP is to change the existing plates to taller plates. This method will be effective if the resulting aspect ratio remains at a reasonable level. The additional fields can also be added by building a new box either on top of the existing ESP (closer to the outlet), on side of, or behind the chimney. Much depends on the existing layout constraints and how these constraints affects the ease of the retrofit.

A final ESP modification is the Indigo Agglomerator. This technology can be installed in the high velocity ductwork leading to the ESP. It uses both electrostatic and fluidic methods to pretreat all of the dust particles entering the ESP, agglomerating small and large particles together. This creates larger and more easily collected particles and reduces the number of small particles for the ESP to collect. The electrostatic method charges the dust half positively and half negatively in the treatment zone and then mixes them in a specially designed mixing field. The fluidic agglomeration method uses a highly specialized mixing regime to increase the interaction, and therefore impact rate, between large and small particles, thus agglomerating them.[17] The agglomerator therefore increases the overall $PM_{2.5}$ control efficiency of the ESP. There are now three commercial installations of the Indigo Agglomerator and one pilot scale installation in the U.S., and a prototype agglomerator in Australia. Test runs show a $PM_{2.5}$ control efficiency of 40%. Cost equations derived for installation and operation of the Agglomerator can be found in Section 6.1. We did not utilize the Agglomerator technology in our control strategies for this RIA since the 2 additional collector plate control measure was more cost-effective. There are other methods by which ESP collection efficiency can be improved – flue gas conditioning, adding a second "polishing" baghouse, and adding filter bags to the last field of an ESP – but we do not have cost or control efficiency data for these methods available for these control strategy analyses.

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[14] A wet $PM_{2.5}$ scrubber is a control device that removes PM along with acid gases from waste gas steams from point sources.
[15] U.S. Environmental Protection Agency. 2004 NEEDS database.
[16] U.S. Environmental Protection Agency. 2004 NEEDS database.
[17] Overview of Indigo Agglomerator technology found at http://www.indigotechnologies.com.au/agg_overview.php.

SO_2 and NO_x Controls Applied to EGUs

Certain EGUs in, or near, Western State nonattainment areas did not use NO_x or SO_2 controls, indicating a possible opportunity to reduce NO_x emissions from these EGUs in a cost-effective manner. These EGU controls include SCR and LNB for NO_x control, and repowering for SO_2 control, for which we considered year-round operation. The cost and control efficiency data in AirControlNET for these controls is identical to that found in the Integrated Planning Model (IPM), but EPA adjusted the applicability of these controls to ensure consistency with IPM. EPA made two adjustments in the control applicability: (1) apply controls only to EGUs with unit capacity of 25 MW or greater; (2) remove repowering as a control option.

Having applied these constraints, we found opportunities to apply LNB to two EGUs in California and SCR to ten EGUs in Utah and three EGUs in Washington. Each of these units are coal-fired, and we considered these controls to apply incrementally to a 2020 emissions inventory that incorporates EGU controls reflecting Best Available Retrofit Technology (BART) as mentioned in Chapter 2 of this RIA. We did not apply any SO_2 controls outside the CAIR region using AirControlNET because we did not identify any EGUs for which repowering would be a cost-effective control. For more information on these control measures, please refer to the AirControlNET 4.1 control measures documentation report.

Within the CAIR region, except in the 14/35 case, EPA did not consider controls for EGU SO_2 and NO_x emissions beyond those already in the baseline– existing rules on the books and the Clean Air Interstate Rule cap-and-trade system. In the 14/35 case, EPA simulated an approach for EGUs that adjusts the CAIR emission caps to require additional SO_2 controls (see discussion below for further details).

3.3.5 Summary of Emission Controls for Each Standard Alternative

The section below summarizes the control measures we applied to simulate attainment, and partial attainment, with the revised and alternative more stringent standards. EPA selected these control strategies on the basis of cost-effectiveness, using the techniques described above. We analyzed the more stringent alternative standards incrementally to the current standard of 15/65.

15/35 Proposed Revised Standards

To simulate attainment with the tighter daily standard of 35 $\mu g/m_3$ by 2020, additional controls are applied incrementally to the controls required to attain the current standard by 2015. In the eastern part of the country we apply additional controls to all available pollutant sector combinations in Pittsburgh, Cleveland, and Detroit except those that the RSM estimates to have a negative impact upon $PM_{2.5}$ air quality. An example of this negative impact is the application of NO_x control technologies in the Pittsburgh area.

Table 3-14 provides a summary of the hierarchy of control strategies employed in each metropolitan statistical area (MSA) analyzed based on the approach described in detail in section 3.1.

Table 3-14: Applications of the Control Strategy Hierarchy by Area for the 15/35 Standard

Location[a]	No Additional Controls Required After Compling with 15/65 Standard[b]	MODELED PARTIAL ATTAINMENT[c]		ANALYSIS OF RESIDUAL NONATTAINMENT	
		Local Known Controls	Developmental	Supplemental	Extrapolated
EAST					
Atlanta	✓				
Birmingham	✓				
Chicago	✓				
Cincinnati	✓				
Cleveland		✓		✓	
Detroit		✓	✓	✓	
Gary, IN	✓				
Pittsburgh		✓	✓		
Portsmouth, OH	✓				
St. Louis	✓				
WEST					
Eugene, OR		✓	✓		
Klamath Falls, OR		✓	✓		
Medford, OR		✓	✓		
Lincoln County, MT		✓	✓		
Missoula, MT		✓	✓		
Shoshone County, ID		✓	✓		
Logan, UT		✓	✓		
Salt Lake City, UT		✓	✓		✓
Seattle, WA		✓	✓		
Tacoma, WA		✓	✓		
CALIFORNIA[d]					
South Coast District			✓		✓
San Joaquin Valley			✓		✓
Other Affected Counties		✓	✓		✓

a For each location, controls are selected in the counties identified in the Metropolitan Statistical Area (MSA) first and then in counties surrounding the MSA if necessary to demonstrate attainment.

b Areas in th East comply with the revised daily standard of 35 ug/m3 after complying with the 15/65 standard. Areas in the West are new nonattainment areas identified for analysis of 15/35, and which already comply with 15/65.

c In a limited number of areas, the modeling of control strategies results in areas that do not fully comply with the proposed standards, (i.e. areas of residual nonattainment). In areas of residual nonattainment, we conducted further analysis using supplemental controls and extrapolated reductions (discussed fully in Chapter 4).

d In California, all available known local controls are applied when modeling compliance with the current standard of 15/65, which impacts counties in the South Coast Air Quality District and the San Joaquin Valley. For the analysis of control strategies to comply with the revised standards of 15/35, several new counties are indicated as exceeding the revised daily standard of 35 ug/m3 (but comply with the annual standard). These counties are located north of the San Joaquin Valley and therefore, we employ available local known controls to this area.

Table 3-15 summarizes the reductions we modeled by sector, pollutant and region. The majority of controls we applied in the East apply to non-EGU SO_2 point sources, followed by SO_2 area sources. We found that applying direct $PM_{2.5}$ is the most effective and efficient method of reducing PM concentrations locally. We applied several available controls to analyze compliance with the current standard of 15/65 (see Appendix A), We applied remaining available direct PM2.5 controls in the analysis of the revised standards. Next, the SO_2 reductions were the second most cost-effective way to achieve the proposed revised daily standard. Examples of control technologies applied to sources emitting SO_2 are flue gas desulfurization (FGD), fuel switching, and dual absorption. Finally, we also applied developmental ammonia controls on agricultural sources to a limited extent and only in areas that could not attain with other control technologies. The developmental control for dairy operations was applied in one county in California, and developmental control for swine operations was applied in Pittsburgh county only.

In the western part of the country our modeling indicates that several new areas outside of California will violate the proposed revised standard, including Salt Lake City,Utah; Seattle, Washington; Eugene, Oregon; and Libby, Montana. In Salt Lake City we applied NO_x controls to EGUs. These reductions were achieved through the application of SCR. We achieved NO_x reductions in the Seattle area primarily through control measures applied to non-EGU point sources and area sources. Examples of controls measures we applied to these categories include: low NO_x burners combined with SCR, RACT to 25 tpy, and water heater + LNB space heaters. The next largest categories of control were sources of direct $PM_{2.5}$, in Oregon direct $PM_{2.5}$ reductions from area sources were the greatest.

In California, we projected additional counties to violate the proposed revised daily standard that did not violate the 1997 standards. Of the additional control technologies applied the largest percent of the reductions are achieved through direct $PM_{2.5}$ area source controls. A small percentage of reductions are from SO_2 area controls, with the remainder being made up of $PM_{2.5}$ point sources and NH_3 area sources, outside of the San Joaquin valley.

Table 3-15: Incremental Emission Reductions by Region Applied in the Modeled Analysis of the Revised Standards of 15/35

Region	*Pollutant*	*Sector*	*Percent of Reduction*	*Tons*[a]
East	NH_3	Area	<1%	197
	$PM_{2.5}$	Area	11%	5,336
		EGU	18%	8,330
		non-EGU	4%	1,844
	SO_2	Area	17%	8,161
		non-EGU	50%	23,451
		Total East	**100%**	**47,320**
West	NH_3	Area	<1%	6
	NO_x	Area	1%	1,091
		EGU	46%	42,928
		non-EGU	24%	22,153
	$PM_{2.5}$	Area	16%	14,780
		EGU	1%	1,239
		non-EGU	6%	5,882
	SO_2	Area	4%	3,484
		EGU	2%	2,111
		Total West	**100%**	**93,674**
California	NH_3	Area	1%	126
	$PM_{2.5}$	Area	95%	13,500
		non-EGU	4%	641
		Total California	**100%**	**14,267**

[a] Reductions are based upon a slightly different emissions inventory than the 2020 baseline inventory used for the rest of this analysis. This discrepancy is discussed in Chapter 2.

14/35 Alternative Revised Standards

We applied an SO_2 control program for EGUs in the CAIR region (complete description contained later in this Chapter) and a regional control program to reduce SO_2 emitted from non-EGU point sources across 6 midwestern and two southern States. These programs were not based on a cost-effectiveness analysis. Instead they were based on developing reasonable programs to illustrate the potential costs and impacts of regional programs for comparison with the impacts of local strategies evaluated in the attainment strategies for the current and selected standards. After applying the regional SO2 strategies, we employed the hierarchy of control strategy selection similar to that which was applied for 15/35 until an area reached attainment. Table 3-16 displays the hierarchy of control strategies applied to the analysis of the 14/35 alternative. As the table indicates, some areas comply with the 14/35 standard after application of the SO2 regioanl strategies and local known controls. However, some areas also require developmental controls, supplemental controls, and/or extrapolated emission reductions. In addition to the developmental controls applied under the 15/35 analysis in California and Pittsburgh, we applied developmental agricultural controls in only one other area for the alternative standards. Developmental controls for for swine operatons were applied in Detroit as part of the 14/35 analysis.

Table 3-16: Application of Control Strategy Hierarchy by Area for the 14/35 Standard

Location[a]	SO2 Regional Program		MODELED PARTIAL ATTAINMENT[b]		ANALYSIS OF RESIDUAL NONATTAINMENT	
	EGU	Non-EGU	Local Known Controls	Developmental	Supplemental	Extrapolated
East						
Atlanta	✓	✓	✓			
Birmingham	✓	✓	✓		✓	
Chicago	✓	✓	✓		✓	
Cincinnati	✓	✓	✓			
Cleveland	✓	✓	✓	✓	✓	
Detroit	✓	✓	✓	✓		
Gary, IN	✓	✓			✓	
Pittsburgh	✓	✓	✓	✓		
Portsmouth, OH	✓	✓	✓			
St. Louis	✓	✓	✓			
West						
Eugene, OR			✓	✓		
Klamath Falls, OR			✓	✓		
Medford, OR			✓	✓		
Lincoln County, MT			✓	✓		
Missoula, MT			✓	✓		
Shoshone County, ID			✓	✓		
Logan, UT			✓	✓		
Salt Lake City, UT			✓	✓		✓
Seattle, WA			✓	✓		
Tacoma, WA			✓	✓		
CALIFORNIA[c]						
South Coast District				✓		✓
San Joaquin Valley				✓		✓
Other Affected Counties			✓	✓		✓

a For each location, controls are selected in the counties identified in the Metropolitan Statistical Area (MSA) first and then in counties surrounding the MSA if necessary to demonstrate attainment.

b In a limited number of areas, the modeling of control strategies results in areas that do not fully comply with the proposed standards, (i.e. areas of residual nonattainment). In areas of residual nonattainment, we conducted further analysis using supplemental controls and extrapolated reductions (discussed fully in Chapter 4).

c In California, all available known local controls are applied when modeling compliance with the current standard of 15/65, which impacts counties in the South Coast Air Quality District and the San Joaquin Valley. For the analysis of control strategies to comply with the revised standards of 14/35, several new counties are indicated as exceeding the revised daily standard of 35 ug/m3 (but comply with the annual standard). These counties are located north of the San Joaquin Valley and therefore, we employ available local known controls to this area.

Non-EGU SO_2 Regional Control Program. The non-EGU regional control program applied to six Midwestern and two southern states that each contained projected nonattainment areas for the alternative revised standards. These two areas contain the following states: Michigan, Illinois, Indiana, Ohio, Missouri and Kentucky in the midwest and Alabama and Georgia in the south. In these two areas we controlled all non-EGU sources emitting SO_2 with the same restrictions set on our analysis as described earlier in this chapter. We applied a cost per ton cut-off for this subregion of $5,000 per ton.[18] In simulating the implementation of this control strategy we were attempting to illustrate the air quality impacts associated with controlling the regional transport of SO_2 from industrial sources located among a multi-state area. While we did not explicitly design, or model, this strategy to be a regional trading program, States could develop such a program if they so chose.

In the eastern part of the country, ninety-eight percent of the initially modeled reductions are a result of the SO_2 non-EGU regional control program and the EGU control program. The remaining two percent are reductions of direct $PM_{2.5}$ from point and area sources. For a complete breakdown of pollutant sector reduction by region see Table 3-15 below.

[18] This cost cut-off was the product of a policy decision informed by an understanding of the relationship between the cost per-ton of non-EGU SO_2 controls and the total amount of SO_2 that would be abated in this region for that cost per ton.

Table 3-15: Incremental Emission Reductions by Region in 2020 for the Modeled Analysis of the Alternative More Stringent Standards of 14/35[a]

Region	*Pollutant*	*Sector*	*% of Reduction*	*Tons*[b]
East	NH_3	Area	<1%	243
	NO_x	Area	<1%	1,060
		non-EGU	<1%	8,983
	$PM_{2.5}$	Area	<1%	5,481
		EGU	<1%	7,592
		non-EGU	<1%	1,930
	SO_2	Area	1%	10,805
		Regional EGU & non-EGU	98%	346,825 + 474,000
		Total East	**100%**	**382,919 + 474,000**
West	NH_3	Area	<1%	6
	NO_x	Area	1%	1,091
		EGU	47%	42,928
		non-EGU	24%	22,153
	$PM_{2.5}$	Area	16%	14,780
		EGU	1%	1,239
		non-EGU	6%	5,882
	SO_2	Area	4%	3,484
		Total West	**100%**	**91,563**
California	NH_3	Area	1%	126
	NO_x	Area	1%	224
		non-EGU	6%	861
	$PM_{2.5}$	Area	88%	13,500
		non-EGU	4%	641
		Total California	**100%**	**15,353**

a The more stringent 14/35 standard was modeled incrementally to the 15/65 current standard

b Reductions are based upon a slightly different emissions inventory than the 2020 baseline inventory used for the rest of this analysis. This discrepancy is discussed in Chapter 2.

C Note that tons of different pollutants are expected to have different air quality impacts. See Appendix C for a summary of estimated µg/ton impacts for each urban area.

Control technologies applied in the western part of the country are very similar to those applied for the revised standard (described above). Some additional controls were needed to achieve the lower annual standard in Lincoln County, Montana. These controls were NO_x controls applied to non-EGU and area sources.

To partially attain both the lower daily and lower annual standard in CA, additional controls are needed incremental to the current standard. Of the additional controls applied most of the reductions are $PM_{2.5}$ area sources, another smaller amount was from SO_2 area sources and NO_x

sources. Negligible amount of NH_3 reductions occur in additional counties which were violating the daily standard.

EGU SO_2 Regional Control Program. The data and projections presented here cover the electric power sector, an industry that will achieve significant emission reductions under the Clean Air Interstate Rule (CAIR) over the next 10 to 15 years. Based on an assessment of the emissions contributing to interstate transport of air pollution and available control measures, EPA determined that achieving required reductions in the identified States by controlling emissions from power plants is highly cost effective. CAIR will permanently cap emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the eastern United States. CAIR achieves large reductions of SO_2 and/or NO_x emissions across 28 eastern states and the District of Columbia.

When fully implemented, CAIR will reduce SO_2 emissions in these states by over 70% and NO_x emissions by over 60% from 2003 levels. This will result in significant environmental and health benefits and will substantially reduce premature mortality in the eastern United States. The benefits will continue to grow each year with further implementation. CAIR was designed with current air quality standard in mind, and requires significant emission reductions in the East, where they are needed most and where transport of pollution is a major concern. CAIR will bring most areas in the Eastern US into attainment with the ozone and current $PM_{2.5}$ standards. Some areas will need to adopt additional local control measures beyond CAIR. CAIR is a regional solution to address transport, not a solution to all local nonattainment issues. The large reductions anticipated with CAIR, in conjunction with reasonable additional local control measures for SO_2, NO_x, and direct PM, will move States towards attainment in a deliberate and logical matter. The suite of control options presented in this RIA shows how this could be done.

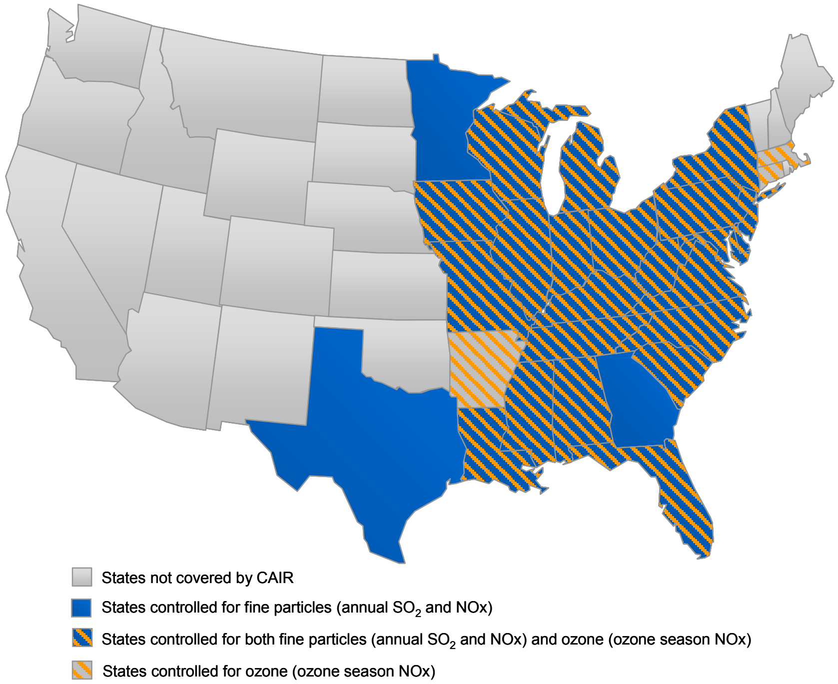


Figure 3-3: CAIR Affected Region

States must achieve the required emission reductions using one of two compliance options. One option is to meet the state's emission budget by requiring power plants to participate in an EPA-administered interstate cap and trade system that caps emissions in two stages—this is EPA's recommended choice because of the cost effectiveness of regional cap-and-trade programs. Or, States can meet an individual state emissions budget through measures of the state's choosing. CAIR provides a Federal framework requiring states to reduce emissions of SO_2 and NO_x, and EPA anticipates that states will achieve this primarily by reducing emissions from the power generation sector. These reductions will be substantial and cost-effective, so in many areas, the reductions are large enough to meet the air quality standards. The Clean Air Act requires that states meet the new national, health-based air quality standards for ozone and $PM_{2.5}$ standards by requiring reductions from many types of sources, and some areas may need to take additional local actions. However, the reductions required by CAIR will lessen the need for additional local controls. The analysis in this section reflects these realities and attempts to show, in an illustrative fashion, the costs and impacts of meeting both current and alternative air quality standards for $PM_{2.5}$ for the power sector.

Modeling Background

CAIR was designed to achieve significant emissions reductions in a highly cost-effective manner to reduce the transport of fine particles that have been found to contribute to nonattainment. EPA analysis has found that the most efficient method to achieve the emissions reduction targets is through a cap-and-trade system on the power sector that States have the option of adopting. The power sector accounted for 67% of nationwide SO_2 emissions and 22% of nationwide NO_x emissions in 2002. States, in fact, can choose not to participate in the optional cap-and-trade program and can choose to obtain equivalent emissions reductions from other sectors. However, EPA believes that a region-wide cap-and-trade system for the power sector is the best approach for reducing emissions. The modeling done with IPM assumes a region-wide cap and trade system on the power sector for the States covered.

The economic modeling using IPM presented in this and other chapters has been developed for specific analyses of the power sector. EPA's modeling is based on its best judgment for various input assumptions that are uncertain, particularly assumptions for future fuel prices and electricity demand growth. To some degree, EPA addresses the uncertainty surrounding these two assumptions through sensitivity analyses. More detail on IPM can be found in the model documentation, which provides additional information on the assumptions discussed here as well as all other assumptions and inputs to the model (www.epa.gov/airmarkets/epa-ipm).

Updated Modeling in Support of the Alternative 14 $\mu g/m^3$ Annual and 35 $\mu g/m^3$ Alternative More Stringent Standard

In addition to the changes in IPM previously discussed, an additional change was made to the power sector modeling for the 14/35 case. As discussed in chapter one, monitored $PM_{2.5}$ speciation data indicates that a substantial fraction of total $PM_{2.5}$ mass is composed of sulfates in the Midwest and eastern United States. These sulfates are formed on a secondary basis from SO_2 emitted from a variety of sources. In light of this fact, a control strategy for $PM_{2.5}$ in this area of the country that considers controlling SO_2 emissions where it is cost-effective to do so is a reasonable approach to demonstrating attainment with the standards.

Considering the alternative 14/35 case in the context of air quality issues, chemistry, future emissions for all anthropogenic sources, and cost-effectiveness has led the EPA to investigate and analyze a reduction in the CAIR SO_2 cap (increase in allowance surrender ratios) for the power sector in the 2020 timeframe. The illustrative analytical approach for the analysis of the 14/35 case is intended to build off the significant reductions already anticipated with CAIR. EPA chose to illustrate the impact of additional EGU emission reductions under a new and tighter standard although the cap levels set in CAIR represent EPA views on the maximum reductions that can be achieved within a cost-per-ton range that EPA considers to be highly cost-effective for addressing interstate transport under the 15/65 PM NAAQS (See CAIR preamble, 70 F.R. 25201).

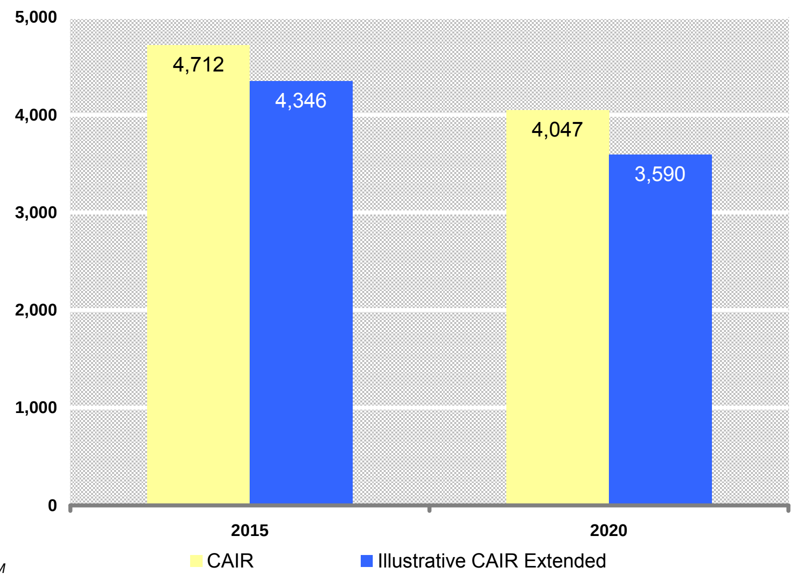
The result is an illustrative "extended" approach to CAIR, with consideration of an additional third phase SO_2 cap (higher surrender ratio) to come into effect in 2020 for the affected region. Key factors in considering the extended approach to CAIR were the longer time horizon, impacts on the power sector, and impacts on consumers. However, EPA developed this augmented EGU approach to illustrate the impacts (costs and benefits) of additional EGU controls. If EPA were to study and investigate additional EGU emission reductions in rulemaking under an alternative standard of 14/35, the Agency would need to go through the regulatory process and perform more complex technical analysis of the merits of additional EGU reductions beyond what is anticipated under CAIR.

Table 3-16: SO_2 Reduction Requirements of CAIR and an Illustrative CAIR Extended

	CAIR		Illustrative CAIR Extended	
	% Reduction from title IV	*Retirement Ratio*	*% Reduction from title IV*	*Retirement Ratio*
2010	50%	2.00	50%	2.00
2015	65%	2.86	65%	2.86
2020	N/A	N/A	75%	4.00

The illustrative CAIR requirements were developed by applying caps consistent with a 50% reduction in the final title IV SO_2 cap levels in 2010 and a 65% reduction in 2015. These caps could be met through retirement of title IV SO_2 allowances (see Final CAIR preamble for further discussion). For the illustrative CAIR Extended, a third phase cap was added consistent with a 75% reduction in the final title IV SO_2 cap levels in 2020.

Figure 3-4. Projected Nationwide SO_2 Emissions from EGUs (1,000 tons)



Source: IPM

Figure 3-5. Projected SO_2 Emissions from EGUs in the CAIR Region (1,000 tons)

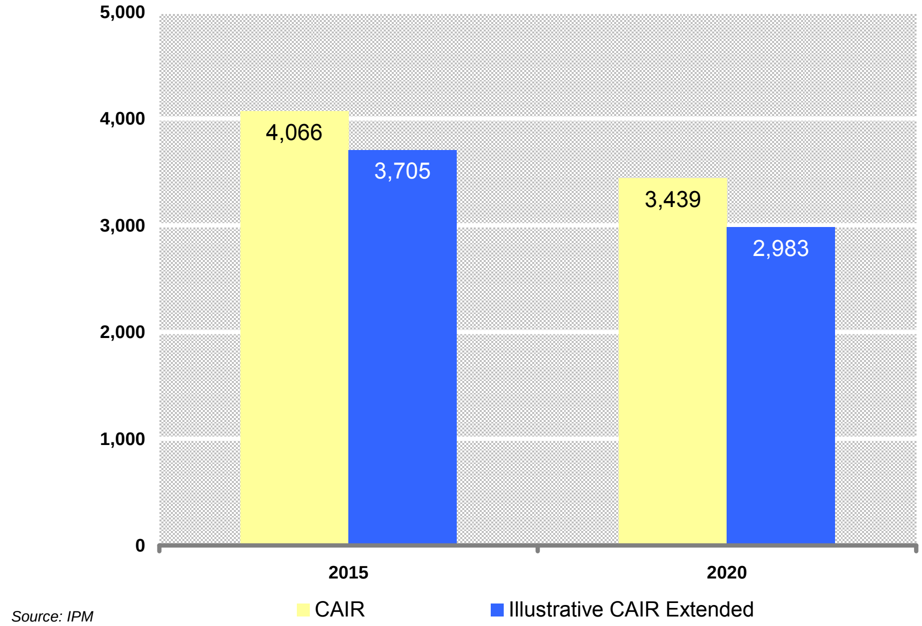


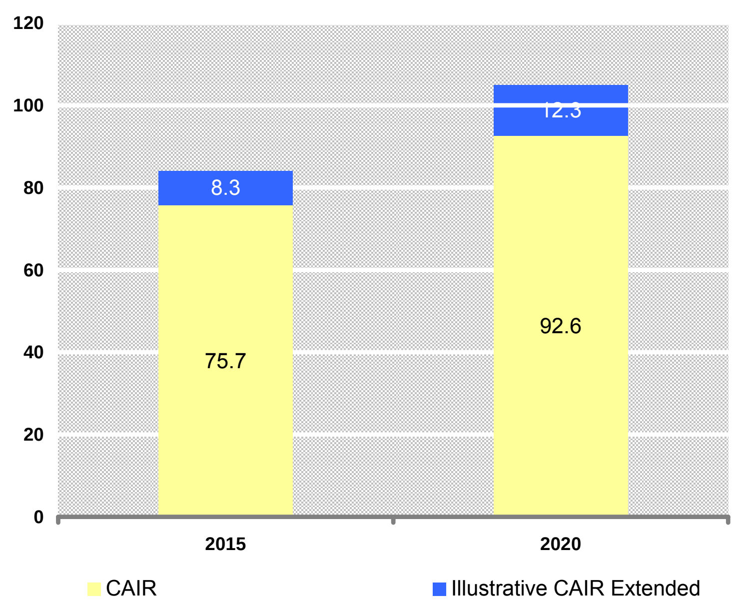
Figure 3-6. 2020 SO_2 Emissions by State (1,000 tons)

Source: IPM

Figure 3-7. 2015 SO_2 Emissions by State (1,000 tons)

Source: IPM

Figure 3-8. Projected Control Technology Retrofits, Incremental FGD (GW)



3.3.5 Limitations and Uncertainties of Analysis

The estimates of emission reductions associated with our control strategies above are subject to important limitations and uncertainties. For each sector we outline, and qualitatively assess the impact of, those limitations and uncertainties that are most significant.

Non-EGU Point and Area Sector

A number of limitations and uncertainties are associated with the analysis of non-EGU point and area source emission controls:

- The technologies applied and the emission reductions achieved in these analyses may not reflect emerging control devices that could be available in future years to meet any BART requirements in SIPs or upgrades to some current devices that may serve to increase control levels. For example, there is increasing use of SCR/SNCR hybrid technologies that can serve to lower the expected capital costs and lead to NO_x control at high levels (90 percent).
- The emission reduction estimates for point and area sources do not reflect potential effects of technological change that could be available in future years. As emission control technologies change, one effect is an increase in performance due to improvements in the capabilities in the underlying technology that are utilized. For example, SCR technology now can provide 90 percent reduction of NOx emissions from a variety of sources; twenty years ago, no more than 60 percent reduction could occur. Hence, we may understate the emission reductions estimated by these analyses.
- The effects from "learning by doing" are not accounted for in the emission reduction estimates for point and area sources. It is possible that an emissions control technology may have better performance in reducing emissions due to greater understanding of how best to operate and maintain the technology. As a result, we may understate the emission reductions estimated by these analyses. The mobile source control measures do account for these effects.
- The effectiveness of the control measures in these analyses is based an assumption that these controls are well maintained throughout their equipment life (the amount of time they are assumed to operate). To the extent that a control measure is not well maintained, the control efficiency may be less than estimated in these analyses. Since these control measures must operate according to specified permit conditions, however, it is expected that the maintenance of controls should yield control efficiencies at or very close to those used in these analyses. As a result, we may overstate the emission reductions estimated by these analyses.
- The application of area source control technologies in these analyses assume that a constant estimate for emission reduction is reasonable despite variation in the extent or scale of application (e.g. amount of watering at cattle feed lots). To the extent that there are economies of scale in area source control applications, we may overstate the emission reductions estimated by these analyses.

EGU Sector

EPA's modeling 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 available engineering studies of air pollution controls and has set up what it believes is the most reasonable modeling framework for analyzing the cost, emission changes, and other impacts of regulatory controls.

The annual cost estimates of the private compliance costs that are provided in this analysis are meant to show the increase in production (engineering) costs of CAIR to the power sector. In simple terms, the private compliance costs that are presented are the annual increase in revenues required for the industry to be as well off after CAIR is implemented as before. To estimate these annual costs, EPA uses a conventional and widely-accepted approach that is commonplace in economic analysis of power sector costs for estimating engineering costs in annual terms. For estimating annual costs, EPA has applied a capital recovery factor (CRF) multiplier to capital investments and added that to the annual incremental operating expenses. The CRF is derived from estimates of the cost of capital (private discount rate), the amount of insurance coverage required, local property taxes, and the life of capital. The private compliance costs presented earlier are EPA's best estimate of the direct private compliance costs of CAIR.

The annualization factor used for pure social cost calculations (for annual costs) normally includes the life of capital and the social discount rate. For purposes of benefit-cost analysis of this rule, EPA has calculated the annual social costs using the discount rates from the benefits analysis for CAIR (3 percent and 7 percent and a 30 year life of capital. The cost of added insurance necessary because of CAIR was included in the calculations, but local taxes were not included because they are considered to be transfer payments, and not a social cost). Using these discount rates, the incremental social costs of the Illustrative CAIR Extended is $0.45 billion in 2020 using a discount rate of 3 percent and $0.53 billion using a discount rate of 7 percent.

The annual regional cost of the illustrative CAIR Extended, as quantified here, is EPA's best assessment of the cost of implementing the additional reductions beyond CAIR, assuming that States adopt the model cap and trade program. These costs are generated from rigorous economic modeling of changes in the power sector due to additional emission control requirements beyond CAIR. This type of analysis using IPM has undergone peer review and federal courts have upheld regulations covering the power sector that have relied on IPM's cost analysis.

The direct private compliance cost includes, but is not limited to, capital investments in pollution controls, operating expenses of the pollution controls, investments in new generating sources, and additional fuel expenditures. EPA believes that the EGU cost assumptions used in the analysis for CAIR reflect, as closely as possible, the best information available to the Agency today.

Cost estimates for SO_2 reductions from EGUs are based on results from ICF's Integrated Planning Model. The model minimizes the costs of producing electricity (including abatement costs) while meeting load demand and other constraints (full documentation for IPM can be found at www.epa.gov/airmarkets/epa-ipm). The structure of the model assumes that the electric utility industry will be able to meet the environmental emission caps at least cost. Montgomery

(1972) has shown that this least cost solution corresponds to the equilibrium of an emission permit system.[19] See also Atkinson and Tietenburg (1982), Krupnick et al. (1980), and McGartland and Oates (1985).[20] [21] [22] However, to the extent that transaction and/or search costs, combined with institutional barriers, restrict the ability of utilities to exhaust all the gains from emissions trading, costs are underestimated by the model. Utilities in the IPM model also have "perfect foresight." To the extent that utilities misjudge future conditions affecting the economics of pollution control, costs may be understated as well.

As a counterweight, the most current of these well-respected assessments was published a decade before empirical evidence was available on cap and trade programs. Comparing empirical evidence (actual market prices of allowances) with forecasts from IPM (and its predecessor, the Coal Electric Utility Model) show that models have significantly overestimated projected compliance costs; industry takes advantage of cap and trade more effectively than EPA can predict.

From another vantage point, this modeling analysis does not take into account the potential for advancements in the capabilities of pollution control technologies for SO_2 and NO_x removal as well as reductions in their costs over time. Market-based cap and trade regulation serves to promote innovation and the development of new and cheaper technologies. As an example, recent cost estimates of the Acid Rain SO_2 trading program by Resources for the Future (RFF) and MIT's Center for Energy and Environmental Policy Research (CEEPR) have been as much as 83 percent lower than originally projected by the EPA.[23] It is important to note that the original analysis for the Acid Rain Program done by EPA also relied on an optimization model like IPM. Ex ante, EPA cost estimates of roughly \$2.7 to \$6.2 billion[24] in 1989 were an overestimate of the costs of the program in part because of the limitation of economic modeling to predict technological improvement of pollution controls and other compliance options such as fuel switching. Ex post estimates of the annual cost of the Acid Rain SO_2 trading program range

[19]Montgomery, W. David. 1972. "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory* 5(3):395-418.

[20]Atkinson, S., and T. Tietenberg. 1982. "The Empirical Properties of Two Classes of Design for Transferable Discharge Permit Markets." *Journal of Environmental Economics and Management* 9:101-121

[21]Krupnick, A., W. Oates, and E. Van De Verg. 1980. "On Marketable Air Pollution Permits: The Case for a System of Pollution Offsets." *Journal of Environmental Economics and Management* 10:233-47.

[22]McGartland, A., and W. Oates. 1985. "Marketable Permits for the Prevention of Environmental Deterioration." *Journal of Environmental Economics and Management* 12:207-228.

[23]See (1) Carlson, Curtis; Burtraw, Dallas R.; Cropper, Maureen, and Palmer, Karen L. 2000. Sulfur Dioxide Control by Electric Utilities: What Are the Gains from Trade? *Journal of Political Economy* 108 (#6): 1292_1326, and (2) Ellerman, Denny. January 2003. Ex Post Evaluation of Tradable Permits: The U.S. SO_2 Cap and Trade Program. Massachusetts Institute of Technology Center for Energy and Environmental Policy Research.

[24] 2010 Phase II cost estimate in \$1995.

from $1.0 to $1.4 billion. Harrington et al. have examined cost analyses of EPA programs and found a tendency for predicted costs to overstate actual implementation costs in market-based programs.[25]
It is also important to note that the capital cost assumptions for scrubbers used in EPA modeling applications are highly conservative. These are a substantial part of the compliance costs. Data available from recent published sources show the reported FGD costs from recent installations to be below the levels projected by IPM.[26] In addition, EPA also conducted a survey of recent FGD installations and compared the costs of these installations to the costs used in IPM. This survey included small, mid-size, and large units. Examples of the comparison of recently published FGD capital cost data with the FGD capital cost estimates obtained from IPM are provided in the Final CAIR docket.

EPA's latest update of IPM incorporates State rules or regulations adopted before March 2004 and various NSR settlements. Documentation for IPM can be found at www.epa.gov/airmarkets/epa-ipm. A very limited set of State and/or settlement actions since that time have been included in EPA analysis for EGUs.

As configured in this application, IPM does not take into account demand response (i.e., consumer reaction to electricity prices). An increase in retail electricity prices would prompt end users to curtail (to some extent) their use of electricity and encourage them to use substitutes.[27] The response would lessen the demand for electricity, resulting in electricity price increases slightly lower than IPM predicts, which would also reduce generation and emissions. Because of demand response, certain unquantified negative costs (i.e., savings) result from the reduced resource costs of producing less electricity because of the lower quantity demanded. To some degree, these saved resource costs will offset the additional costs of pollution controls and fuel switching that we would anticipate with CAIR. Although the reduction in electricity use is likely to be small, the cost savings from such a large industry ($250 billion in revenues in 2003) is likely to be substantial. EIA analysis examining multi-pollutant legislation under consideration in 2003 indicates that the annual costs of CAIR may be overstated substantially by not considering demand response, depending on the magnitude and coverage of the price increases.[28]

Recent research suggests that the total social costs of a new regulation may be affected by interactions between the new regulation and pre-existing distortions in the economy, such as

[25] Harrington, W. R.D. Morgenstern, and P. Nelson, 2000. "On the Accuracy of Regulatory Cost Estimates," Journal of Policy Analysis and Management 19(2): 297-322.

[26] There is evidence that scrubber costs will decrease in the future because of the learning-by-doing phenomenon, as more scrubbers are installed. See Manson, Nelson, and Neumann, 2002. "Assessing the Impact of Progress and Learning Curves on Clean Air Act Compliance Costs," Industrial Economics Incorporated.

[27] The degree of substitution/curtailment depends on the price elasticity of demand for electricity.

[28] See "Analysis of S. 485, the Clear Skies Act of 2003, and S. 843, the Clean Air Planning Act of 2003." Energy Information Administration. September, 2003. EIA modeling indicated that the Clear Skies Act of 2003 (a nationwide cap and trade program for SO_2, NO_x, and mercury), demand response could lower present value costs by as much as 47% below what it would have been without an emission constraint similar to CAIR.

taxes. In particular, if cost increases due to a regulation are reflected in a general increase in the price level, the real wage received by workers may be reduced, leading to a small fall in the total amount of labor supplied. This "tax interaction effect" may result in an increase in deadweight loss in the labor market and an increase in total social costs. Although there is a good case for the existence of the tax interaction effect, recent research also argues for caution in making prior assumptions about its magnitude. Chapter 8 of EPA's draft "Guidelines for Preparing Economic Analysis" discusses in detail the tax interaction effect in the context of environmental regulation. These economic analysis guidelines are still under review within EPA. The limited empirical data available to support quantification of any such effect leads to this qualitative identification of the costs.

On balance, after consideration of various unquantified costs (and savings that are possible), EPA believes that the annual private compliance costs that we have estimated are more likely to overstate the future annual compliance costs that industry will incur, rather than understate those costs.

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Chapter 4: Air Quality Impacts

Chapter Synopsis

This chapter details the three-step process we employed to estimate the air quality impacts of our emission control strategies. First we used the Community-Scale Air Quality (CMAQ) model to estimate the reductions in ambient concentration of PM2.5 resulting from our illustrative attainment strategy. Next, where our modeled attainment strategy did not result in attainment with the revised daily standard of 35µg/m^3 or the alternative more stringent annual standard of 14 µg/m^3 we conducted a supplemental control analysis for particular areas by examining additional emission controls on carbonaceous particles. As a final step, we made a final determination of attainment and non-attainment among those areas which were not able to attain the revised or alternative more stringent standard after applying additional controls on carbonaceous particles. For these areas we analyzed the CMAQ-projected design values within the context of the available empirical modeling and monitoring data to determine whether these areas attained the standard for the purposes of this analysis. Finally, in areas determined to be non-attainment after our full modeled and empirical assessments, we discuss how air quality might be affected by full attainment.

4.1 Modeled $PM_{2.5}$ Air Quality Estimates

4.1.1 Air Quality Modeling Overview

A national scale air quality modeling analysis was performed to estimate future year annual and daily $PM_{2.5}$ concentrations as well as visibility degradation (i.e., regional haze). These projections were used as inputs to the calculation of expected benefits from the alternative NAAQS considered in this assessment. The 2001-based CMAQ modeling platform was used as the tool for air quality modeling of future baseline emissions and control scenarios designed to attain specific daily and annual standards. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial and boundary condition data which are inputs to this model. The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations and deposition over regional and urban spatial scales (e.g., over the contiguous U.S.) (EPA, 1999; Byun and Schere, 2006; Dennis et al., 1996). Consideration of the different processes (e.g. transport and deposition) that affect primary (directly emitted) and secondary (formed by atmospheric processes) PM at the regional scale in different locations is fundamental to understanding and assessing the effects of pollution control measures that affect PM, ozone and deposition of pollutants to the surface.

The CMAQ model was peer-reviewed in 2003 for EPA as reported in *"Peer Review of CMAQ Model*" (Amar et al., 2004). The latest version of CMAQ (Version 4.5) was employed for this PM NAAQS RIA modeling analysis. This version reflects updates in a number of areas to improve the underlying science and address comments from the peer-review including (1) use of a state-of-the-science inorganic nitrate partitioning module (ISORROPIA) and updated gaseous, heterogeneous chemistry in the calculation of nitrate formation, (2) a state-of-the-science secondary organic aerosol (SOA) module that includes a more comprehensive gas-particle partitioning algorithm from both anthropogenic and biogenic SOA, (3) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH, and (4) an updated CB-IV gas-phase chemistry mechanism and aqueous chemistry mechanism that provide a comprehensive simulation of aerosol precursor oxidants.[1]

4.1.2 Model Domain and Configuration

As shown in Figure 4-1, the CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico (Figure 4-1). The domain extends from 126 degrees to 66 degrees west longitude and from 24 degrees north latitude to 52 degrees north latitude. The horizontal grid cells are approximately 36 km by 36 km. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 mb.

Figure 4-1. Map of the CMAQ Modeling Domain Used for PM NAAQS RIA.

[1] Please see the Community Modeling and Analysis System (CMAS) Center Web site for complete details on CMAQ version 4.5: http://www.cmascenter.org/

4.1.3 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from a simulation of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model (Grell, Dudhia, and Stauffer, 1994) for the entire year of 2001. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. For this analysis, version 3.6.1 of MM5 was used. The horizontal domain consisted of a single 36 x 36 km grid with 165 by 129 cells, selected to cover the CMAQ modeling domain with some buffer to avoid boundary effects. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.1: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer (EPA, 1999).

The lateral boundary and initial species concentrations were obtained from a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model (Yantosca, 2004). The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2001 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at 3-hour intervals and the initial concentration field for the CMAQ simulations.

A complete description of the development and processing of model-ready meteorological inputs and initial and boundary condition inputs used for this analysis are discussed in the CAIR TSD (EPA, 2005). In addition, the development of the gridded, hourly model-ready emissions inputs used for the 2001 base year and each of the future year base cases and control scenarios are summarized below in this chapter.

4.1.4 Evaluation of Air Quality Modeling System

EPA performed an extensive evaluation of our CMAQ air quality modeling system as part of the support analyses for CAIR[2]. This evaluation has been updated to consider model performance using the revised base year emissions inventories, as described above in Chapter 2. The updated operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using the 2001 data in order to estimate the ability of the modeling system to replicate base year concentrations. The details of the $PM_{2.5}$ performance evaluation are provided in Appendix O. In summary, model performance statistics were calculated for pairs of observed/predicted concentrations. Statistics were generated for the following geographic groupings: (1) the entire modeling domain, (2) the Eastern U.S. and (3) the Western U.S. As in the evaluation for CAIR modeling, the "acceptability" of model performance for the PM NAAQS modeling was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA

[2] CMAQ Model Evaluation Report, March 2005 (CAIR Docket OAR-2005-00532149).

studies[3]. As decribed in Appendix X,, overall, the performance for this application is within the range or better than these other applications.

4.1.5 Model Simulation Scenarios

As part of our analysis the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations and visibility estimates for each of the following seven emissions scenarios:

- 2001 base year
- 2015 base case projection with CAIR/CAMR/CAVR
- 2015 15/65 (projection to 2015 with controls estimated to attain an annual standard of 15 $\mu g/m^3$ and daily standard of 65 $\mu g/m^3$)
- 2020 base case projection with CAIR/CAMR/CAVR
- 2020 15/65 (projection to 2020 with controls estimated to attain an annual standard of 15 $\mu g/m^3$ and daily standard of 65 $\mu g/m^3$)
- 2020 15/35 (projection to 2020 with controls to estimated to attain an annual standard of 15 $\mu g/m^3$ and daily standard of 35 $\mu g/m^3$)
- 2020 14/35 (projection to with controls estimated to attain an annual standard of 14 $\mu g/m^3$ and daily standard of 35 $\mu g/m^3$)

Note that the 2020 15/65 scenario is the future baseline used for evaluating the benefits of the 15/35 and 14/35 alternative NAAQS. The growth assumptions and emissions controls for each of these scenarios are described elsewhere in the RIA.

We use the predictions from the model in a relative sense by combining the 2001 base-year predictions with predictions from each future-year scenario and speciated ambient air quality observations to determine $PM_{2.5}$ concentrations and visibility for each of the 2015 and 2020 scenarios. After completing this process, we then calculated daily and seasonal PM air quality metrics as inputs to the health and welfare impact functions of the benefits analysis. The following sections provide a more detailed discussion of our air quality projection method and a summary of the results.

4.1.6 Projection Methods for Air Quality Concentrations

To forecast future year annual average and daily 98th percentile $PM_{2.5}$ concentrations we used air quality modeling results from the $PM_{2.5}$ NAAQS CMAQ model runs.

In general, the procedures for projecting both the annual and daily $PM_{2.5}$ design values are based on utilization of model predictions in a relative sense. In this manner, the 2001 base year model predictions and the 2015 (or 2020) future-year model predictions are coupled with ambient data to forecast future concentrations. This approach is consistent with the EPA draft guidance document for modeling $PM_{2.5}$ (EPA, 2001).

[3] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

Projection Methodology for Annual Average Design Values

The procedures used to project the annual design values are generally consistent with the projection techniques used in the CAIR. The projected annual design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. This approach is used to ensure that the $PM_{2.5}$ concentrations are closely related to the observed ambient data. The SMAT procedure combines absolute concentrations of ambient data with the relative change in PM species from the model.

The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its noncarbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the US. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of $0.5 ug/m^3$).

More complete details of the SMAT procedures used in the CAIR analysis can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)" (EPA, 2004). For the PM NAAQS analysis, several datasets and techniques were updated. The changes and updates include:

1. Revised database of $PM_{2.5}$ speciation data which includes data from 2002 and 2003.
2. Revised interpolations of $PM_{2.5}$ species data using updated techniques.
3. An updated equation to calculate particle bound water.
4. Revised treatment of ambient ammonium data.

Documentation of these updates and changes can be found in (EPA, 2006).

Below are the steps we followed for projecting future $PM_{2.5}$ concentrations. These steps were performed to estimate future case concentrations at each FRM monitoring site. The starting point for these projections is a 5 year weighted average design value for each site. The weighted average is calculated as the average of the 1999–2001, 2000–2002, and 2001–2003 design values at each monitoring site. By averaging 1999–2001, 2000–2002, and 2001–2003, the value from 2001 is weighted three times, whereas, values for 2000 and 2002 are each weighted twice, and 1999 and 2003 are each weighted once. This approach has the desired benefits of (1) weighting the $PM_{2.5}$ values towards the middle year of the five-year period (2001), which is the base year for our emissions projections, and (2) smoothing out the effects of year-to-year variability in emissions and meteorology that occurs over the full five-year period. This approach provides a robust estimate of current air quality for use as a basis for future year projections.

Step 1: Calculate quarterly mean ambient concentrations for each of the major components of $PM_{2.5}$ (i.e., sulfate, nitrate, ammonium, elemental carbon, organic carbon, water, and crustal material) using the component species concentrations estimated for each FRM site.

The component species concentrations were estimated using an average of 2002 and 2003 ambient data from speciation monitors. The speciation data was interpolated to provide estimates for all FRM sites across the country. The interpolated component concentration information was used to calculate species fractions at each FRM site. The estimated fractional composition of each species (by quarter) was then multiplied by the 5 year weighted average 1999–2003 FRM quarterly mean concentrations at each site (e.g., 20% sulfate multiplied by 15.0 $\mu g/m^3$ of $PM_{2.5}$ equals 3 $\mu g/m^3$ sulfate). The end result is a quarterly concentration for each of the $PM_{2.5}$ species at each FRM site.

Step 2: Calculate quarterly average Relative Reduction Factors (RRFs) for sulfate, nitrate, elemental carbon, organic carbon, and crustal material. The species-specific RRFs for the location of each FRM are the ratio of the 2015 (or 2020) future year cases to the 2001 base year quarterly average model predicted species concentrations. The species-specific quarterly RRFs are then multiplied by the corresponding 1999–2003 quarterly species concentration from Step 1. The result is the future case quarterly average concentration for each of these species for each future year model run.

Step 3: Calculate future case quarterly average concentrations for ammonium and particle-bound water. The future case concentrations for ammonium are calculated using the future case sulfate and nitrate concentrations determined from Step 2 along with the degree of neutralization of sulfate (held constant from the base year). Concentrations of particle-bound water are calculated using an empirical equation derived from the AIM model using the concentrations of sulfate, nitrate, and ammonium as inputs.

Step 4: Calculate the mean of the four quarterly average future case concentrations to estimate future annual average concentration for each component species. The annual average concentrations of the components are added together to obtain the future annual average concentration for $PM_{2.5}$.

Step 5: For counties with only one monitoring site, the projected value at that site is the future case value for that county. For counties with more than one monitor, the highest future year value in the county is selected as the concentration for that county.

Change in Annual Average $PM_{2.5}$ for the Benefits Calculations

For the purposes of projecting future $PM_{2.5}$ concentrations for input to the benefits calculations, we applied the SMAT procedure using the base-year 2001 modeling scenario and each of the future-year scenarios. In our application of SMAT we used temporally scaled speciated $PM_{2.5}$ monitor data from 2002 as the set of base-year measured concentrations. Temporal scaling is based on ratios of model-predicted future case $PM_{2.5}$ species concentrations to the corresponding model-predicted 2001 concentrations.[4] Output files from this process include both quarterly and annual mean $PM_{2.5}$ mass concentrations.

The SMAT procedures for calculating PM benefits are the same as documented above for projecting future nonattainment counties for the annual NAAQS with the following exceptions:

1. The benefits analysis uses interpolated $PM_{2.5}$ data[5] (FRM and IMPROVE) that cover all of the grid cells in the modeling domain (covering the entire country), whereas the nonattainment analysis is performed at each ambient monitoring site using measured FRM $PM_{2.5}$ data (only the species data are interpolated).
2. The benefits analysis is anchored by the interpolated $PM_{2.5}$ data from the single year of 2002, whereas the nonattainment analysis uses a 5-year weighted average (1999–2003) of $PM_{2.5}$ design values at each monitoring site.

Projection Methodology for 24-Hour Average Design Values

The daily design values are based on applying a projection method similar to that used for annual design values. Monitoring data for the years 1999 to 2003 are used as the basis for the projection of daily design values. Since the 24-hour NAAQS is based on annual 98th percentile values, we want to use ambient data and model data that represent the high concentrations at each site. As such, we have focused the 24-hour analysis on ambient data from the highest 25% of measured days[6] (by $PM_{2.5}$ concentration) in each quarter at each site. We are also deriving the modeled RRFs from the top 25% of modeled days for each quarter.

There are several steps in the projection for 24-hour concentrations for each of the base years of monitoring data:

Step 1: The first step in projecting the daily design value is to identify the maximum daily average $PM_{2.5}$ concentration in each quarter that is less than or equal to the annual 98th percentile value over the entire year. This results in data for each year (1999–2003) for each site which contains one quarter with the 98th percentile value and three quarters with the maximum values from each quarter which are less than or equal to the 98th percentile value.

Step 2: These quarterly $PM_{2.5}$ concentrations are then separated into their component species by multiplying the quarterly maximum daily concentration at each site by the estimated fractional composition of $PM_{2.5}$ species, by quarter, based on the observed species fractions for the top 25% days from speciation monitors in 2002 and 2003 (using the same methodology as the quarterly average fractional species data used in the annual average calculations from above).

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[4] Monitoring data from 2002 was used to develop the species specific information because there was not sufficient PM2.5 speciation data for 2001 or previous years.

[5] Interpolation of the PM2.5 data is necessary for the benefits analysis because PM2.5 concentrations are needed for every grid cell. But for the design value calculations at the monitoring sites, interpolation of the measured PM2.5 is not needed.

[6] Many of the monitoring sites have a relatively infrequent measurement cycle (once every 6 days). Therefore, the top 25% of measured days from each quarter for those sites is ~3days. We believe that this is consistent with the high end of the distribution of days that represent the 98th percentile concentrations. Sites with more frequent measurement schedules will have more days in the mean top 25% of days.

Step 3: The component species are then projected by multiplying each species concentration by the quarterly relative reduction factors for each species derived from the 2015 (or 2020) and 2001 $PM_{2.5}$ air quality modeling (using quarterly RRFs derived from the top 25% modeled days in each quarter). The methodology is the same as used in the annual average calculations.

Step 4: The projected species components are then summed to obtain a $PM_{2.5}$ concentration for each quarter that represents a potential daily design value. This procedure is repeated for each of the years of monitoring data (1999–2003). The highest daily value for each year at each monitor is considered to be the estimated 98th percentile value for that year.

Step 5: The estimated 98th percentile values for each of the 5 years are averaged over 3 year intervals (1999–2001, 2000–2002, 2001–2003), and then averaged over the three interval averages. This creates a 5 year weighted average for each monitor. The projected daily design value for a county is then calculated as the maximum 5 year weighted average design value across all monitors within a county.

Annual and daily average county level design values were then compared to the potential alternative annual and daily standards and mapped.

4.1.7 Air Quality Modeling Results for $PM_{2.5}$

Annual average and daily average 98th percentile $PM_{2.5}$ concentrations were estimated for each FRM site by applying the SMAT techniques described above to the CMAQ-predicted $PM_{2.5}$ species concentrations for each scenario modeled (i.e., 2015 baseline, 2020 baseline, 2020 15/65, 2020 14/35, and 2020 15/35). The projected annual and daily $PM_{2.5}$ concentrations are provided in Appendix M for all counties with an FRM site included in this analysis. In Table 4-1 we provide the highest projected design values for the 2020 base case scenario. Note that this table and subsequent tables with projected annual and daily values for the other scenarios modeled contain data for those counties that exceed a 14 µg/m^3 annual or 35 µg/m^3 daily NAAQS. This covers the range of annual and daily values which are the subjects of this analysis. Again, the data for all counties for all scenarios are provided in Appendix M.

The projected base and control-case design values below represent the initial step in our attainment analysis. Section 4.2 below describes how we analyzed these design values in the context of other available empirical data to make a final determination of attainment and non-attainment for certain areas. Note that section 4.1.6 above describes the methodology we followed to derive the modeled base case and control case daily design values in the tables that follow.

Table 4-1. Projected Annual and Daily $PM_{2.5}$ Design Values ($\mu g/m^3$): 2020 Base Case

		2020 Base	
State	**County**	*Annual ($\mu g/m^3$)*	*Daily ($\mu g/m^3$)*
California	Riverside Co	27.5	73.9
California	San Bernardino Co	24.6	65.8
California	Los Angeles Co	23.9	62.7
California	Kern Co	20.8	77.9
California	Tulare Co	20.6	73.6
California	Orange Co	20.2	40.7
California	Fresno Co	19.6	70.4
Michigan	Wayne Co	17.3	39.0
California	Kings Co	16.8	67.6
California	Stanislaus Co	16.2	59.2
Pennsylvania	Allegheny Co	16.2	52.7
California	San Joaquin Co	16.0	52.0
Alabama	Jefferson Co	15.7	36.3
California	San Diego Co	15.7	40.1
California	Merced Co	15.6	53.1
Ohio	Scioto Co	15.4	33.8
Georgia	Fulton Co	15.3	31.5
Illinois	Cook Co	15.3	36.5
Ohio	Cuyahoga Co	15.2	39.7
Illinois	Madison Co	15.1	35.3
Montana	Lincoln Co	14.9	42.2
California	Imperial Co	14.8	44.9
Illinois	St. Clair Co	14.5	30.2
Ohio	Hamilton Co	14.1	33.6
California	Ventura Co	14.0	38.7
Ohio	Jefferson Co	14.0	33.8
Indiana	Lake Co	13.3	40.4
California	Alameda Co	13.2	58.7
California	Butte Co	13.0	48.6
Maryland	Baltimore City	12.9	35.2
Oregon	Lane Co	12.8	53.0
California	Contra Costa Co	12.5	61.1
Idaho	Shoshone Co	12.4	36.0
Utah	Cache Co	12.3	51.4
Utah	Salt Lake Co	12.2	47.6
California	Sacramento Co	12.1	48.3
Pennsylvania	York Co	12.1	35.5
California	Santa Clara Co	12.0	52.3
Pennsylvania	Berks Co	12.0	35.3
California	Solano Co	11.7	57.3
Washington	Pierce Co	11.6	44.9
California	San Francisco Co	11.4	52.4
Washington	Snohomish Co	11.4	40.5
California	Placer Co	11.2	36.5

State	County	2020 Base	
		Annual ($\mu g/m^3$)	*Daily ($\mu g/m^3$)*
California	Sutter Co	10.9	37.9
Oregon	Jackson Co	10.8	37.2
California	San Mateo Co	10.5	41.6
Idaho	Power Co	10.4	36.4
Oregon	Klamath Co	10.0	38.7
California	Sonoma Co	9.8	38.2
California	San Luis Obispo Co	9.4	35.6
Idaho	Bannock Co	9.1	40.0
Utah	Utah Co	9.1	35.3
Utah	Weber Co	8.9	35.3
Utah	Box Elder Co	8.5	38.4
California	Inyo Co	6.0	37.7

Modeling Attainment of Current 15/65 NAAQS

The projected 2015 base case $PM_{2.5}$ concentrations were used in the analysis to determine which locations are expected to remain nonattainment post-existing programs and therefore need additional local controls for attainment of the current 15/65 NAAQS. In brief, procedures for determining the additional "local" controls need for each area to attain include (1) application of the Response Surface Model to estimate the emissions reduction targets needed for attainment of 15/65 and (2) identification of specific controls which achieve the emissions reduction targets. These controls were applied to the 2020 base case to form the 2020 15/65 scenario. Details on these procedures are provided in Chapter 2. Table 4-2 shows the amount of reduction in $PM_{2.5}$ provided by the controls in the 2020 15/65 scenario, compared to the 2020 base case for those counties that exceed a 14 $\mu g/m^3$ annual or 35 $\mu g/m^3$ daily NAAQS.

Table 4-2. Modeled Impact of 15/65 Controls on Annual and Daily $PM_{2.5}$ Design Values ($\mu g/m^3$): 2020

		Annual			Daily		
State	**County**	*2020 Base ($\mu g/m^3$)*	*2020 15/65 ($\mu g/m^3$)*	*Impact of 15/65 controls in Annual DV ($\mu g/m^3$)*	*2020 Base ($\mu g/m^3$)*	*2020 15/65 ($\mu g/m^3$)*	*Impact of 15/65 controls on Daily DV ($\mu g/m^3$)*
California	Riverside Co	27.5	22.7	-4.8	73.9	63.2	-10.7
California	San Bernardino Co	24.6	21.4	-3.2	65.8	58.1	-7.7
California	Los Angeles Co	23.9	21.6	-2.3	62.7	58.1	-4.6
California	Kern Co	20.8	18.6	-2.2	77.9	68.0	-9.9
California	Tulare Co	20.6	18.9	-1.7	73.6	65.4	-8.2
California	Orange Co	20.2	18.2	-2.0	40.7	35.6	-5.1
California	Fresno Co	19.6	17.3	-2.3	70.4	59.6	-10.8
Michigan	Wayne Co	17.3	16.9	-0.4	39.0	38.4	-0.6
California	Kings Co	16.8	15.6	-1.2	67.6	61.0	-6.6
California	Stanislaus Co	16.2	14.5	-1.7	59.2	51.5	-7.7
Pennsylvania	Allegheny Co	16.2	15.8	-0.4	52.7	51.5	-1.2
California	San Joaquin Co	16.0	14.4	-1.6	52.0	45.3	-6.7
Alabama	Jefferson Co	15.7	15.1	-0.6	36.3	34.2	-2.1
California	San Diego Co	15.7	13.7	-2.0	40.1	34.6	-5.5
California	Merced Co	15.6	14.4	-1.2	53.1	47.7	-5.4
Ohio	Scioto Co	15.4	15.1	-0.3	33.8	33.3	-0.5
Georgia	Fulton Co	15.3	14.9	-0.4	31.5	30.7	-0.8
Illinois	Cook Co	15.3	14.5	-0.8	36.5	35.3	-1.2
Ohio	Cuyahoga Co	15.2	14.7	-0.5	39.7	39.1	-0.6
Illinois	Madison Co	15.1	14.6	-0.5	35.3	34.4	-0.9
Montana	Lincoln Co	14.9	14.8	-0.1	42.2	41.8	-0.4
California	Imperial Co	14.8	14.4	-0.4	44.9	43.0	-1.9
Illinois	St. Clair Co	14.5	14.1	-0.4	30.2	29.4	-0.8
Ohio	Hamilton Co	14.1	13.7	-0.4	33.6	33.0	-0.6
California	Ventura Co	14.0	12.0	-2.0	38.7	33.4	-5.3
Indiana	Lake Co	13.3	12.4	-0.9	40.4	36.9	-3.5
California	Alameda Co	13.2	11.7	-1.5	58.7	50.7	-8.0
California	Butte Co	13.0	12.7	-0.3	48.6	46.3	-2.3
Oregon	Lane Co	12.8	12.7	-0.1	53.0	52.5	-0.5
California	Contra Costa Co	12.5	11.1	-1.4	61.1	52.6	-8.5
Idaho	Shoshone Co	12.4	12.3	-0.1	36.0	35.9	-0.1
Utah	Cache Co	12.3	12.3	0.0	51.4	51.3	-0.1
Utah	Salt Lake Co	12.2	12.2	0.0	47.6	47.5	-0.1
California	Sacramento Co	12.1	10.9	-1.2	48.3	42.0	-6.3
Pennsylvania	York Co	12.1	12.0	-0.1	35.5	35.4	-0.1
California	Santa Clara Co	12.0	11.3	-0.7	52.3	48.2	-4.1
California	Solano Co	11.7	10.2	-1.5	57.3	48.3	-9.0
Washington	Pierce Co	11.6	11.5	-0.1	44.9	44.7	-0.2
California	San Francisco Co	11.4	9.6	-1.8	52.4	42.4	-10.0
Washington	Snohomish Co	11.4	11.4	0.0	40.5	40.2	-0.3
California	Placer Co	11.2	9.8	-1.4	36.5	30.6	-5.9
California	Sutter Co	10.9	10.5	-0.4	37.9	35.5	-2.4

State	County	Annual			Daily		
		2020 Base (µg/m³)	*2020 15/65 (µg/m³)*	*Impact of 15/65 controls in Annual DV (µg/m³)*	*2020 Base (µg/m³)*	*2020 15/65 (µg/m³)*	*Impact of 15/65 controls on Daily DV (µg/m³)*
Oregon	Jackson Co	10.8	10.8	0.0	37.2	37.1	-0.1
California	San Mateo Co	10.5	9.6	-0.9	41.6	36.5	-5.1
Idaho	Power Co	10.4	10.4	0.0	36.4	36.3	-0.1
Oregon	Klamath Co	10.0	9.9	-0.1	38.7	38.5	-0.2
California	Sonoma Co	9.8	9.4	-0.4	38.2	35.3	-2.9
California	San Luis Obispo Co	9.4	8.6	-0.8	35.6	31.6	-4.0
Idaho	Bannock Co	9.1	9.1	0.0	40.0	39.9	-0.1
Utah	Box Elder Co	8.5	8.5	0.0	38.4	38.3	-0.1
California	Inyo Co	6.0	5.9	-0.1	37.7	36.0	-1.7

Modeling Attainment of the Alternative 15/35 and 14/35 NAAQS

As indicated above, the 2020 15/65 scenario serves as our regulatory base case for analyzing the benefits of the revised and alternative more stringent NAAQS. Table 4-3 shows the reductions in $PM_{2.5}$ expected from the emissions controls in the 2020 15/35 scenario. These $PM_{2.5}$ reductions are incremental to the 2020 15/65 base case concentrations. Results are provided for those counties that are projected to be nonattainment for 15/35 in the 2020 15/65 baseline scenario.

Table 4-3. Modeled Impact of 15/35 Controls on Annual and Daily $PM_{2.5}$ Design Values (µg/m³): 2020

State	County	Annual			Daily		
		2020 15/65 (µg/m³)	*2020 15/35 (µg/m³)*	*Impact of 15/35 controls (µg/m³)*	*2020 15/65 (µg/m³)*	*2020 15/35 (µg/m³)*	*Impact of 15/35 controls (µg/m³)*
California	Riverside Co	22.7	22.3	-0.4	63.2	61.1	-2.1
California	Los Angeles Co	21.6	21.3	-0.3	58.1	56.8	-1.3
California	San Bernardino Co	21.4	21.1	-0.3	58.1	56.7	-1.4
California	Tulare Co	18.9	18.5	-0.4	65.4	64.2	-1.2
California	Kern Co	18.6	18.2	-0.4	68.0	66.5	-1.5
California	Orange Co	18.2	17.9	-0.3	35.6	35.0	-0.6
California	Fresno Co	17.3	16.9	-0.4	59.6	58.2	-1.4
Michigan	Wayne Co	16.9	16.8	-0.1	38.4	38.1	-0.3
California	Kings Co	15.6	15.2	-0.4	61.0	59.5	-1.5
Alabama	Jefferson Co	15.1	15.1	0.0	34.2	34.1	-0.1
Ohio	Scioto Co	15.1	15.0	-0.1	33.3	33.2	-0.1
Georgia	Fulton Co	14.9	14.9	0.0	30.7	30.7	0.0
Illinois	Madison Co	14.6	14.6	0.0	34.4	34.3	-0.1
Illinois	Cook Co	14.5	14.5	0.0	35.3	35.3	0.0
Montana	Lincoln Co	14.8	14.5	-0.3	41.8	41.3	-0.5
Ohio	Cuyahoga Co	14.7	14.4	-0.3	39.1	38.3	-0.8

State	County	Annual: *2020 15/65 (µg/m³)*	Annual: *2020 15/35 (µg/m³)*	Annual: *Impact of 15/35 controls (µg/m³)*	Daily: *2020 15/65 (µg/m³)*	Daily: *2020 15/35 (µg/m³)*	Daily: *Impact of 15/35 controls (µg/m³)*
Pennsylvania	Allegheny Co	15.8	14.2	-1.6	51.5	46.9	-4.6
California	San Joaquin Co	14.4	14.1	-0.3	45.3	44.0	-1.3
California	Stanislaus Co	14.5	14.1	-0.4	51.5	49.9	-1.6
California	Merced Co	14.4	14.0	-0.4	47.7	46.3	-1.4
Illinois	St. Clair Co	14.1	14.0	-0.1	29.4	29.3	-0.1
California	Imperial Co	14.4	13.8	-0.6	43.0	41.5	-1.5
Indiana	Lake Co	12.4	12.4	0.0	36.9	36.8	-0.1
Idaho	Shoshone Co	12.3	12.2	-0.1	35.9	35.6	-0.3
Utah	Cache Co	12.3	12.0	-0.3	51.3	50.0	-1.3
California	Butte Co	12.7	11.8	-0.9	46.3	42.2	-4.1
Oregon	Lane Co	12.7	11.7	-1.0	52.5	47.9	-4.6
California	Alameda Co	11.7	11.4	-0.3	50.7	49.5	-1.2
Utah	Salt Lake Co	12.2	11.3	-0.9	47.5	42.9	-4.6
California	Santa Clara Co	11.3	11.2	-0.1	48.2	47.1	-1.1
California	Contra Costa Co	11.1	10.9	-0.2	52.6	51.5	-1.1
California	Sacramento Co	10.9	10.5	-0.4	42.0	40.0	-2.0
Washington	Snohomish Co	11.4	10.4	-1.0	40.2	37.0	-3.2
Idaho	Power Co	10.4	10.1	-0.3	36.3	35.1	-1.2
California	Solano Co	10.2	9.9	-0.3	48.3	46.6	-1.7
Washington	Pierce Co	11.5	9.9	-1.6	44.7	38.0	-6.7
California	Sutter Co	10.5	9.6	-0.9	35.5	32.0	-3.5
California	San Francisco Co	9.6	9.4	-0.2	42.4	41.5	-0.9
California	San Mateo Co	9.6	9.4	-0.2	36.5	35.7	-0.8
Oregon	Jackson Co	10.8	9.1	-1.7	37.1	32.6	-4.5
Oregon	Klamath Co	9.9	8.9	-1.0	38.5	35.0	-3.5
Idaho	Bannock Co	9.1	8.8	-0.3	39.9	38.7	-1.2
Utah	Box Elder Co	8.5	8.3	-0.2	38.3	36.9	-1.4
California	Inyo Co	5.9	5.8	-0.1	36.0	35.4	-0.6

The interpolation procedure used to generate the national sets of daily design values was formulated to account for the potentially steep gradients in air pollution that occur around urbanized areas. In this procedure, urban areas that do not have sufficiently close speciation monitors may be assigned ambient species profiles based on rural monitoring networks that do not represent the effects on the species profile of local sources within the urban area. This may result in projected design values in the urban area that are not as responsive to local controls as might be expected. Section 4.1.10 below provides information on adjustments to these CMAQ modeled results to better reflect the responsiveness to local controls in Bannock County, ID (Pocatello), Cache County, UT (Logan), Pierce County, WA (Tacoma), and Snohomish County, WA (Seattle).

Table 4-4 shows the reductions in $PM_{2.5}$ expected from emissions controls in the 2020 14/35 scenario. These $PM_{2.5}$ reductions are incremental to the 2020 15/65 regulatory base case concentrations. Results are provided for those counties that are projected to be nonattainment for 14/35 in the 2020 15/65 baseline scenario.

Table 4-4. Modeled impact of 2020 14/35 controls on annual and daily $PM_{2.5}$ design values (μg/m^3)

		Annual			Daily		
State	**County**	*2020 15/65 (μg/m^3)*	*2020 14/35 (μg/m^3)*	*Impact of 14/35 controls (μg/m^3)*	*2020 15/65 (μg/m^3)*	*2020 14/35 (μg/m^3)*	*Impact of 14/35 controls (μg/m^3)*
California	Riverside Co	22.7	22.3	-0.4	63.2	61.1	-2.1
California	Los Angeles Co	21.6	21.3	-0.3	58.1	56.8	-1.3
California	San Bernardino Co	21.4	21.1	-0.3	58.1	56.7	-1.4
California	Tulare Co	18.9	18.6	-0.3	65.4	64.3	-1.1
California	Kern Co	18.6	18.2	-0.4	68.0	66.6	-1.4
California	Orange Co	18.2	17.9	-0.3	35.6	35.0	-0.6
California	Fresno Co	17.3	17.0	-0.3	59.6	58.3	-1.3
Michigan	Wayne Co	16.9	16.4	-0.5	38.4	37.5	-0.9
Pennsylvania	Allegheny Co	15.8	14.1	-1.7	51.5	46.7	-4.8
California	Kings Co	15.6	15.2	-0.4	61.0	59.6	-1.4
Alabama	Jefferson Co	15.1	14.5	-0.6	34.2	33.0	-1.2
Ohio	Scioto Co	15.1	14.5	-0.6	33.3	32.4	-0.9
Georgia	Fulton Co	14.9	14.2	-0.7	30.7	29.6	-1.1
Montana	Lincoln Co	14.8	14.6	-0.2	41.8	41.3	-0.5
Ohio	Cuyahoga Co	14.7	14.1	-0.6	39.1	38.0	-1.1
Illinois	Madison Co	14.6	14.0	-0.6	34.4	33.2	-1.2
California	Stanislaus Co	14.5	14.1	-0.4	51.5	49.9	-1.6
Illinois	Cook Co	14.5	14.2	-0.3	35.3	34.7	-0.6
California	Imperial Co	14.4	13.8	-0.6	43.0	41.5	-1.5
California	Merced Co	14.4	14.0	-0.4	47.7	46.3	-1.4
California	San Joaquin Co	14.4	14.1	-0.3	45.3	44.0	-1.3
Illinois	St. Clair Co	14.1	13.4	-0.7	29.4	28.2	-1.2
California	Butte Co	12.7	11.7	-1.0	46.3	42.1	-4.2
Oregon	Lane Co	12.7	11.7	-1.0	52.5	48.0	-4.5
Indiana	Lake Co	12.4	12.2	-0.2	36.9	36.5	-0.4
Idaho	Shoshone Co	12.3	12.2	-0.1	35.9	35.6	-0.3
Utah	Cache Co	12.3	12.0	-0.3	51.3	50.0	-1.3
Utah	Salt Lake Co	12.2	11.3	-0.9	47.5	42.9	-4.6
California	Alameda Co	11.7	11.5	-0.2	50.7	49.6	-1.1
Washington	Pierce Co	11.5	10.0	-1.5	44.7	38.0	-6.7
Washington	Snohomish Co	11.4	10.4	-1.0	40.2	37.0	-3.2
California	Santa Clara Co	11.3	11.2	-0.1	48.2	47.1	-1.1
California	Contra Costa Co	11.1	10.9	-0.2	52.6	51.5	-1.1
California	Sacramento Co	10.9	10.5	-0.4	42.0	39.9	-2.1
Oregon	Jackson Co	10.8	9.1	-1.7	37.1	32.6	-4.5
California	Sutter Co	10.5	9.6	-0.9	35.5	32.0	-3.5
Idaho	Power Co	10.4	10.1	-0.3	36.3	35.1	-1.2
California	Solano Co	10.2	9.9	-0.3	48.3	46.6	-1.7

State	County	Annual: 2020 15/65 (µg/m³)	Annual: 2020 14/35 (µg/m³)	Annual: Impact of 14/35 controls (µg/m³)	Daily: 2020 15/65 (µg/m³)	Daily: 2020 14/35 (µg/m³)	Daily: Impact of 14/35 controls (µg/m³)
Oregon	Klamath Co	9.9	8.9	-1.0	38.5	35.0	-3.5
California	San Francisco Co	9.6	9.4	-0.2	42.4	41.5	-0.9
California	San Mateo Co	9.6	9.4	-0.2	36.5	35.7	-0.8
Idaho	Bannock Co	9.1	8.8	-0.3	39.9	38.7	-1.2
Utah	Box Elder Co	8.5	8.3	-0.2	38.3	36.9	-1.4
California	Inyo Co	5.9	5.8	-0.1	36.0	35.4	-0.6

4.1.8 Population-Weighted Air Quality Results

As a means of better describing the relationship between air quality changes and population exposure, below we provide population-weighted air quality results. Population-weighted air quality is simply the product of the projected PM2.5 air quality change and the population at each model grid cell. Weighting the air quality change in this way can help illuminate the extent to which the projected air quality improvement is occurring in locations where people are actually exposed. Table 4-5 summarizes the total and incremental population-weighted change in annual average $PM_{2.5}$ concentrations between each control scenario. The first row illustrates how the population-weighted air quality for each air quality modeling case declines across attainment scenarios as both the projected air quality improves and the number of individuals exposed decreases. The subsequent rows summarize the incremental change between the base and each of the attainment scenarios.

Table 4-5. Population-Weighted Impacts on Annual Average $PM_{2.5}$

Air Quality Metric	*2020 Baseline*	*2020 15/65 Attainment Scenario*	*2020 15/35 Attainment Scenario*	*2020 14/35 Attainment Scenario*
Population Weighted Average Concentration	10.372	10.003	9.894	9.713
Population Weighted Change from Base	---	0.369	0.478	0.659
Incremental Population-Weighted Change 15/65 to 15/35	---	---	0.109	---
Incremental Population-Weighted Change 15/65 to 14/35	---	---	---	0.290
Incremental Population-Weighted Change 15/35 to 14/35	---	---	---	0.181

4.1.9 Visibility Degradation Estimates

The PM2.5 modeling platform described above was also used to calculate changes in visibility degradation. The estimate of visibility benefits was based on the projected improvement in annual average visibility at Class I areas. There are 156 Federally mandated Class I areas which, under the Regional Haze Rule, are required to achieve natural background visibility levels by 2064. These Class I areas are mostly national parks, national monuments, and wilderness areas. There are currently 110 Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites (representing all 156 Class I areas) collecting ambient PM2.5 data at Class I areas, but only 81 of these sites have complete data for 2001. For this analysis, we quantified visibility improvement at the 116 Class I areas which have complete IMPROVE ambient data for 2001 or are represented by IMPROVE monitors with complete data.[7]

Visibility impairment is quantified in extinction units. Visibility degradation is directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient (b_{ext}) and visual range. The light extinction coefficient is based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil (Sisler, 1996).

Visual range is a measure of visibility that is inversely related to the extinction coefficient. Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. Visual range (in units of kilometers) can be calculated from b_{ext} using the formula: Visual Range (km) = $3912/b_{ext}$ (b_{ext} units are inverse megameters [Mm^{-1}])

The future year visibility impairment was calculated using a methodology which applies modeling results in a relative sense similar to the Speciated Modeled Attainment Test (SMAT). In calculating visibility impairment, the extinction coefficient is made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility is calculated as the percent change in the extinction coefficient for each of the PM species (on a daily average basis). The individual daily species extinction coefficients are summed to get a daily total extinction value. The daily extinction coefficients are converted to visual range and then averaged across all days. In this way, we can calculate annual average extinction and visual range at each IMPROVE site. Subtracting the annual average control case visual range from the base case visual range gives a projected improvement in visual range (in km) at each Class I area. This serves as the visibility input for the benefits analysis (See Chapter 5).

For visibility calculations, we are continuing to use the IMPROVE program species definitions and visibility formulas which are recommended in the draft modeling guidance. Each

[7] There are 81 IMPROVE sites with complete data for 2001. Many of these sites collect data that is "representative" of other nearby unmonitored Class I areas. There are a total of 116 Class I areas that are represented by the 81 sites. The matching of sites to monitors is taken from "Guidance for Tracking Progress Under the Regional Haze Rule".

IMPROVE site has measurements of PM2.5 species and therefore we do not need to estimate the species fractions in the same way that we did for FRM sites (using interpolation techniques and other assumptions concerning volatilization of species).

4.1.10 Adjustments to Modeled Daily Design Values for 15/35 Control Scenario

This subsection describes the approach taken to address the previously identified deficiency with specific interpolated species fractions at monitors where controls are unexpectedly ineffective by applying a more appropriate species profile that is from a similar urban area in close proximity to the area of concern (while not being close enough to be included in the interpolation). An indicator that the species profile may be non-representative is an excessively high percent of organic carbon. A high percent organic carbon at a site may be of concern because the SMAT method assigns organic carbon by a difference method where the sum of all other interpolated PM species is compared with the total FRM PM2.5 mass at the design value monitor and the difference between the two is assumed to be organic carbon. When interpolated species values are derived from speciation sites with very different PM composition, the differences in total mass tend to be larger, and thus the amount assigned to the organic carbon fraction will be large.

Based on the organic carbon fraction and the emissions profiles of the monitor locations, we identifed 4 monitor locations where a species profile adjustment would be appropriate: Bannock County, ID (Pocatello), Cache County, UT (Logan), Pierce County, WA (Tacoma), and Snohomish County, WA (Seattle). For the Bannock County, ID site, we determined that there were no speciation monitors located within 50 km of the FRM monitor. The two most likely candidate urban sites for speciation profiles include sites in Boise City, Idaho (Ada County) and in Davis County, UT (suburb of Salt Lake City). Using the speciation profiles for these counties results in a large reduction in the fraction associated with organic carbon, and a higher fraction of ammonium nitrates and sulfates. Depending on the specific speciation site selected, there are slight differences in the alternative profiles, however, the overall impact on design values is similar. Using the speciation profile from Ada County, the adjusted daily design value for the 2020 15/35 attainment strategy is 35.5 $\mu g/m^3$. Using the Davis County, UT species profile, the adjusted daily design value is 34.7 $\mu g/m^3$. As such, using either of the alternative speciation profiles, Bannock County attains the daily standard.

Cache County has no co-located speciation monitor available. However, there were three speciation monitors near Salt Lake City located within 85 km of the Cache County FRM monitor. Using the average of the speciation profiles from these 3 monitors resulted in a large reduction in the fraction attributed to organic carbon, and increases in the fractions associated with ammonium nitrate and ammonium sulfate. Some experimental monitoring conducted by Utah State University suggests that even this alternative speciation profile may be understating the contribution of nitrates in wintertime months, when nitrate may contribute over 70 percent of total mass. Using the alternative speciation profile results in an estimated daily design value in Cache County for the 2020 15/35 attainment strategy of 44.6 $\mu g/m^3$. Thus, even with the alternative species profile, Cache County does not attain with available controls. However, the design value is now much closer to the design value of 40.7 $\mu g/m^3$ in Salt Lake City. In both of the above cases (Bannock County and Cache County) prior to the use of alternative speciation profiles, organic carbon was estimated to account for 90 percent or more of the total mass.

Based on the alternative speciation profiles, organic carbon may in reality account for less than 25 percent PM2.5 in wintertime months when peak daily concentrations are likely to occur.

In Washington, the two monitor locations near Seattle and Tacoma that were relatively unresponsive to emission controls were also characterized by unusually high organic carbon fractions. The monitor in Pierce County (Tacoma) had over 70 percent estimated organic carbon, while the monitor in Snohomish County (Seattle suburb) had over 85 percent estimated organic carbon. Using only the closest speciation monitors for each of these sites resulted in relatively large reductions in the estimated percent organic carbon at each monitor. For the Pierce County monitor, we used a speciation monitor located in Seattle, approximately 45 km from the FRM site. This resulted in a decrease in the percent organic carbon at the monitor to 50 percent, and increases in percent elemental carbon to 15 percent, with smaller increases in crustal, nitrates, and sulfates. This resulted in an adjusted daily design value for the 2020 15/35 attainment strategy of 34.2 $\mu g/m^3$, thus resulting in attainment at this monitor. For the Snohomish County monitor, we used a speciation monitor located close to Seattle, approximately 35km from the FRM site. This resulted in a decrease in the percent organic carbon at the monitor to 65 percent, with increases in percent elemental carbon to 11 percent, with smaller increases in crustal, nitrates, and sulfates. This resulted in an adjusted daily design value for the 2020 15/35 attainment strategy of 34.2 $\mu g/m^3$, thus resulting in attainment at this monitor.

The adjusted design values are provided below in Table 4-6. These adjusted daily design values form the starting point for the next step in the nonattainment determination process, which continues in Section 4.2.

Table 4-6. Adjusted Daily Design Values for 15/35 Control Scenario

Location	*Adjusted 15/35 Daily DV*
Bannock County, ID	35.5
Cache County, UT	44.6
Pierce County, WA	34.2
Snohomish County, WA	34.2

4.1.11 Characterization of Air Quality Modeling and Limitations to the Analysis

While EPA's regional scale air quality modeling system has been extensively peer reviewed and represents the state of the science in terms of the formation and fate of $PM_{2.5}$ in the atmosphere, a number of factors affect the conclusions that can be reached about the effectiveness, costs, and benefits of alternative control strategies:

- Overall, the air quality model performs well in predicting monthly to seasonal concentrations, similar to other state-of-the-science air quality model applications for

$PM_{2.5}$.[8] The model is less well suited to predicting 24-hour values. Thus, there is less certainty in analyses involving 24-hour model predictions than those involving longer-term averages (i.e., month, quarter, annual) concentrations.

- In general, model performance is better for the Eastern U.S. than for the West. The air quality model performs well in predicting the formation of sulfates, which are the dominant species in the East. Ambient monitoring data indicate high levels of PM in the West, especially in California, are dominated by nitrate and organics. While the modeling system performs well for nitrate in the East, large under predictions are noted in the West. In both the East and West, carbonaceous aerosols are the most challenging species for the modeling system to predict in terms of evaluation against ambient data. There is considerable uncertainty and lack of understanding of formation, fate, and properties of organic particles.[9] It is estimated that only 10 to 20 percent of the PM organic compounds have been quantified using existing methodologies. Work is underway at EPA and elsewhere to improve our understanding or secondary organic aerosols and our ability to characterize these compounds and their precursors in air quality models. In view of these limitations and uncertainties, current air quality models, including CMAQ, may understate the reduction in secondary organic PM from controls on particle-forming VOCs, including aromatic compounds and higher carbon alkanes and olefins.

- A number of uncertainties arise from use of baseline data from EPA's National Emissions Inventory, especially in terms of the overall magnitude of emissions of primary particles from stationary and mobile sources, spatial allocation of area and other source categories, and the relative split of emissions into $PM_{2.5}$ species. Of particular concern is the apparent disparity between estimated contributions of mobile source emissions with receptor modeling results based on ambient air quality data. While the results of the source receptor modeling studies themselves contain significant uncertainties (particularly in dealing with secondary organic aerosols, or SOAs), it is probable that the mobile source emission inventory of directly emitted PM2.5 is biased low. The most uncertain portion of the current mobile source inventory for direct PM2.5 is probably that from gasoline vehicles and nonroad equipment. While it is likely that updated emissions estimates from these sources will be higher than those used in our analysis, it is not certain the extent to which existing emissions control programs will reduce these emissions.

- Additional uncertainty is introduced as a result of our limited understanding concerning the collective impact on future-year emission estimates from economic growth estimates, increases in technological efficiencies, and limited information on the effectiveness of control programs.

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[8] U.S. Environmental Protection Agency, March 2005. Updated CMAQ Model Performance Evaluation for the 2001 Annual Simulation, Appendix C. Office of Air Quality Planning and Standard, Research Triangle Park, NC. (Docket No. OAR-2005-0053-2149).
[9] Particulate Matter Science for Policy Makers, a NARSTO Assessment. McMurry, P. M.F. Shepherd, and J.S. Vickery, 2004.

- The set-up of the CMAQ modeling system used for this assessment was configured with a 36 kilometer receptor grid, which spreads point and mobile source emissions that may be concentrated in particular locations across the entire area of each grid. This serves to obscure local-scale air quality improvements that result from urban-area controls. To the extent that this occurs, our estimates may underestimate the effectiveness of local or urban-area controls as compared to broad scale regional controls. We performed a sensitivity modeling analysis with CMAQ in which we modeled our 2015 base case at 12 km resolution for a modeling domain covering the Eastern U.S. The results of this analysis are provided in Appendix N.

4.2 Supplemental Carbonaceous Particle Emission Controls Analysis

Because we based our selection of controls on the expected impact on $PM_{2.5}$ (which we estimated by using the RSM-derived µg/ton estimates described in Chapter 3), in some locations the CMAQ-modeled impact on $PM_{2.5}$ at the violating monitor was less than expected. In these cases our control strategies did not result in full attainment of the standards, even though additional cost-effective carbonaceous particle controls were still available in our database of AirControlNET and developmental emission controls.[10] To demonstrate the costs and benefits of reaching full attainment in these areas, we identified remaining cost-effective carbonaceous particle emission controls in each of the projected residual nonattainment areas. We then determined whether those supplemental controls would likely be sufficient to simulate full attainment with the revised and more stringent alternative standards. If we estimated these controls to be sufficient, then we included the costs of those controls were in our overall full attainment cost estimate (see Chapter 6). Note that this method does not apply to the projected non-attainment areas of Salt Lake City and many counties in California, where we exhausted emission controls in our CMAQ analysis; for these areas we estimated full attainment cost by using an a cost-extrapolation methodology that we describe in Chapter 6.

Supplemental Analysis to Simulate Attainment with Revised Daily Standard of 35 $\mu g/m^3$

After modeling the air quality impacts of our illustrative attainment strategy for the revised 15/35 standards, we determined that two locations, Eugene OR and Cleveland, OH, did not simulate attainment with the revised daily standard of 35 µg/m3. However, our emission controls database indicated that there were still carbonaceous particle controls available to apply. We calculated the average $PM_{2.5}$ impact per ton of reducing elemental and organic carbonaceous particles in each location, and then estimated the amount of additional elemental and organic carbonaceous particle emissions reductions that would be necessary to reach attainment. If the total amount of tons available was less than the amount needed, then we added the costs to the full attainment cost estimate and continued with the weight of evidence assessment discussed in Section 4.4 below. After applying supplemental controls, we found that neither Cleveland nor Eugene was able to attain the 15/35 revised standards. For a discussion of the emissions reductions and engineering costs associated with the application of these controls, see Chapter 6.

[10] For a description of the emission controls available in the AirControlNET database, and a discussion of the developmental emission controls, see Chapter 3.

Supplemental Analysis to Simulate Attainment with Alternative More Stringent Annual Standard of 14 µg/m^3

After modeling the air quality impacts of our illustrative attainment strategy for the 14/35 standards, we determined that Birmingham, AL, Chicago, IL, and Cleveland, OH had not simulated attainment. However, our emission controls database indicated that there were still carbonaceous particle emission controls available to apply. We calculated the average $PM_{2.5}$ impact per ton of reducing elemental and organic carbonaceous particles in each location, and then estimated the amount of additional elemental and organic carbonaceous particle emissions reductions that would be necessary to reach attainment. We then used that impact per ton estimate to determine the number of tons of carbonaceous particles would be necessary to control to simulate attainment the residual increment to attainment (the modeled design value after application of the illustrative control scenario minus 14.05). Finally, we calculated the total remaining tons of emissions that could be reduced with known controls. If the total controllable tons was greater than or equal to the amount of tons needed to reach full attainment, then we added the costs of control to the overall full attainment cost. If the total amount of tons available was less than the amount needed, then we added the costs to the full attainment cost estimate and continued with the weight of evidence assessment discussed in Section 4.4 below. After applying supplemental controls, we found that Birmingham, Chicago and Cleveland were able to attain the more stringent alternative standards of 14/35. For a discussion of the emissions reductions and engineering costs associated with the application of these controls, see Chapter 6.

Calculating Monetized Human Health Benefits of Achieving the Residual Air Quality Increment Through Supplemental Controls

It is extremely difficult to accurately estimate the benefits of fully attaining a set of ambient $PM_{2.5}$ standards when using the supplemental controls approach. This difficulty is due to the complex nature of the atmospheric chemistry and fate and transport mechanisms that connect precursor emissions with ambient concentrations of $PM_{2.5}$. In the absence of air quality modeling associated with specific sets of emissions controls, it is not certain how ambient $PM_{2.5}$ levels throughout the U.S. would be affected by programs to bring residual nonattainment areas into attainment. If broad scale programs to reduce transport of precursor emissions were enacted, then ambient PM2.5 levels throughout a region would be reduced. On the other hand, if extremely local reductions in emissions affecting a single nonattaining monitor were enacted, then air quality improvements would be very localized, with little impact on regional ambient $PM_{2.5}$ levels. When modeling benefits, we have assumed that these areas would apply emission controls using the latter method.

In order to provide at least a lower bound estimate of the benefits associated with fully attaining the revised and alternative standards, we used a simple rollback approach. This approach makes the bounding assumption that ambient $PM_{2.5}$ concentrations can be reduced only at monitors that are above the standards, regardless of the proximity of neighboring monitors. In essence, the monitor values are simply rolled back so that no monitor in the U.S. is above the standard being analyzed. From a benefits perspective, this leads to a likely downward bias in the estimates, because populations are assumed to be exposed to a distance weighted average of surrounding monitors, so their exposure to the reductions at a single nonattaining monitor will be weighted less if there are other, attaining monitors in close proximity.

Below we provide a summary of the mechanics of these calculations:

Step 1: Rollback annual design values from modeled levels to 15 µg/m^3 to simulate attainment of the 1997 standards.

Step 2: Estimate the improvement in the daily standard that results from meeting the annual standard. This estimated impact on the daily standard is based on relationships between annual and daily design values from existing air quality modeling results. For example, in Los Angeles, the daily design value is typically 2.6 times the annual design value. Assuming this relationship will continue to hold in the future, for every 1 µg/m^3 reduction in the annual design value there would be approximately a 2.6 µg/m^3 reduction in the daily design value. This relationship was derived for each nonattainment monitor.

Step 3: Rollback daily design values from the estimated values resulting from Step 2 to the revised daily standard of 35 µg/m^3.

Step 4: Estimate the impact of meeting the revised 35 µg/m^3 standard on annual design values. Similar to the calculations in Step 2, we used the relationship between annual and daily design values to estimate how annual design values would be affected by reducing the daily design values. Following the example above, for every 1 µg/m^3 reduction in the daily design value, the annual design value would be reduced by 0.38 µg/m^3.

Step 5: Rollback annual design values from the estimated values resulting from Step 4 to the alternative more stringent annual standard of 14 µg/m^3.

Step 6: Combine rolled-back annual design value data from Step 1 with modeled design value data from the 15/65 baseline CMAQ modeling for attaining monitors and interpolate the annual design values to CMAQ grid cell domain to provide the baseline air quality inputs for the benefits analysis (details of the spatial interpolation method are provided in Appendix H).

Step 7: Combine rolled back annual design value data from Step 4 with modeled design value data from the 15/35 CMAQ modeling for attaining monitors and interpolate to CMAQ grid cell domain to provide air quality inputs for the benefits analysis for the 15/35 standards.

Step 8: Combine rolled back annual design value data from Step 5 with modeled design value data from the 14/35 CMAQ modeling for attaining monitors and interpolate to CMAQ grid cell domain to provide air quality inputs for the benefits analysis for the 15/35 standards.

For a discussion and presentation of modeled and full attainment benefits, see Chapter 5.

4.3 Illustrative Attainment Determinations

In this section we make a final determination of attainment for those areas whose projected design values, based on the air quality modeling analysis, exceed the revised or more stringent alternative standards, and for which supplemental controls did not simulate full attainment. To make this determination we combine the projected design values from the air quality modeling with urban-area specific data, including: an analysis of the projected violating monitor, dispersion modeling, a characterization of emissions inventory uncertainties, modeling uncertainties and updated design values. In this way we assess whether the balance of empirical data suggests that each projected nonattainment county will or will not attain the revised and more stringent alternative standards. In the subsections below we outline the data we drew upon to make these attainment determinations and then analyze each of the six areas that the air quality modeling analysis projects to violate one or more standards. These areas include: Detroit, MI, Pittsburgh, PA, Cleveland, OH, Salt Lake City UT, Eugene, OR and Libby MT. We separately present an analysis of projected non-attainment areas in California at the end of this chapter.

Table 4-7 below summarizes the projected annual and daily design values for each of these six urban areas. The design values in these tables reflect the application of any supplemental carbonaceous particle emission controls, and thus vary from the CMAQ-projected design values found in the preceding tables:

Table 4-7. Areas Projected to Not Attain the Revised or Alternative More Stringent $PM_{2.5}$ Standards

State	County	Violating Monitor	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
			Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Ohio	Cuyahoga	390350038	15.2	39.7	14.4	14.0	36.6	35.4
Michigan	Wayne	261630033	17.3	39.0	16.8	16.4	38.1	37.5
Pennsylvania	Allegheny	420030064	16.2	52.7	14.12	14.0	46.9	46.7
Montana	Lincoln	300530018	14.9	42.2	14.5	14.0	41.3	41.3
	Box Elder	490030003	8.5	38.4	8.3	8.3	36.9	36.9
Utah	Cache	490050004	12.3	51.4	12.0	12.0	44.6	44.6
	Salt Lake	490350003	12.2	47.6	11.3	11.3	42.9	42.9
Oregon	Lane	410392013	12.8	53.0	11.7	11.7	48.0	48.0

4.3.1 Data Sources

Our attainment determination considered a variety of data sources, each of which we describe below. Because not all of these data were available for, or germane to, each urban area we did not include all data sources in each attainment determination.

Detailed Monitor and Emissions Analyses

EPA sought to better understand the local-scale characteristics of those monitors that, based on 1993 to 2003 measured data, are projected to violate the 1997 standards or the revised or more stringent alternative standards. To develop this information, EPA conducted four general types of evaluations, where we: 1) using aerial photographs, identified the proximate areas of the monitoring sites in order to explore the potential impacts of local sources; 2) recalculated baseline design values; 3) re-evaluated modeled speciation profiles; and 4) gleaned pertinent information on the specific geographic areas and associated monitoring sites from online sources and/or from EPA regional office staff. EPA evaluated thirteen different geographic areas, encompassing approximately 20 priority monitoring sites, with one or more of these methods.

More detail on the four evaluative techniques we employed is presented below; these are followed by summaries of the pertinent findings.

1. *Examinations utilizing geographic information systems (GIS) and aerial photographs of the local areas around an area's priority monitors (those projected to violate the revised or more stringent alternative standards) to explore the potential impacts of local sources.* These studies employed gathering data on the priority monitors, and mapping these data along with the locations of point sources as provided in the emission data set representing the 2015 base case, which incorporates all known controls from the base year inventory of 2001. Aerial photos were used to capture the area surrounding the priority monitors. Some aerial views were evaluated across different time periods, as available, to ascertain the possibility that activity, and thus source profiles, may have changed over time and may not accurately represent the area. A common issue noted in this review relates to the precision of the inventory point source coordinates (latitude and longitudes). The precision of the point source locations is accurate to only 2 decimal places. This equates to a precision of about half of a kilometer if rounded, and 1 kilometer if truncated. It thus becomes difficult to match sources in the inventory with sources shown in the aerial photographs. Therefore, it is not known to the extent to which sources are underrepresented or located in different areas from the photos. A frequent observation of the aerial photo review was that there are some emission source types that are not well characterized in the emission inventory. For example, emissions from railroads or depots are based on national level emissions that are allocated to grid cells using railway miles and railway activity. Areas with heavy rail use or rail depots could have significant local impacts that are nearly impossible to model accurately in a national-level analysis.
2. *Recalculation of initial baseline design values.* The design values that were originally calculated could overestimate the actual aggregated regulatory values due to our treatment of data "flagged" for exceptional events. Under current EPA guidance and practice, only data flagged for events that have been approved ('concurred' with) by the appropriate EPA regional office (RO) are excluded when making comparisons to the NAAQS. The flagging process, as a whole, includes: flagging of data by the State monitoring agency in an appropriate timeframe; submission (by the State agency) of documentation proving the event occurred and its causal role in a NAAQS exceedence; subsequent review of the documentation by the RO; and eventual

acceptation or rejection of the assertion by the RO. States typically flag about 85% more $PM_{2.5}$ data than are documented.. This discrepancy usually exists because States often only submit documentation for flagged data points that could make a difference in an attainment/nonattainment designation. Because the annual NAAQS is controlling in most areas, it could be several years before it could be determined if flagged data points make that difference. Thus, flagged values for which documentation was not submitted could actually be legitimate, but irrelevant to current NAAQS levels. This phenomenon must be taken into account in the evaluation of future nonattainment scenarios given different ambient air standards. Also, in certain situations some States flag data for their own purposes, such as for internal trends analyses. These cases do not always have supporting documentation. It takes resources to compile supporting documentation in a cohesive manner, and the States often do not expend these resources unless a nonattainment designation is imminent. Based on the flagging and documentation of several large regional exceptional events (e.g., the Quebec fire of 2002) it is speculated that most "flagged but not documented" events are potentially valid. Furthermore, most documented events are generally eventually approved. Thus, this exercise entailed treating all flagged events as documented and approved events. In some cases, this recalculation lowered the baseline model DV such that it would not result in future modeled nonattainment.

3. *Comparison of species profiles used in the projection of future design values to alternative, potentially more representative profiles.* The species profiles used for projecting future design values were based on limited 2002 Speciation Trends Network (including State speciation sites, or "STN+") data. More robust (i.e., multi-year) estimates of speciation profiles are now available for some of the priority monitoring sites. Also, some newer speciation monitors closer to the priority sites now have data. These newer data are useful for determining a more representative estimates of the speciation profiles in the vicinity of priority sites. A lack of representative profiles for the priority sites increases the potential for underpredicting the species emitted by local sources (e.g., crustal material), further limiting our ability to show the impact of potential control strategies on these sources. If an area was deemed to be in residual nonattainment of the annual standard, then the speciation profile review focused on the aggregate annualized profile. If an area was deemed to be in residual nonattainment of the 24-hour standard, then the speciation profile review focused on the profile(s) of the quarter(s) with the highest concentrations (that is, the one(s) where the 98^{th} percentile was expected).

4. *Gleaning of information from online sources and/or EPA Regional Office staff.* Internet queries were conducted with search engines such as Excite and Google to garner relevant information about the geographic areas and monitoring locations with respect to particle pollution. This information included studies of air quality trends and characterization by universities and state and local air quality organizations. Staff in EPA Regional Offices were contacted to summarize the particle problem in these areas, provide site-specific characterizations, ascertain the identity of possible sources, and/or verify various postulations.

Readers interested in reviewing the complete monitor and emissions analysis should consult the technical support document located in the docket.

Local-Scale Dispersion Modeling (AERMOD)

EPA used local-scale air quality modeling to examine the spatial variability of direct $PM_{2.5}$ concentrations associated with emissions of primary $PM_{2.5}$ within each urban area, and to estimate the contribution of primary $PM_{2.5}$ emissions from local sources in the urban area to ambient $PM_{2.5}$ concentrations at Federal Reference Method (FRM) monitoring sites. In addition, attribution of the modeled concentrations to specific emission source groups in the urban area such as electric generating facilities, industrial facilities, residential wood burning, commercial cooking, mobile sources and others (see Appendix B for a complete list) allowed for an investigation into the impact of controls of primary $PM_{2.5}$ emissions from local sources on attainment. This assessment complements the regional-scale modeling analyses through its ability to provide concentrations at a higher spatial resolution and an estimate of the impact of local sources of primary $PM_{2.5}$. We focused this assessment on five urban areas: Birmingham, Seattle, Detroit, Pittsburgh and Chicago. Each of these areas has different characteristics in terms of the mixture of emissions sources, meteorology, and associated $PM_{2.5}$ air quality issues. This assessment focused on future incremental impacts of direct $PM_{2.5}$ sources within these areas after implementation of the regulatory base case.

Based on 2001 meteorology data and the 2015 regulatory base case emissions inventory used in the CMAQ analysis, the AERMOD modeling system was applied to each urban area to provide concentration estimates of directly emitted $PM_{2.5}$ by species across a specified network of receptors within each urban area. AERMOD provides a more refined geographic view of local $PM_{2.5}$ concentrations compared to the coarse view provided by the 36 kilometer resolution of used for our CMAQ modeling. Appendix B provides detailed results for each urban area for both annual and daily concentrations. These results indicate high annual concentration gradients for primary PM2.5 over distances much less than the 36 or 12 kilometer resolution typically used in photochemical grid modeling for the study area. Furthermore, local sources of primary $PM_{2.5}$ are significant contributors to these concentration gradients. These sources vary in their importance by monitor location and include industrial sources (iron and steel manufacturing, coke ovens, pulp and paper mills), human activities like residential wood/waste burning, and onroad and nonroad sources.[11]

Updated Design Value Data

Our 2020 base case design values were determined using data which includes ambient design values calculated with 1999–2003 monitoring data. Because the projections of future design values are sensitive to the design values used in the base years, it may be insightful in some projected non-attainment areas to assess whether or not more current design value differ greatly from what was used in our projections. For example, an area that we project to not attain the revised standards by a small margin might be expected to attain, or might be closer to attainment,

[11] Note that while we modeled nonroad mobile sources, the inventories for locomotives are not yet detailed enough to allow us to fully capture the air quality impacts associated with controlling this source.

if we used much lower design values as the starting point for our projections. For this reason, we have examined more current design value data to improve our characterization of the potential for future improvement in air quality in these areas.

Source Apportionment Studies

Source apportionment analyses such as receptor modeling are useful in both qualifying and quantifying potential fine particulate regional and local source impacts on a receptor's ambient concentrations. Receptor modeling techniques utilize measured ambient species' concentrations to estimate the contribution that regional and local sources have at a given receptor which, in this case, is an ambient monitoring location. Currently, two established receptor models are being widely used for source apportionment: the Chemical Mass Balance (CMB) and Positive Matrix Factorization (PMF). Both have been used to characterize fine particulate source contributions to ambient $PM_{2,5}$levels. For one projected non-attainment area below we consider the source apportionment data to better characterize the impact of our control strategies on the monitor projected to not attain the 1997 standards, the proposed revised standards and the alternative revised standards.

4.2.2 *Area Specific Analyses*

The subsections that follow detail each of the six urban-area analyses we performed. As noted above, these urban areas include Cleveland, Detroit and Pittsburgh in the East and Salt Lake City, Libby, and Eugene in the West.

4.2.2.2 Cleveland

Projected Design Values. Under the base case, the Cuyahoga county monitor violates the revised daily standard. In our control case we were unable to simulate attainment with the revised daily standard of 35 µg/m^3 under our 15/35 control scenario. However, we were able to meet the revised daily standard of 35 µg/m^3 under our 14/35 control scenario, indicating that the addition of regional emission reductions were effective in bringing this area into attainment with a tighter daily standard.

Table 4-8. Projected Design Values for Priority Site in Cuyahoga County, Ohio

County	Violating Monitor	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Cuyahoga	390350038	15.2	39.7	14.4	14.0	36.6	35.4

Monitoring and Emissions Analysis. Monitoring site 390350038 is the priority monitor for Cleveland and has a projected 2020 base DV of 19.3 µg/m^3 based on 1999-2003 monitoring data. The next highest DV in the area is 1.3 µg/m^3 lower (18.0) but is less than a mile away. As with the priority Cleveland monitor and its closest counterpart, this fact suggests that local emission sources account for the increment. Based on a review of aerial photographs, the Cleveland priority monitor appears to have numerous potential local $PM_{2.5}$ influences consisting of heavy transportation and industrial sources. However, the 2015 base inventory shows no point sources in the immediate area or even in the 1 kilometer radius and few emission sources with the 3 kilometer radius. Several steel manufacturing operations are present in the inventory within the 3 kilometer radius but their emission estimates are atypically low. Hence, the industrial areas are probably not properly characterized in the inventory. The monitor is located in a major transportation corridor, containing an interstate, railroads and ports (on the Cuyahoga River). There are several railroad lines within a kilometer of the monitor; a dense set of railroad lines lie approximately 500 meters away. The monitor is approximately 75 meters from Interstate 490, and 130 meters from a cloverleaf intersection. Port terminals along the Cuyahoga are about 700 – 1300 meters from the monitor.

Updated Design Values. More current design value data in Figures 4-3 and 4-4 below for the Cleveland priority monitor (site 390350038) suggests a slight upward trend in the daily design value and a slight downward trend in the annual design value. Had the analysis used more current design value data to project future baseline air quality in Cleveland, it is possible that our estimates of the baseline daily values might be higher and the baseline annual values might be somewhat lower.

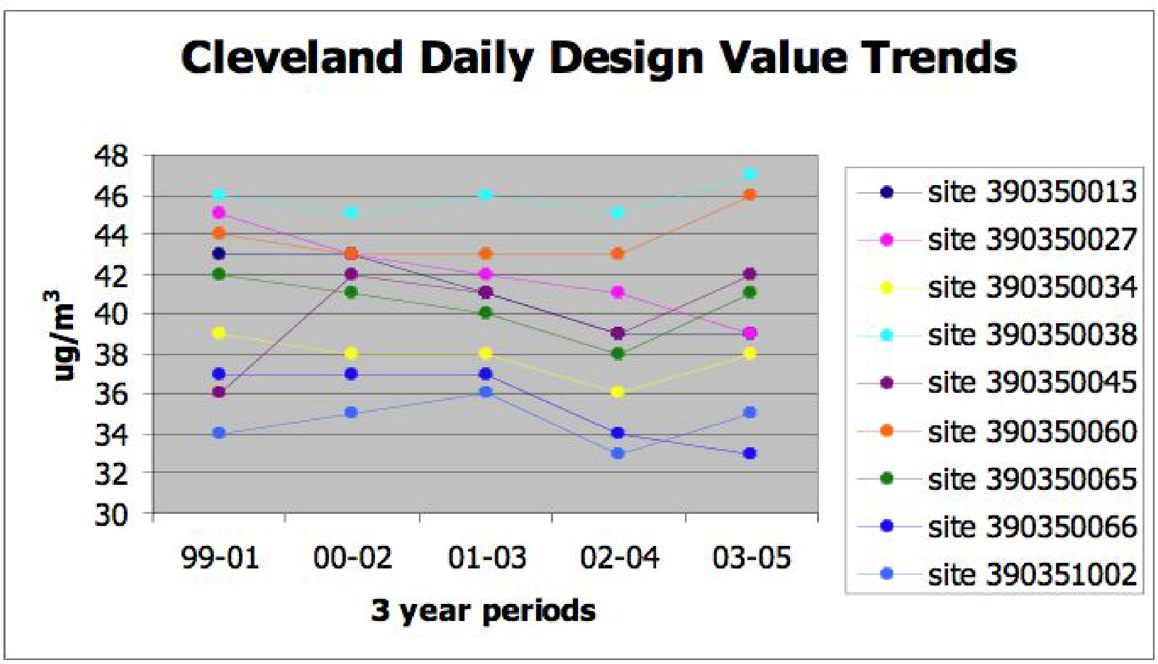

Figure 4-3. Daily Design Value Trend for Monitors in Cleveland Metropolitan Area

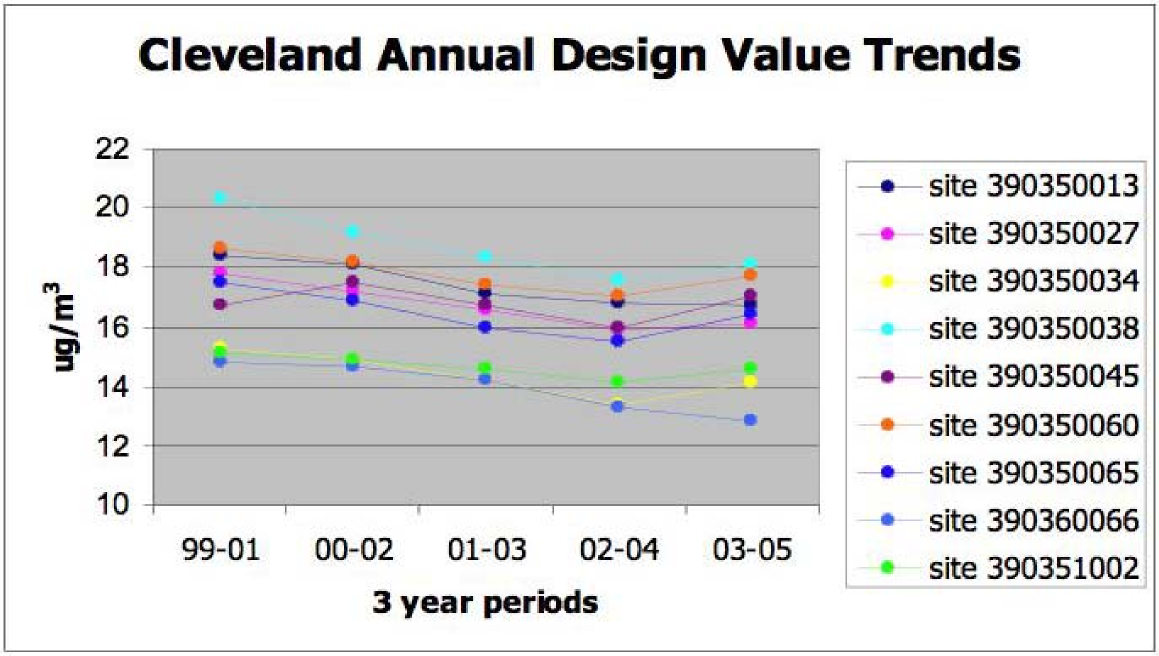

Figure 4-4. Annual Design Value Trend for Monitors in Cleveland Metropolitan Area

Conclusions. The monitoring and emissions analysis indicates that there are a sufficient number of sources located in close proximity to the monitor that are likely contributing to high annual and daily design values. Due to uncertainties in our emissions inventories, we may not have fully captured the impact of controlling these sources in our air quality modeling. Moreover, due in part to the relatively coarse-scale of our modeling grid cells our analysis was most likely not able to fully capture the near-field effects of controlling these sources. This suggests that an emission reduction strategy that applies controls to sources in close proximity to the priority monitor would be expected to further reduce future design values.

The updated design value data suggests a declining trend in the annual design value but an increasing trend in the daily value at the priority monitor. Thus, using these updated design values in our air quality modeling would be unlikely to have produced 2015 and 2020 base case air quality estimates that significantly differ from our current projections.

Considering the balance of the empirical evidence above, we believe that for the purposes of this illustrative attainment analysis that our projected design values do not properly characterize the future air quality at the priority monitor in Cleveland and that the controls we simulated were more effective than we modeled. Thus, for the purposes of this analysis, we are presuming that Cleveland does attain the new and more stringent alternative standards in 2020.

4.2.2.2 Detroit

Projected Design Values. Under the base case, the Wayne county monitor violates the revised and more stringent alternative standards. The Wayne county monitor also violates each both of these standards under the three control cases.

Table 4-9. Projected Design Values for Wayne County, Michigan

County	Violating Monitor	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Wayne	261630033	17.3	39.0	16.8	16.4	38.1	37.5

Monitoring and Emissions Analysis. There are two priority monitors in the Detroit area, site 261630033 with a starting DV of 19.5 µg/m^3 and site 261630015 with a starting DV of 17.4 µg/m^3 based on 1999-2003 design value data. Other $PM_{2.5}$ monitors located elsewhere in the Detroit MSA indicate a much lower design value. Available speciation data from years not used in the attainment analysis shows that the interpolated model data for this location has significantly lower metals/crustal material than actually is present. The speciation profile we used for the site 261630015 was obtained by interpolation of measurements at other sites. That data had about 4% of the PM mass as crustal material. However, updated speciation data, from a collocated monitor at site 261630015, shows the crustal fraction to be closer to 14%. This indicates that local, directly emitted PM, have a greater influence on this site, compared to what we used in our analysis.. In addition, a review of aerial photographs of the vicinity of site 261630015 from different years, indicates that construction and/or demolition activity occurred in the immediate vicinity of the site during the model base timeframe. This would also affect the magnitude of $PM_{2.5}$ and the speciation for this site in a way that we could not account for in our analysis.

Our analysis of emissions data indicates that both priority sites in Detroit are likely to be highly influenced by nearby emissions sources located within 3 km of the site. Many of these sources may not have been characterized with the precision needed for a local scale assessment for these locations. As noted in the general analyses method descriptions, the point source locations in our inventory are specificed to 2 decimal places. This equates to a precision of about half of a kilometer, if rounded and 1 km if truncated. Also as previously noted, emissions for railroads and switching yards are not specified to the exact location of individual rail lines and yards. Site 261630033 is extremely close to a large number of parallel railroad lines (4 parallel lines adjacent and maybe 50 meters away from monitor). Furthermore, there appears to be point sources at the railroad which may correspond to nearby sources that are in our inventory.

AERMOD Analysis. Figure 4-6 shows the spatial distribution of $PM_{2.5}$ for Detroit resulting from AERMOD modeling of primary $PM_{2.5}$ emissions from local sources. These modeling results indicate high annual concentration gradients of primary $PM_{2.5}$ within typical photochemical modeling grid resolutions. Thus, spatial gradients exist within the study area for primary $PM_{2.5}$ with a variety of local sources such as metal manufacturing, commercial cooking, and onroad and nonroad vehicles being significant contributors depending upon the location of the monitor. The local sources of direct PM2.5 contribute roughly 25 percent of the projected concentrations of total $PM_{2.5}$ at monitoring site 261630033. Based on application of the 15/65 control set in Detroit, AERMOD predicted reductions in annual direct PM2.5 that were roughly 2.5 times higher than that predicted by CMAQ, i.e., a reduction in predicted direct PM2.5 concentrations by 0.68 $\mu g/m^3$ versus 0.26 $\mu g/m^3$. The models produced similar reductions in direct PM2.5 concentrations for the 15/35 control set, i.e., a reduction in predicted direct PM2.5 concentrations by 0.046 $\mu g/m^3$ versus 0.057 $\mu g/m^3$. For the 14/35 control set, the AERMOD predicted reductions were again higher than the CMAQ predictions like the 15/65 control set. The difference in results here are due to the nature of the controls so that when controls are applied to stationary point sources there will be greater differences while controls applied to more dispersed sources like area and mobile will result in more similar results.

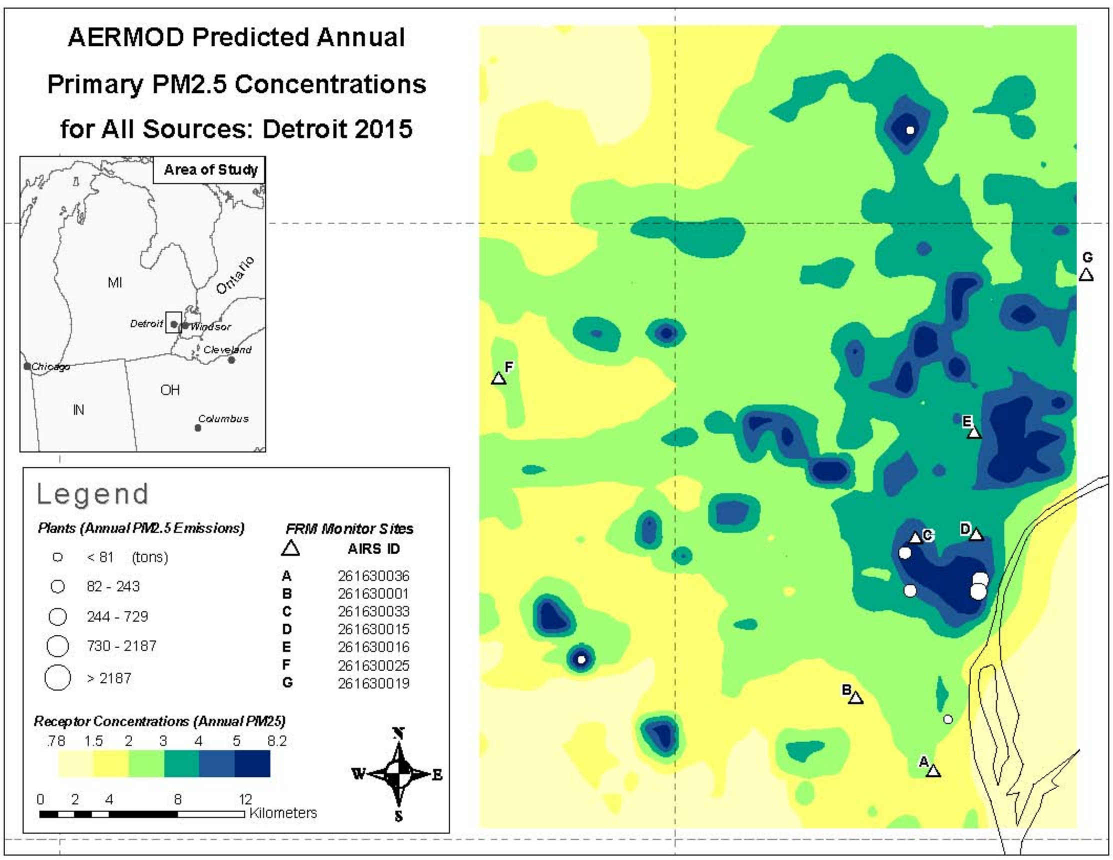

Figure 4-6. Spatial Gradient in Detroit, MI of AERMOD Predicted Annual Primary $PM_{2.5}$ Concentrations (ug/m^3) for All Sources: 2015

Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

Source Apportionment Analysis. Table 4-10 summarizes the methods used for three studies within the Detroit Metropolitan Area.

Table 4-10: Summary of Methods Used for Three Studies within the Detroit Metropolitan Area

Study	*Ambient Data Collected*	*Type of Analysis Performed*
Rizzo, M. “A Source Apportionment Analysis of the Dearborn Speciation Trends Network Site.” USEPA OAQPS. 2005.	Speciation Trends Network data collected at Dearborn site in Detroit, MI between May 2002 and August 2004 (106 samples)	Used PMF to perform receptor modeling and HYSPLIT for wind trajectory analysis of the receptor modeling results. Compared Dearborn location to four other sites within the Midwestern United States
Center for Air Resources Engineering and Science. Final Report of the Project: Analyses of Midwest PM-Related Measurements. Clarkson University. 2005.	Speciation Trends Network data collected at Dearborn between May 2002 and December 2003 (89 samples); Allen Park between December 2000 and December 2003 (320 observations)	Used PMF to perform receptor modeling; Receptor modeling results were analyzed using meteorological data
Hafner, H., Brown, S., McCarthy, M. Data Analyses for Detroit, Michigan, Air Toxics Data Collected in 2001. Prepared for Lake Michigan Air Directors Consortium. Final Report STI-903553-2557-FR. 2004.	Carbonyl, VOC, Speciated $PM_{2.5}$ (Speciation Trends Network), Metals (TSP), SVOCs and PAHs collected at three Detroit sites (Allen Park, East 7 Mile and 696/Lodge) during 2001	Used PMF to perform receptor modeling; Source contributions represent total contribution from the sum of $PM_{2.5}$, VOC, SVOC

Tables 4-11 through 4-13 show the source apportionment results for the studies listed in Table 4-8.

Table 4-11: PMF Results for Two Sites in Detroit MI and Compared to Other Sites within the Midwestern United States

	Contribution (Percent of Total $PM_{2.5}$ in parentheses) (μg/m³)				
Source	*Detroit, MI (Dearborn)*	*Detroit, MI (Allen Park)*	*Chicago, IL*	*Indianapolis, IN*	*Mayville, WI*
Soil	1.4 (7%)		0.6 (4%)	0.3 (2%)	0.4 (3%)
Industrial (Utility and Petroleum Refineries)	1.7 (8%)	0.7 (4%)	0.2 (1%)	0.7 (4%)	0.5 (4%)
Road Salt	0.8 (4%)	0.4 (2%)	0.5 (3%)		
Fe/Mn (Qualified Diesel)	1.3 (6%)	0.2 (1.1%)	0.1 (0.6%)	0.2 (1%)	1.5 (12%)
Vehicles	5.3 (25%)	5.9 (35%)	4.1 (26%)	5.9 (32%)	2.1 (17%)
Nitrates	3.7 (18%)	3.5 (21%)	3.3 (21%)	2.9 (16%)	3.2 (26%)
Sulfates	4.6 (22%)	5.0 (30%)	5.4 (35%)	6.8 (37%)	3.9 (31%)
Steel (Metals Processing)	1.1 (5%)	0.3 (2%)	0.4 (3%)	1.3 (7%)	
Vegetative Burning	0.9 (4%)	0.9 (5%)	0.9 (6%)	0.2 (1%)	0.9 (7%)
Copper		0.1 (0.6%)	0.1 (0.6%)		
Total $PM_{2.5}$	20.8	16.9	15.5	18.4	12.4

Source: Rizzo, M. 2005. "A Source Apportionment Analysis of the Dearborn Speciation Trends Network Site." USEPA OAQPS.

Table 4-12: Average Source Contributions and Percent of Total Fine Particulate for Two Sites in the Detroit Metropolitan Area

	Average Contribution (Percent of Total $PM_{2.5}$ in parentheses) (μg/m³)	
Source	*Allen Park (Site 261630001)*	*Dearborn (Site 261630033)*
Secondary Sulfate	5.1 (30.5%)	8.0 (35.9%)
Secondary Nitrate	3.4 (20.1%)	3.98 (17.9%)
Soil	0.98 (5.9%)	2.23 (10.1%)
Aged Sea and Road Salt	0.46 (2.7%)	0.46 (2.1%)
Iron & Steel	0.84 (5.1%)	2.32 (10.5%)
Spark-ignition Vehicles	3.7 (22.1%)	4.07 (18.4%)
Diesel Vehicles	0.84 (5.1%)	1.13 (5.1%)
Biomass Burning	0.37 (2.2 %)	
Mixed Industrial	0.41 (2.5%)	

Source: Center for Air Resources Engineering and Science. 2005. Final Report of the Project: Analyses of Midwest PM-Related Measurements. Clarkson University.

Table 4-13: Total $PM_{2.5}$, VOC and SVOC Contributions at Five Sites within the Detroit Metropolitan Area

Source	*Average Contribution (Percent of Total $PM_{2.5}$, VOC, SVOC in parentheses) ($\mu g/m^3$)*		
	Allen Park (Site 261630001)	*696/Lodge (Site 261250010)*	*East 7 Mile (Site 261630019)*
Motor Vehicle	1.33 (6%)	1.74 (7%)	1.73 (11%)
Secondary Sulfates/Nitrates	9.63 (36%)	8.70 (36%)	5.40 (35%)
Coal, smelter	2.02 (9%)		
Industrial, oil	2.87 (14%)	0.23 (1%)	
Secondary VOCs	4.18 (19%)	4.88 (21%)	6.44 (41%)
Industrial	2.30 (12%)	3.38 (14%)	1.21 (8%)
Diesel (trains and trucks)	1.15 (6%)	2.04 (9%)	
Background organic carbon/wood burning		2.83 (12%)	
Industrial PAH			0.12 (1%)
Soil			0.56 (4%)

Source: Hafner, H., Brown, S., McCarthy, M. 2004. Data Analyses for Detroit, Michigan, Air Toxics Data Collected in 2001. Prepared for Lake Michigan Air Directors Consortium. Final Report STI-903553-2557-FR.

Common sources seen across all three studies include secondary sulfates and nitrates, diesel emissions, gasoline vehicle emissions, road salt, soil and biomass (vegetative) burning. Secondary sulfates and nitrates consistently account for approximately 40 to 50% of the total fine particulate at the sites in Detroit. Furthermore, the relative similarity in contribution of secondary particles across sites in the Midwest suggests the regional influence of secondarily formed particulate matter. While a large portion of the ambient $PM_{2.5}$ consists of regional sources, local emissions from gasoline and diesel vehicles can contribute a combined total of approximately 25 to 30% of the total fine particulate. This leaves other local point sources potentially contributing approximately 20% of the remaining $PM_{2.5}$ mass. For Detroit, these source categories include road salt which is highly seasonal, soil which has a similar source signature to cement kilns, metals processing facilities, biomass burning and other mixed industrial sources such as local area power generation facilities.

Updated Monitoring Data. Figures 4-7 and 4-8 below illustrate the trend in daily and annual design values for monitors in the Detroit area between 1999 and 2005. The daily and annual design value trends between 1999 and 2003 for sites 261630033 and 261630015—the two violating monitors in Detroit—are upward sloping and slightly declining, respectively. Between 2001 and 2005, these two sites indicate declining annual design values. These trends suggest that Detroit might be closer to attainment of the 1997 standards for the 2020 base case than we projected in our analysis.

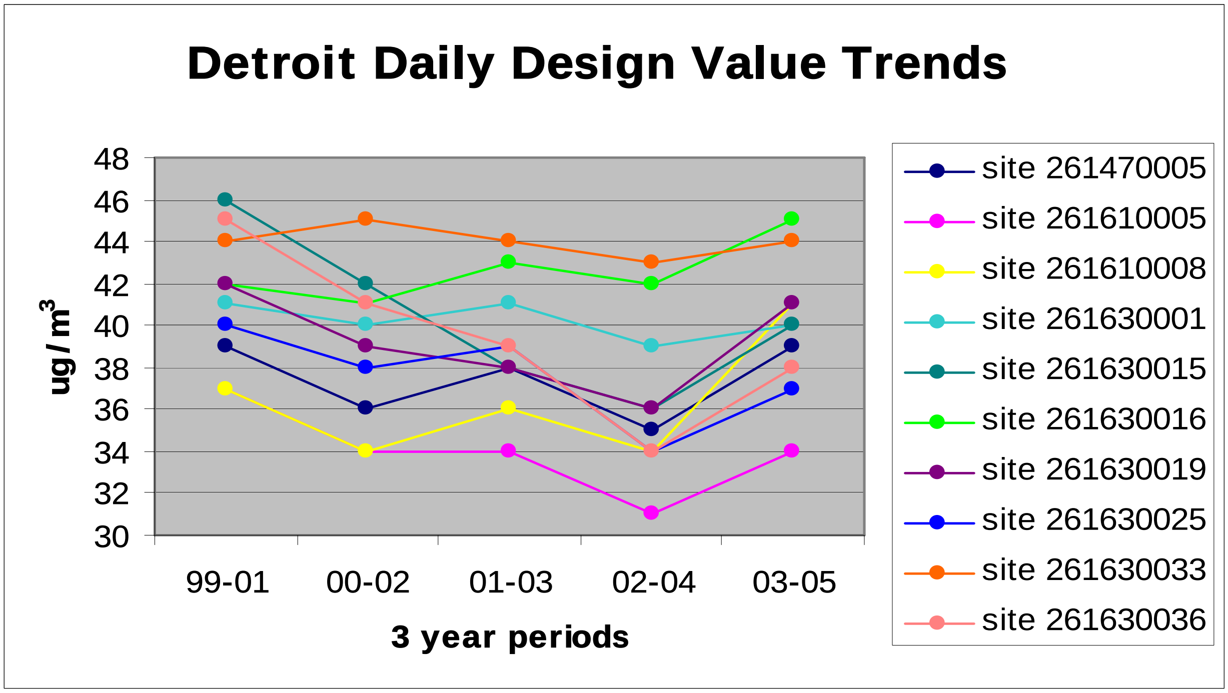

Figure 4-7. Daily Design Value Trend for Monitors in Detroit Metropolitan Area

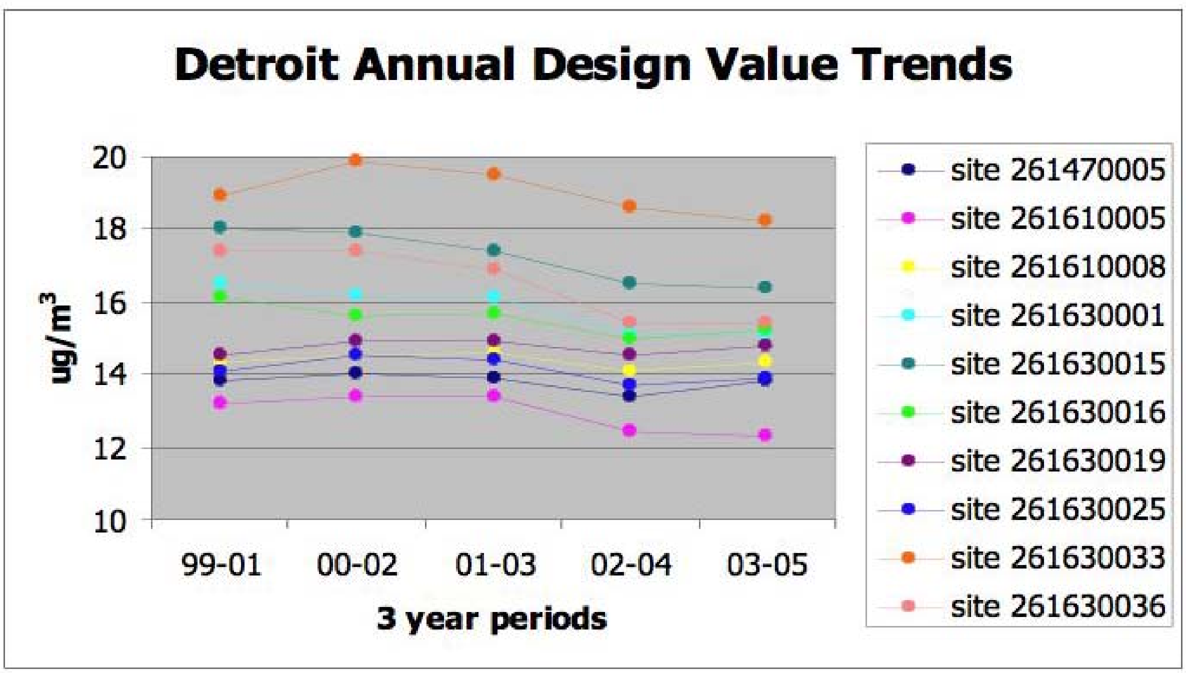

Figure 4-8. Annual Design Value Trend for Monitors in Detroit Metropolitan Area

Conclusions. The monitoring and emissions analysis identifies sources near the priority monitoring sites that may not be well characterized for a local air quality assessment. Thus, we may not have fully captured the benefits of controls in our projected design value analysis. The AERMOD local-scale modeling indicates that controlling local sources of direct $PM_{2.5}$ would have a substantial impact on the design value at the violating monitor—impacts that our projected design values likely do not fully reflect due to the coarse resolution of our CMAQ modeling and uncertainties in the location and characterization of emissions sources. The source apportionment studies highlight the importance of mobile sources and indicates that we may not have fully captured the air quality benefits associated with controlling these sources. Finally, the updated design value data suggests that the air quality trend is improving. Taken together, these data argue that for the purpose of this illustrative analysis, we are presuming that Detroit attains the selected revised and alternative revised standards for the purposes of this analysis.

4.2.2.3 Pittsburgh

Projected Design Values. The air quality modeling analysis projects Allegheny County to violate the annual 1997 standard as well as the daily revised standard and the more stringent alternative revised standards in 2020 under our base case emissions. For our control cases, the analysis projects this area to exceed the annual and daily 1997 standards as well as the revised and more stringent alternative daily standard.

Table 4-14. Projected Design Values for Allegheny County, Pennsylvania

County	Priority Monitor	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Allegheny	420030064	16.2	52.7	14.12	14.0	46.9	46.7

Monitoring and Emissions Analysis. Monitoring site 420030064 was the monitoring site in the Pittsburgh area that remained nonattainment of both annual and alternative daily standard NAAQS levels. This monitoring site is situated close to several large industrial facilities, including Clairton Coke Works and U.S. Steel Irvin Plant. Pollution roses indicate that most of the highest $PM_{2.5}$ concentrations result when the wind blows from the southeast where the Clairton facilities are located. The speciation profile used in our projection analysis for this site consists of approximately 27% sulfate, 6% nitrate, 10% ammonium, 8% water, 41% organic carbon mass (OCM), 4% elemental carbon (EC), and 4% metals /crustal materials (MCM). Updated speciation data available at the monitor site indicate the following speciation: 29% sulfate, 3% nitrate, 11% ammonium, 9% water, 33% OCM, 11% EC, and 3% MCM. The fractions of sulfate, ammonium, MCM, and total carbon (sum of OCM and EC) are fairly consistent. However, it appears that (1) nitrate was overestimated initially and (2) the OCM/EC split was not representative for this site in that there is considerably more EC than we initially assumed. From a daily standard perspective, more than just one quarter merited attention; most high values occur in either quarter 2 or quarter 3 depending on the definition of ‘high’. Quarter 2 has more values over 65 µg/m^3 (from 1999–2005) but quarter 3 has more values over 35 µg/m^3. Although comparisons of initial versus revised profiles for these two quarters show some inconsistencies (e.g., sulfate appears overestimated in initial analysis in quarter 3 but looks reasonable for quarter 2), both quarters clearly show that EC was significantly underestimated initially (by a factor of about 4).

AERMOD Analysis. Figure 4-9 shows the spatial distribution of direct $PM_{2.5}$ for Pittsburgh resulting from AERMOD modeling of primary $PM_{2.5}$ emissions from a limited set of local sources. These modeling results indicate high annual concentration gradients of primary $PM_{2.5}$ within typical photochemical modeling grid resolutions. Thus, spatial gradients exist within the study area for primary $PM_{2.5}$ with a variety of local sources such as metal manufacturing, coal combustion, and mining being significant contributors to direct PM2.5 at monitoring site 420030064. The modeled local sources of direct PM2.5 emitted roughly 5,700 tons resulting in a total contribution of 1.75 ug/m^3 to the total annual concentrations of PM2.5 at monitoring site 420030064. AERMOD results reflecting July 23rd show a total contribution of 7.89 ug/m^3 from these sources to the daily annual concentrations of PM2.5 at this monitor. Given the limited number of local sources modeled through AERMOD, the modeling results are not comparable to those obtained from CMAQ which included all regional and local sources of direct PM2.5 contributing to this monitoring site.

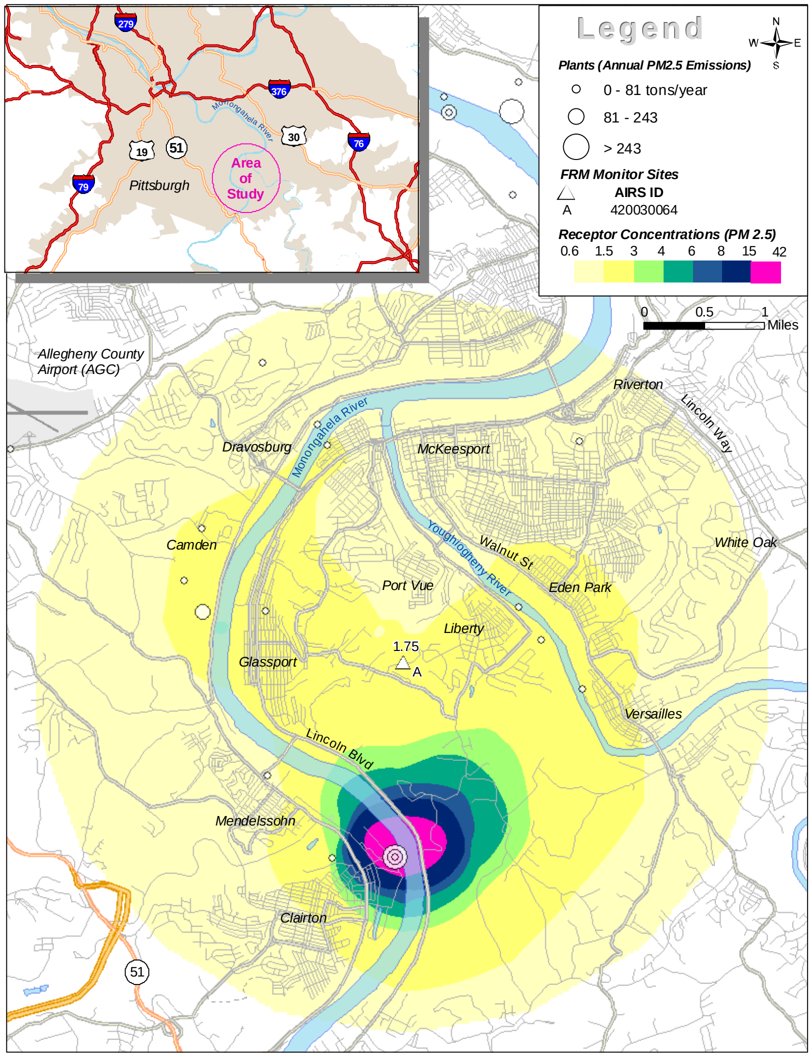

Figure 4-9. Spatial Gradient in Pittsburgh, PA of AERMOD Predicted Annual Primary $PM_{2.5}$ Concentrations (ug/m^3) for Selected Sources: 2015

Updated Design Values. The six-year annual and daily design value trend illustrated in figures 4-10 and 4-11 below for the priority monitor 420030064 indicates a fairly flat trend for the annual design value and a slightly increasing trend for the daily design value. Had we used more current design value data, our 2020 base-case estimates of the daily design value might have been somewhat higher than we projected.

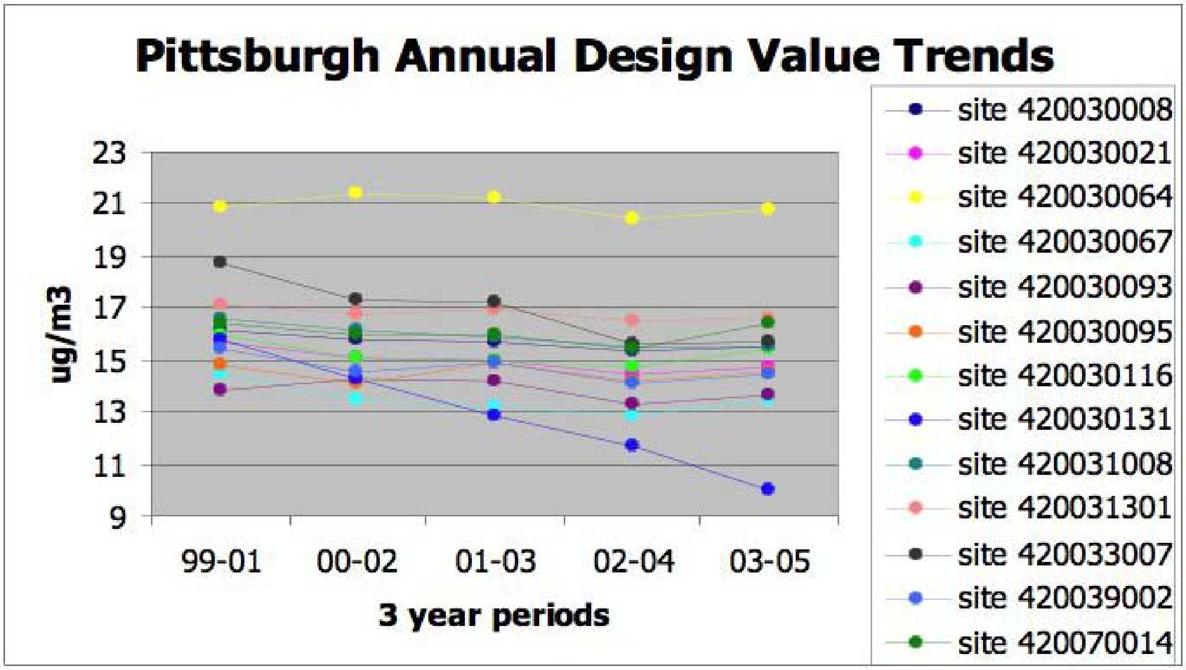

Figure 4-10. Annual Design Value Trend for Monitors in Pittsburgh Metropolitan Area

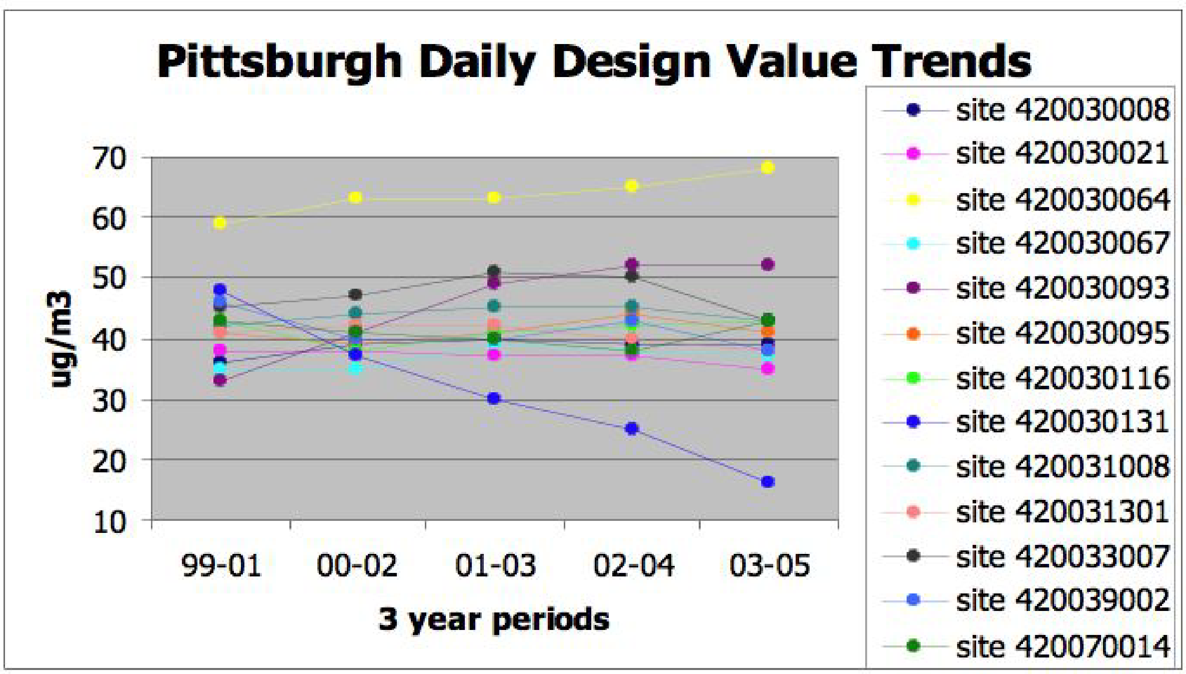

Figure 4-11. Daily Design Value Trend for Monitors in Pittsburgh Metropolitan Area

Conclusions. The non-attainment problem at site 420030064 in Alleghany County is principally associated with meeting the selected revised daily standard. The site is projected to exceed this standard by approximately 10 µg/m^3. The AERMOD local-scale modeling suggests that there is a significant spatial gradient in $PM_{2.5}$ concentrations surrounding several facilities. Consequently, controlling the emissions at these facilities may substantially improve the ability of the county to attain the selected daily standard. However, we cannot make a determination that Pittsburgh would attain with our modeled controls.

4.2.2.4 Libby, Montana

Projected Design Values. Lincoln County (Libby, MT) is projected to attain the 1997 standards in 2020 in both our base and control cases. Lincoln does not reach simulated attainment with the proposed revised daily standard or the alternative revised annual standard in 2020 after the application of emission controls.

Table 4-15. Projected Design Values for Lincoln County, Montana

County	Violating Monitor	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Lincoln	300530018	14.9	42.2	14.5	14.0	41.3	41.3

Monitoring and Emissions Analysis. Libby is a small, isolated northwestern Montana town with no industry that produces a significant level of emissions. The town is in a deep valley and has very cold, long winters. Because of the topography of the area and northern geographic location, this area is susceptible to strong wintertime temperature inversions with low wind speeds that result in poor atmospheric dispersion. Thus, pollutants can become trapped below the inversion, producing high short-term concentrations.

Emissions from woodstoves used during the winter are a large source of directly emitted $PM_{2.5}$ in Libby. Woodstoves are used heavily as there is no natural gas supply into the area and there is an abundance of firewood. The combination of short-term wintertime inversion events and the ubiquity of wood stove emissions results in high daily concentrations of $PM_{2.5}$. In fact, source attribution analyses identify residential woodsmoke as the source of 82% of the wintertime $PM_{2.5}$. Currently, there is an extensive woodstove changeout program being implemented in Libby that is expected to mitigate these contributions.[12]

Almost all high $PM_{2.5}$ values (greater than 35 µg/m^3) occur during the winter months (November through March). The speciation profile for the high quarter (quarter 1) had over 95% of the mass identified as OCM. More robust collocated profiles for the top 25% of quarter 1 shows the OCM component to be closer to 85% with EC being the majority of the difference (i.e., EC was underestimated in the model profile). Summertime wildfire $PM_{2.5}$ impacts are not uncommon in parts of Montana, but this location only has had an average of one day a year flagged for forest fire events.

[12] http://www.lincolncountymt.us/woodstovechangeout/

Wildfire and prescribed burning emissions represent a substantial proportion of total PM2.5 emissions in Lincoln County. EPA estimates annual wildfire and prescribed burning emissions to be approximately 550 tons of $PM_{2.5}$, or about 70% of the total PM2.5 emissions for this county. Because these emissions originate from wildfires and prescribed burning, they are largely stochastic and uncontrollable; therefore, they have complicated our attempts to simulate attainment with the daily design value for this county. Moreover, the manner in which EPA temporally and spatially allocates these emissions is subject to substantial uncertainties that are likely to have implications for our attainment analysis. First, EPA modeled the fires using an average of 5 years of data for monthly allocation, which smoothes peak fire years from any given state. This approach results in EPA's allocation of emissions to winter months (when the 98th percentile design value in Lincoln County occurs) even though the fire emissions in those months are small and more likely should have been zero. Because the fire emissions are not zero in these months, emissions controls on other sources have less percent reduction needed for showing attainment in these counties through modeling. Second, when allocating these emissions to each month, the processing approach assumes that these emissions occur every day of the month at the same rate; this does not represent real wildfire or prescribed burning events that typically are shorter in duration, e.g., a single day to one week. Third, the spatial assignment of fire emissions allocates emissions to forested areas in the state, since the information on where the fires actually occurred was not available in a form we could use for this work.

The combined affect of these uncertainties is to potentially over-state the daily design value. EPA is adjusting these assumptions as it implements its updated 2002 National Emissions Inventory.

Updated Design Values. The six-year design value trend for Lincoln County indicates a slight downward trend in the annual and daily design value for the priority monitor, site 300530018. Thus, had we projected future air quality off of more current 2001-2005 design values our 2020 base case design values would likely be somewhat lower than we projected by using 1999-2003 design values.

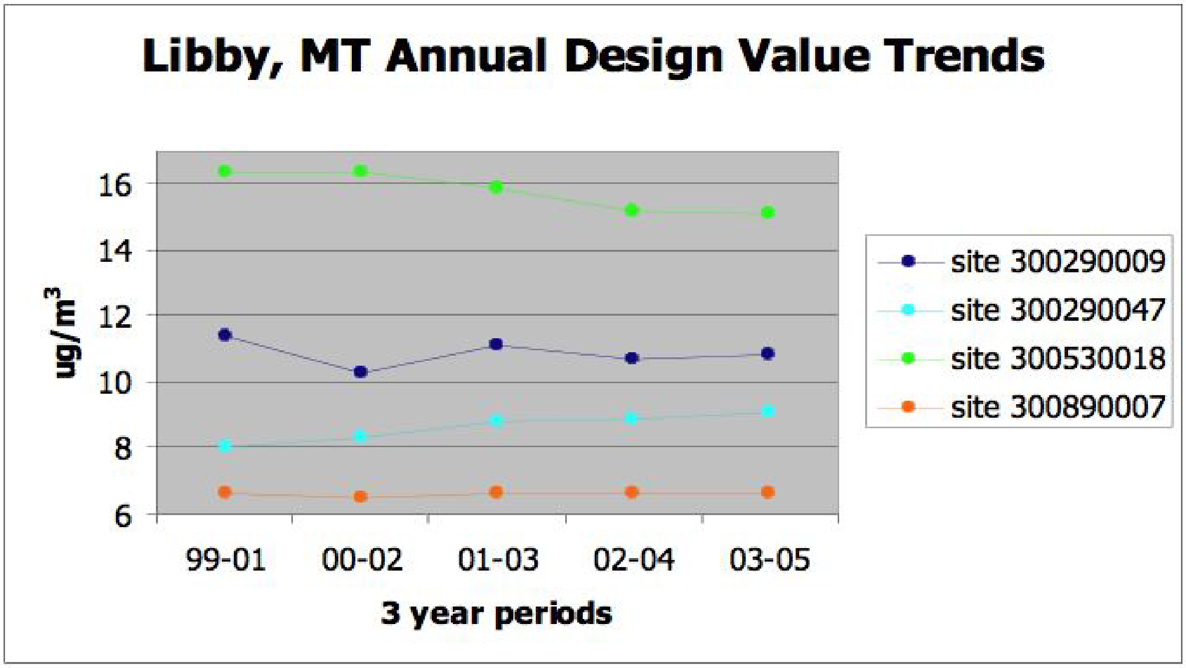

Figure 4-12. Annual Design Value Trend for Monitors in Libby Metropolitan Area

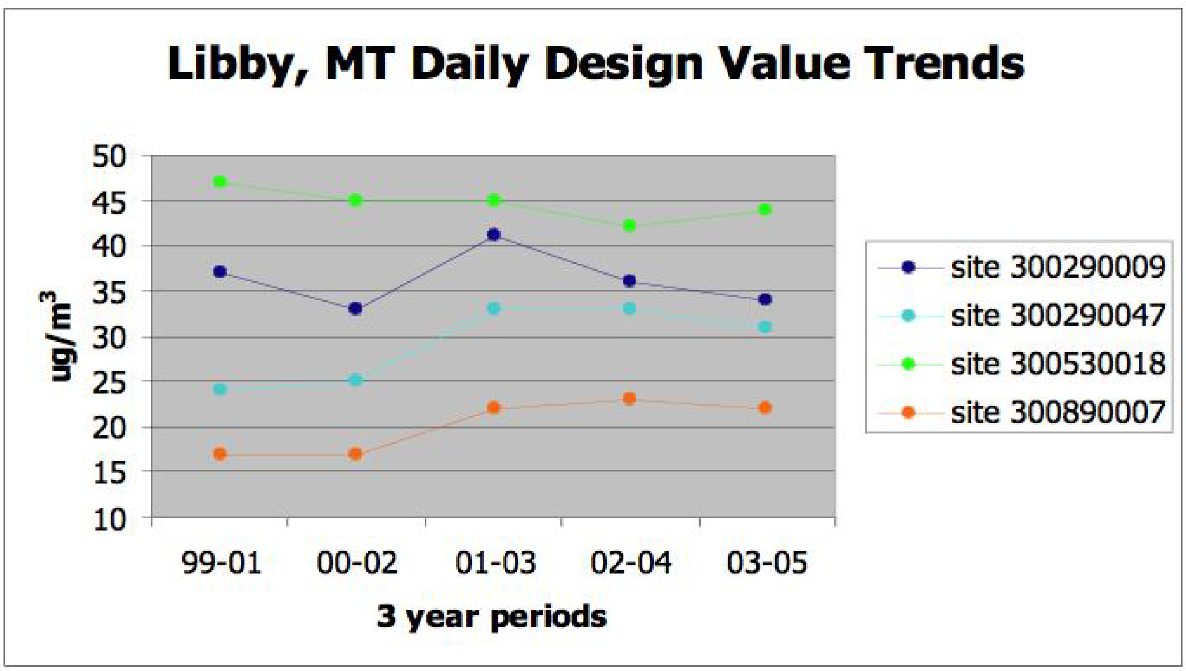

Figure 4-13. Daily Design Value Trend for Monitors in Libby Metropolitan Area

Conclusions. Wintertime inversions coupled with high emissions of PM from woodstoves are key to the nonattainment problem in Libby, MT. Uncertainties in the our analysis, including the tendency to obscure near-field effects, likely understate the effectiveness of our emission controls (particularly the effectiveness of the wood stove change-out program). The temporal allocation of wildfire emissions is also likely to have overstated the daily design value projections. Finally, the moderately improving trend in design values suggests that we may have slightly over-estimated 2020 annual and daily design values. The balance of the empirical evidence suggests that for the purposes of this illustrative analysis, we presume that Libby will be able to attain the proposed revised standards.

4.2.2.5 Salt Lake City

Projected Design Values. Box Elder, Cache and Salt Lake Counties are projected to attain the 1997 standards in the base and control cases. These three counties do not attain the proposed revised daily standard after applying emission controls.

Table 4-16. Projected Design Values for Salt Lake City, Utah

County	Violating Monitors	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Box Elder	490030003	8.5	38.4	8.3	8.3	36.9	36.9
Cache	490050004	12.3	51.4	12.0	12.0	44.6	44.6
Salt Lake	490350003	12.2	47.6	11.3	11.3	42.9	42.9

Monitor and Emissions Analysis. There are four $PM_{2.5}$ monitoring sites in Salt Lake county that have similar, high (model) 24-hour design values: site 490350003 has a DV of 57 µg/m3; site 490350012 has a DV of 55 µg/m3; site 490353006 also has a DV of 55 µg/m3; and site 490353007 has a DV of 53 µg/m3. All of the monitoring sites are located in the 500 square mile Salt Lake Valley. This valley is surrounded in every direction except the northwest by steep mountains that at some points rise 7,100 ft from the valley floor's base elevation. It lies nearly encircled by the Wasatch Mountains on the east, the Oquirrh Mountains on the west, the Traverse Mountains to the south, and the Great Salt Lake on the northwest. As with Libby, MT, wintertime temperature inversions contribute significantly to the high $PM_{2.5}$ levels. Over 98% of the site-day exceedances of the 35 µg/m3 level (from 1999 through 2005) occurred during the four month November through February. Speciation monitoring is conducted at site 490353006. A comparison of the modeled profile at that site location for the highest quarter (quarter 1) to the updated actual (collocated) profile for the top 25% days of that quarter revealed that nitrate was underestimated in the initial model runs. The model profile had 27% nitrate and the comparison profile has 32% nitrate. Similar results were obtained in comparisons of modeled data at the other site locations with the speciation site's updated data. Those comparisons also identified an apparent overestimation of the OCM fraction in the model runs (of up to 15%).

Updated Design Values. The three monitors in and around Salt Lake City projected to violate the proposed revised standard (sites 490350003, 49005004, and 490030003), see a flat or slightly upward trend in the annual design value and a downward trend in the daily design value. This improved trend in daily design value trend suggests that were to have projected daily design values off of these later data that our base case might reflect lower projected daily design values.

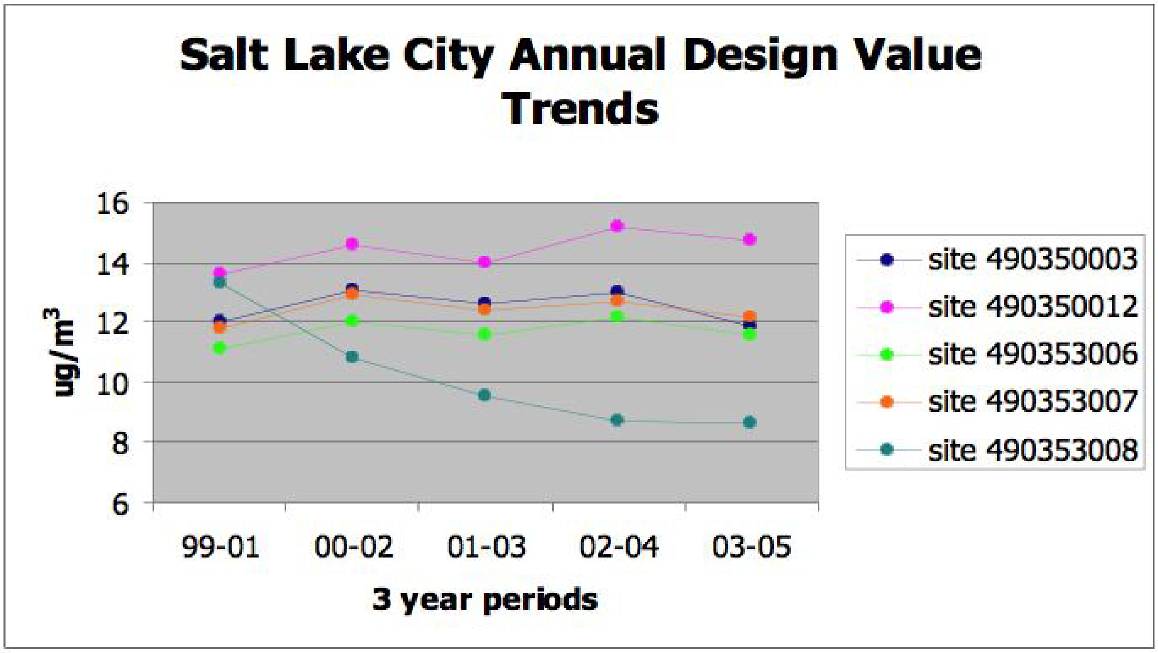

Figure 4-14. Annual Design Value Trend for Monitors in Salt Lake City Metropolitan Area

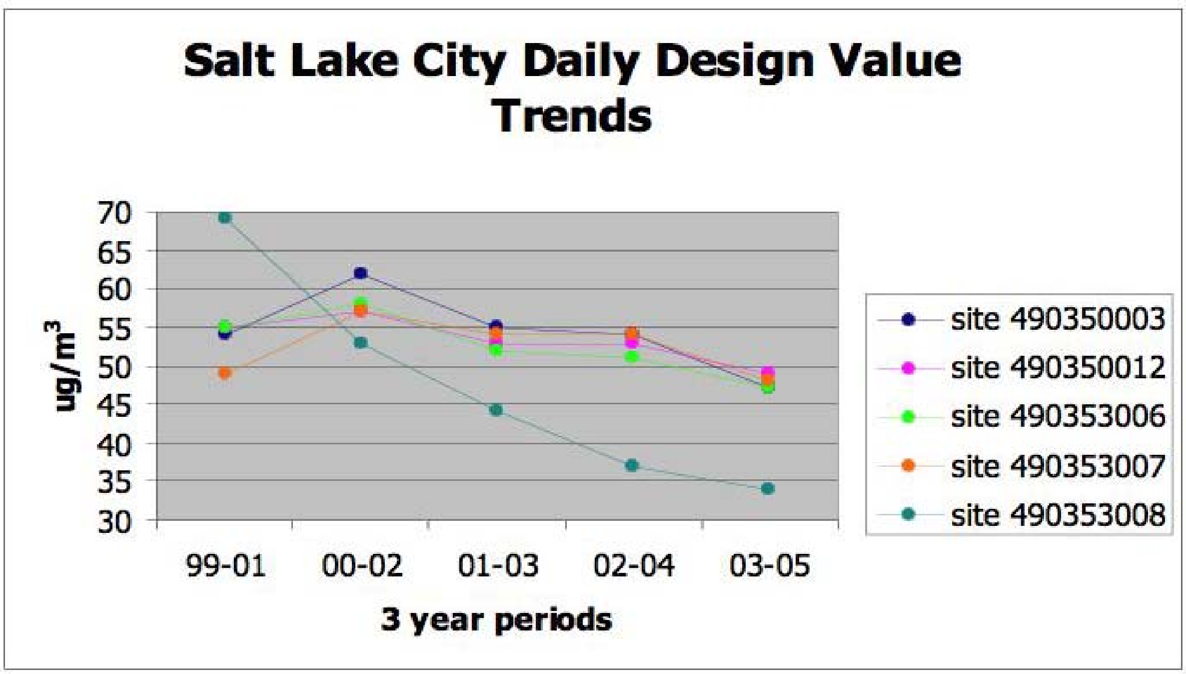

Figure 4-15. Daily Design Value Trend for Monitors in Salt Lake City Metropolitan Area

Conclusions. Wintertime inversions in the Salt Lake Valley contribute to elevated daily design values among the three monitors projected to not attain the proposed revised daily standard. Updated design value data suggests a significant downward trend in the daily design value. While Salt Lake experiences a seasonal air quality problem, we did not model the seasonal application of emission controls, and thus may not have fully captured the air quality improvements associated with our control strategy. Moreover, the relatively coarse-scale air quality modeling may not have adequately reflected the near-field effects of our control strategy. However, the magnitude by which Cache and Salt Lake counties are projected to not attain the proposed revised standard (as much as 15 µg/m^3) suggests that the area would remain out of attainment after implementing the emission controls we identified for this area in chapter 3. The weight of the empirical evidence suggest that Salt Lake City would not be able to attain the selected standard by 2020 with the emission controls that we have identified.

4.2.2.6 Eugene, Oregon

Projected Design Values. The Lane county monitor is projected to attain the revised and alternative revised annual standard. However, the county does not attain the revised daily standard after the simulated application of emission controls.

Table 4-17. Projected Design Values for Lane County, Oregon

County	Violating Monitors	2020 Basecase Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Lane	410392013	12.8	53.0	11.7	11.7	48.0	48.0

Monitoring and Emissions Data. Monitoring site 410392013 is located in Oakridge city, which is southeast of the larger urban areas of Eugene and Springfield. Oakridge is located in a small narrow valley surrounded by steep mountains of the Cascade range. As with Salt Lake City and Libby, the major source of particle pollution in Oakridge, specifically very high concentrations during wintertime, is woodsmoke emissions trapped by temperature inversions. A woodstove changeout program is imminent. There are some local emission sources which may exacerbate the $PM_{2.5}$ problem. The Oakridge site is about 200 meters from highway 58 and about 400 meters from Union Pacific railroad line. Although no nearby speciation data are available (the nearest site is over 125 miles away), a review of the modeled Oakridge profile information was conducted using a surrogate speciation site. Libby, MT (site 300530018) was deemed a similar site due to topography and wood smoke impacts. Based on a comparison of the modeled (interpolated) Oakridge site profile for the high quarter (quarter 1) with actual data from Libby, the following supposition was made. The modeled speciation profile probably overestimated organic carbon and significantly underestimated elemental carbon.

Wildfire and prescribed burning emissions represent a substantial proportion of total PM2.5 emissions in Eugene County. EPA estimates annual wildfire and prescribed burning emissions to be approximately 3,300 tons of $PM_{2.5}$, or about 50% of the total PM2.5 emissions for this county. Because these emissions originate from wildfires and prescribed burning, they are largely stochastic and uncontrollable; therefore, they have complicated our attempts to simulate attainment with the daily design value for this county. Moreover, the manner in which EPA temporally and spatially allocates these emissions is subject to substantial uncertainties that are likely to have implications for our attainment analysis. First, EPA modeled the fires using an average of 5 years of data for monthly allocation, which smoothes peak fire years from any given state. This approach results in EPA's allocation of emissions to winter months (when the 98th percentile design value in Eugene County occurs). Even though the fire emissions in those months are small, they should most likely have been zero. Because the fire emissions are not zero in these months, emissions controls on other sources have less percent reduction needed for showing attainment in these counties through modeling. Second, when allocating these emissions to each month, the processing approach assumes that these emissions occur every day of the month at the same rate; this does not represent real wildfire or prescribed burning events that typically last 1 day to 1 week. Third, the spatial assignment of fire emissions allocates emissions to forested areas in the state, since the information on where the fires actually occurred was not available in a form we could use for this work.

The combined affect of these uncertainties is to potentially over-state the daily design value.

Updated Design Values. The daily and annual design value trends for the priority Eugene monitor (site 410392013) are fairly constant between 1999 to 2005, as illustrated by figures 4-16 and 4-17. Thus, the use of more current 2002-2005 design value measurements to project future air quality would be unlikely to have produced estimates that were significantly different from our existing estimates.

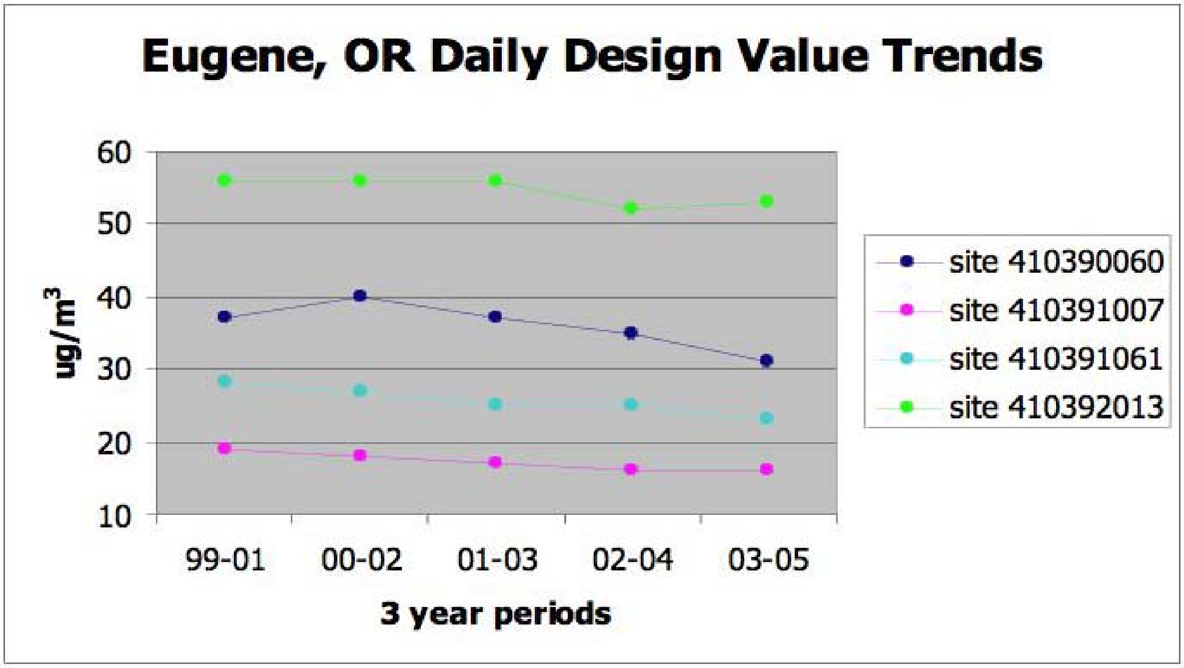

Figure 4-16. Daily Design Value Trend for Monitors in Eugene Metropolitan Area

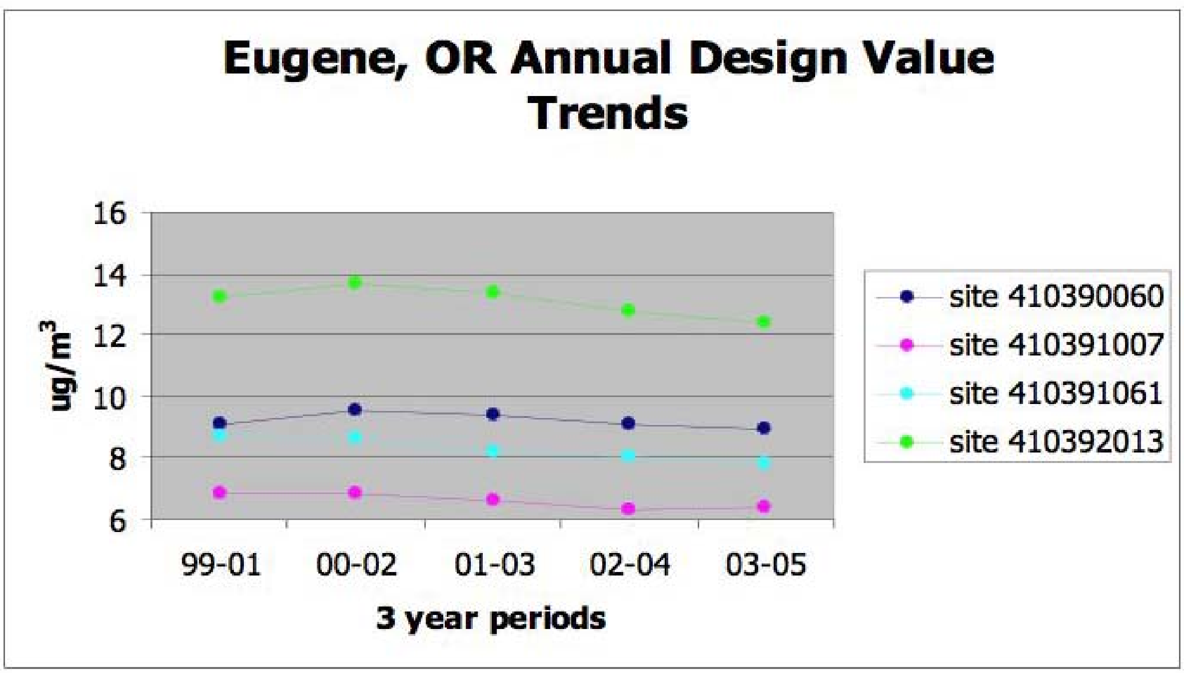

Figure 4-17. Annual Design Value Trend for Monitors in Eugene Metropolitan Area

Conclusions. The $PM_{2.5}$ problem in this county is primarily short-term in nature. Wood smoke emissions, trapped by wintertime inversions, significantly contribute to the projected non-attainment of the selected daily standard. The temporal allocation of wildfire emissions is also likely to have overstated the projected daily design value. The balance of empirical data suggests that for the purposes of this illustrative analysis, we presume that Eugene will attain the revised daily standard in 2020.

Table 4-18: Attainment Determinations for Selected Urban Areas

Urban Area and Standard Alternative	*Annual or Daily Controlling?*	*Projected Nonattainment Increment*	*Final Attainment Determination*
15/35			
Libby, MT	Daily	6 $\mu g/m^3$	Attains revised standard
Salt Lake City	Daily	10 $\mu g/m^3$	Does not attain revised standard
Eugene, OR	Daily	13 $\mu g/m^3$	Attains revised standard
Detroit	Annual	1.75 $\mu g/m^3$	Attains revised standard
Pittsburgh	Daily	12 $\mu g/m^3$	Does not attain revised standard
Cleveland	Daily	3 $\mu g/m^3$	Attains revised standard
14/35			
Detroit	Annual	2.25 $\mu g/m^3$	Attains alternative revised standard
Pittsburgh	Daily	12 $\mu g/m^3$	Attains alternative revised annual standard. Does not attain revised daily standard.

Within this illustrative attainment analysis, each of these urban areas located outside of California—with the exception of Salt Lake City and Pittsburgh—would attain the revised and more stringent alternative revised standards. As described above, Salt Lake City is a special case due both to its unique topography that exacerbates wintertime inversions, and the magnitude of its projected non-attainment with the revised daily standard. To estimate full attainment cost for this urban area, we have developed extrapolated cost estimates described in Chapter 6.

Implications for the estimation of benefits and costs in these six areas

The determination of attainment and non-attainment for these urban areas has certain implications for our final estimates of full attainment costs and benefits. As we describe above, the empirical data support a determination that certain projected non-attainment areas will likely attain the revised and more stringent alternative standards. As such, we believe that the emission controls that we have applied are sufficient to reach attainment, even if our air quality modeling does not reflect this result. Thus, our cost estimates derived from AirControlNET and supplemental controls in Chapter 6 reflect the cost of a control strategy that reaches simulated attainment with the revised and alternative revised standards for those areas that we note in table 4-18 above. As we describe above, when making an attainment determination for a given area, we adjusted the design value to be equal to the revised standard or more stringent alternative standard. Thus, we use this adjusted design value when performing the benefits assessment in these areas.

4.3 Special Analyses for California

It is well-recognized that California faces a set of unique and exceptionally difficult challenges in meeting national air quality standards, including those for fine particulates. The projected design values above indicate that several California counties will not attain the revised or alternative more stringent standards. California poses a unique $PM_{2.5}$ nonattainment challenge in this RIA due both to the magnitude of this projected nonattainment and the number of California-specific limitations in our data and tools. Both this chapter and the controls analysis in chapter 3 describe four factors that tend to inhibit our ability to simulate attainment in all California counties:

1. We exhausted our emission controls database, which prevented us from controlling all emission sources that contribute to nonattainment.
2. Key uncertainties exist with regard to both emissions inventories and air quality modeling in the West, which may understate the effectiveness of certain controls.
3. The relatively broad spatial resolution of our air quality modeling (36 km) means that emission reductions from local sources are not accurately "captured" by the relevant nonattaining monitors, resulting in possible understatements of local control efficiencies.[13]
4. The magnitude of projected non-attainment is larger than any other state, making the task of simulating attainment much more challenging than elsewhere in the nation.

Even as we recognize the limitations to our models and the magnitude of the state's challenge, we are able to make a number of analytical observations on the nature of California's PM problem. This section describes these limitations and observations in greater depth before providing updated design values for projected non-attainment counties and characterizing the impact that California's emerging emission reduction programs may have on future attainment.

[13] For further discussion of the CMAQ air quality model grid scale and its implications for our controls analysis, see discussion earlier in this chapter.

4.3.1 Understanding the California Nonattainment Problem

<u>Projected Non-Attainment</u>

The scope and magnitude of the $PM_{2.5}$ problem is unique in California. As Chapter 3 describes, our control strategy applied all cost-effective and available direct $PM_{2.5}$, NOx and NH_3 emission controls in the state.[14] As Table 4-17 below shows, our control-case modeling projects twelve counties to violate one or both of the 1997 annual and daily standards in 2020. Our modeling also projects another ten counties to violate the proposed revised daily standard and two counties to violate the alternative revised annual standard. The projected non-attainment is evenly distributed between counties located in the north and south parts of the state. See Chapter 2 for a map illustrating the geographic distribution of projected non-attainment in the baseline with the revised and more stringent alternative standards.

[14] We did not apply NH_3 controls in the San Joaquin Valley because modeling indicates that these controls would not be effective because the area is NO_x limited.

Table 4-17. Projected Design Values for California Counties Projected to Violate the Revised or Alternative Revised Standards.

County Name	Violating Monitor	2020 Base Case Design Values		2020 Control Case: Annual Design Values		2020 Control Case: Daily Design Values	
		Annual	*Daily*	*15/35*	*14/35*	*15/35*	*14/35*
Violates 35 µg Daily Std. Only							
Inyo	060271003	6.0	37.7	5.8	5.8	35.4	35.4
Sonoma	060970003	9.9	38.2	9.2	9.2	34.1	34.1
San Mateo	060811001	10.5	41.6	9.4	9.4	35.7	35.7
San Francisco	060750005	11.4	52.5	9.5	9.5	41.5	41.5
Solano	060950004	11.7	57.3	9.9	9.9	46.6	46.6
Santa Clara	060852003	12.0	52.3	11.2	11.2	47.1	47.1
Sacramento	060670010	12.1	48.3	10.5	10.5	40.0	39.9
Contra Costa	060130002	12.5	61.1	10.9	10.9	51.5	51.5
Butte	060070002	13.0	48.6	11.8	11.8	42.2	42.1
Alameda	060010007	13.2	58.7	11.5	11.5	49.5	49.6
Violates 14 µg Annual Std. and 35 Daily Std.							
Ventura	061112002	14.0	38.7	11.8	11.8	32.7	32.7
Imperial	060250005	14.8	44.9	13.8	13.8	41.5	41.
Violates 15 µg Annual Std. and 35 Daily Std.							
Merced	060472510	15.6	53.1	14.0	14.0	46.3	46.3
San Diego	060731002	15.7	40.1	13.5	13.5	34.0	34.0
San Joaquin	060771002	16.0	52.0	14.1	14.1	44.0	44.0
Stanislaus	060990005	16.2	59.3	14.1	14.1	49.9	49.9
Kings	060310004	16.8	67.6	15.2	15.2	59.5	59.6
Fresno	060190008	19.6	70.4	17.0	17.0	58.2	58.3
Orange	060590007	20.2	40.7	17.9	17.9	35.0	35.0
Tulare	061072002	20.6	73.6	18.5	18.6	64.3	64.3
Kern	060290010	20.8	77.9	18.2	18.2	66.5	66.6
Los Angeles	060371601	23.9	62.7	21.3	21.3	56.8	56.8
San Bernardino	060710025	24.6	65.8	21.1	21.1	56.7	56.8
Riverside	060658001	27.5	73.9	22.3	22.3	61.1	61.1

Emission Inventory and Air Quality Modeling Uncertainties

As described earlier in this chapter, there are some uncertainties associated with the mobile source inventory and specifically, emissions of organic carbon. Several recent source apportionment studies indicate that it is possible that EPA's mobile source inventories understate these emissions. To the extent that EPA emission inventories underestimate these emissions, then the emission control strategies that we applied in California would be less effective in simulating attainment of the revised or alternative more stringent standards.

As described above, CMAQ air quality model performance is generally less robust in the West as compared to the East. CMAQ performs well in predicting the chemistry formation of sulfate and nitrate in the Eastern U.S., where sulfate species are a larger component, and nitrates a smaller component, of PM2.5. However, in the West, and particularly California where nitrate and organics dominate, the modeling system tends to under-predict nitrate. Thus, CMAQ may understate the reductions achieved through application of certain NOx controls. We also used a 36-kilometer grid resolution, which may have the effect of obscuring the air quality effects associated with local-scale emission reductions.

These limitations are especially important for our ability to model attainment in California. Our control strategies for California are heavily weighted toward reductions in both $PM_{2.5}$ and NOx, and CMAQ's ability to reflect accurately NOx reductions in the West is limited. Finally, due to the density of emission sources in California and the large number of monitors projected to violate the 1997 and proposed revised standards, the 36 kilometer grid cell resolution is a limitation which can underestimate the effectiveness of local or urban-area controls. For all these reasons, our modeling of future air quality scenarios and impacts in California is associated with a higher degree of uncertainty than is similar analysis for other parts of the U.S.

4.3.2 Characterizing the Impact of California's Emission Reduction Programs on Future Nonattainment

As mentioned above, California will have to implement an aggressive strategy of both known and innovative control measures to reduce emissions of direct PM and PM precursors to meet the 1997 or the selected revised standards. Later sections in this analysis (see Chapter 6) make reference to the potential benefits and costs of attaining the standards, but the question of *how* California might reach attainment still remains. Our analytical limitations, along with the scope of California's nonattainment problem, prevent us from modeling pathways to full attainment—as we do for other nonattaining areas of the country—but we can summarize some of California's likely strategies and describe how they promise to help the state reach attainment for the 1997 and selected revised standards.

As of this RIA's writing, the areas of California that are likely to face nonattainment issues are in the early stages of analytical modeling to determine the target reductions in PM and its precursors; these are the approximate amounts that are likely to be necessary to reach attainment with the current standard (15 annual/65 daily). While these efforts are focused on meeting the standards already in place, the fact that California has its own, lower standards for ambient $PM_{2.5}$

(12 annual) allows us to characterize the state's control strategies in the context of meeting the revised or more stringent alternative NAAQS.

The California Air Resources Board (CARB) has conducted initial rollback analyses for two areas that are likely to be in nonattainment with future PM standards, the South Coast and the San Joaquin Valley nonattainment areas. These analyses present *preliminary* ideas on the scale of the precursor reductions that would be needed. The estimated range of necessary NOx, SOx, and VOC reductions in both areas is between 45-50% measured from 2005 levels, or between 20-30% measured from 2014 emissions levels (that is, reductions beyond those achieved from fleet turnover to more stringent mobile source standards). No numbers are available for direct PM contributions. It must be emphasized that these numbers present bounding estimates for the State as it considers types of controls and extent of various reduction contributions to make; they are not finalized targets.

Such preliminary figures are informative in that they describe the approximate size of the reductions that are likely necessary, but a great deal of analysis remains to be done with regard to designing an implementation program. Still, CARB and various air districts in the state have already devoted substantial time to understanding and addressing ambient PM emissions, and it is possible to get a sense of what future attainment pathways might look like based on the work that has already been done.

For example, both the South Coast and the San Joaquin Valley are likely to see reductions of NOx and VOCs as a result of the following representative control strategies:

(1) The Goods Movement Action Plan Emission Reduction Plan measures;
(2) Incentive programs to accelerate fleet turnover or retrofit;
(3) New State and Federal mobile emission standards;
(4) State and local regulations mandating retrofit of mobile sources (especially light duty vehicles, heavy duty diesel vehicles, construction equipment, and, in the case of the San Joaquin valley, farm equipment);
(5) Electrification of small combustion sources;
(6) Possibly, some improvements in energy efficiencies associated with the State's climate change action plan.

Other control strategies are also possible, including regulations that tighten limits in existing rules for stationary/area sources as well as development of new rules.

CARB recently approved an "Emission Reduction Plan for Ports and Goods Movement in California," as part of its effort to ensure an environmentally friendly system of goods movement within the state.[15] "Goods movement" encompasses activities including international trade, port activities, logistical services, and short- and long-haul transportation of materials and finished goods. As a policy approach, the goods movement Emission Reduction Plan (ERP) helps focus emissions abatement efforts on areas that have been identified as current and projected significant contributors to air emissions of multiple pollutants, including particulates. The ERP encompasses existing measures and regulations as well as a slate of new or in-progress control

[15] More information can be found at http://www.arb.ca.gov/planning/gmerp/gmerp.htm

strategies, including those that affect marine ships, commercial harbor craft, cargo handling equipment, trucks, locomotives, and some other areas.

We highlight the ERP here to draw attention to the fact that California is already conducting analyses on policies that are designed to achieve emission reductions of magnitudes similar to those that will likely be necessary to reach attainment with various PM standards. For example, if all the elements of the ERP are fully implemented, by 2020 NOx emissions will be reduced by 63% over 2001 levels, SOx by 78%, and diesel PM by 79%.

At this point it is impossible to fully and accurately characterize the impact of these programs on future air quality attainment/nonattainment status in California's various areas. We can, however, make a number of basic observations with regard to potential attainment pathways.

a) *Mobile source emissions will be aggressively targeted.* Given the large contribution of NOx, VOCs, and direct PM (from diesel-powered vehicles) in California, it is evident that any attainment strategy will focus extensively on reducing emissions from the mobile source sector. California has already taken a leadership role in efforts to address port-related emissions, for example.

b) *Costs will be significant.* Given the magnitude and nature of California's PM situation, it is clear that the costs of reducing emissions to move closer to the standard will be significant. In section 6.2 of Chapter 6 we provide an estimate for the cost of California reaching full attainment with the revised and more stringent alternative standards. While there is a significant amount of uncertainty associated with this cost estimate—as explained in Chapter 6—it is apparent that the cumulative cost of reaching attainment would be sizeable. While California has not conducted a formal costing exercise with regard to meeting the PM standards, the costs associated with emission reduction programs, such as the Goods Movement ERP, are of a similar magnitude to what one might expect. For example, CARB estimates the cumulative cost of implementing the Goods Movement ERP strategies by 2020 to be between $6-10 billion in present value dollars.

c) *New and advanced technologies are likely to play a role.* Historical experience has shown that the obligation to meet national air quality standards has created incentives and pressures for technological advances that aid in improving air quality, and it can be anticipated that similar dynamics will exist as California moves to meet the standards. To address the particularly difficult issues the state faces with regard to the PM standards, substantial technological advance is needed, particularly with regard to mobile sector technologies. California has a number of initiatives in place that encourage such advances, ranging from more "conventional" approaches employed in the Goods Movement ERP, to more far-reaching strategies focused on vehicles powered by hydrogen fuel cells.[16] It is difficult to pinpoint the exact catalyst for such change, and in the case of California, there are potentially multiple reasons the State would seek to encourage technological change in the transportation and/or energy sectors. Once again,

[16] See http://hydrogenhighway.ca.gov/ for more information on California's pilot programs involving hydrogen technologies.

it should be stressed that the costs that might be incurred if technological shifts in the mobile sector occurred at a scale large enough to substantially improve air quality would be significant. At the same time, technological change brings with it positive externalities that may serve to reduce overall attainment costs on a nationwide level.

4.3.2 Updated Design Values

There is a clear trend toward decreasing design values over the past six years among California monitors. The figures below illustrate this trend for monitors that in 1999-2001 exceeded either the existing 15 ug/m3 or more stringent alternative 14 ug/m3 annual standard, or the revised 35 ug/m3 daily standard. While we captured some of this improving trend when we projected future air quality off of 1999-2003 design value data, more current data would likely have yielded lower projected 2015 and 2020 baseline design values.

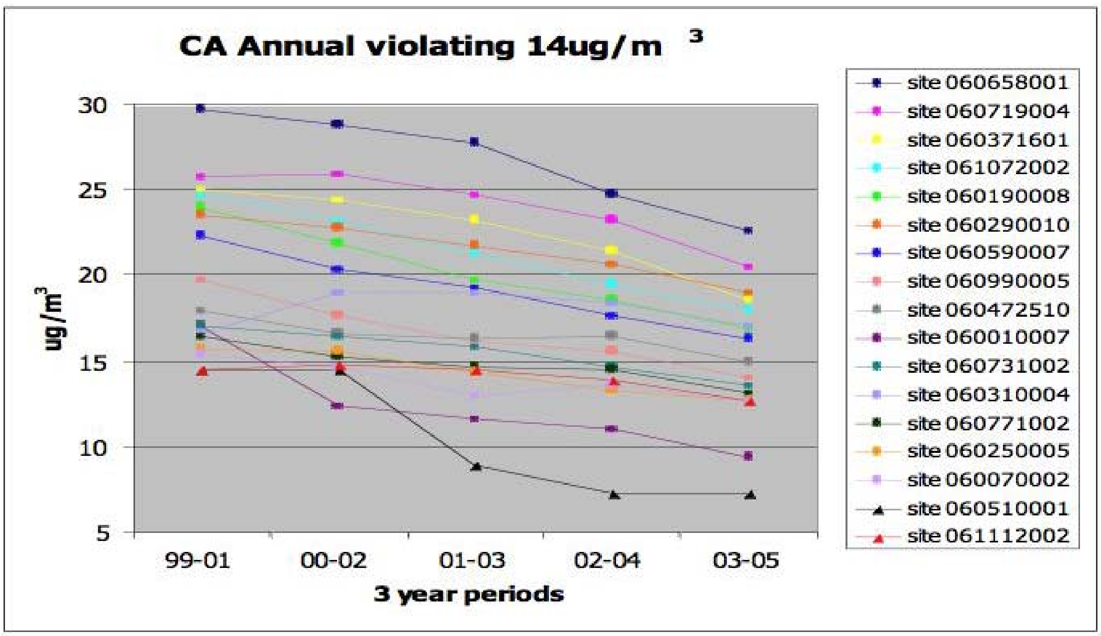

Figure 4-18. Trend in Annual Design Values Among Monitors Currently Violating either 1997 Annual Standard or More Stringent Alternative Annual Standard

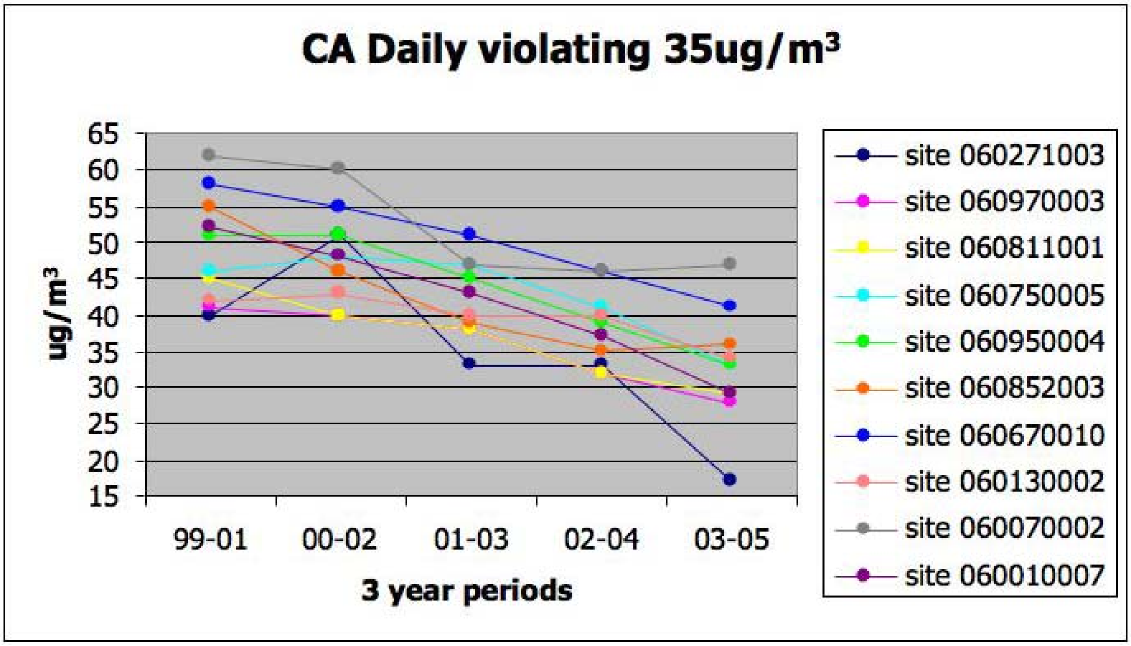

Figure 4-19. Trend in Daily Design Values Among Monitors Currently Violating Revised Daily Standard

4.3.5 Conclusions

As described above, California exhibits a number of unique attributes that made simulating attainment with the revised and more stringent alternative standards especially challenging. California-specific emission inventory and air quality modeling uncertainties made the emission controls analysis more difficult than it was for other projected non-attainment areas. However, the implementation of an ambitious emission control strategy that focuses on an array of emission sources is likely to achieve a substantial improvement in future air quality. An examination of the design value data over the past six years indicates that the overall trend in design values is trending downward—suggesting that many areas may be able to attain the revised daily standard by 2020.

4.4 References

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Chapter 5: Benefit Analysis and Results

This chapter reports EPA's analysis of a subset of the public health and welfare impacts and associated monetized benefits to society of illustrative implementation strategies to attain alternative NAAQS for fine particulate matter ($PM_{2.5}$) incremental to attainment of the current NAAQS. Accordingly, the analysis presented here attempts to answer two questions: (1) what are the estimated nationwide physical health and welfare effects of changes in ambient air quality resulting from reductions in precursors to particulate matter (PM) including directly emitted carbonaceous particles, NO_x, SO_2, and NH_3 emissions? and (2) what is the estimated monetary value of the changes in these effects attributable to the revised standards and a more stringent alternative annual standard? This benefit analysis constitutes one part of EPA's thorough examination of the relative merits of this regulation.

The analysis presented in this chapter uses a methodology generally consistent with benefits analyses performed for the recent analysis of the Clean Air Interstate Rule (EPA, 2005). The methodology diverges in four areas:

1. Rather than presenting both a "primary" estimate of the benefits and a separate characterization of the uncertainty associated with that estimate, the current analysis follows the recommendation of NRC's 2002 report "Estimating the Public Health Benefits of Proposed Air Pollution Regulations" to begin moving the assessment of uncertainties from its ancillary analyses into its main benefits presentation through the conduct of probabilistic analyses.
2. Since the publication of CAIR, we have completed a full-scale expert elicitation designed to more fully characterize the state of our understanding of the concentration-response function for PM-related premature mortality. The elicitation results form a major component of the current effort to use probabilistic assessment techniques to integrate uncertainty into the main benefits analysis.
3. We have updated our projections of mortality incidence rates to be consistent with the U.S. Census population projections that form the basis of our future population estimates. Compared to the methodology used in the CAIR analysis, this change will result in a reduction in mortality impacts in future years, as overall mortality rates are projected to decline for most age groups.
4. We are providing additional characterizations of the impacts of assuming alternative thresholds in the concentration-response functions derived from the epidemiology literature. Unless specifically noted, our base premature mortality benefits estimates are based on an assumed cutpoint in the long-term mortality concentration-response function at 10 $\mu g/m^3$, and an assumed cutpoint in the short-term morbidity concentration-response functions at 10 $\mu g/m^3$. We also show the results of a sensitivity analysis for premature mortality, with 4 alternative cutpoints, at 3 $\mu g/m^3$, 7.5 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$.

The benefits analysis takes as inputs the results of the CMAQ air quality modeling described in Chapter 4. Reductions in certain $PM_{2.5}$ precursors such as NO_x and VOC may also lead to changes in ambient concentrations of ozone. These changes in ozone will also have health and welfare effects. However, for this RIA, because the majority of the illustrative strategies evaluated do not affect NO_x and VOC emissions (with the exception of nonattainment areas in parts of the western U.S., where we do not currently have adequate modeling data for ozone), we focus on estimating the health and welfare effects associated with changes in ambient $PM_{2.5}$. This adds some uncertainty to the overall results, but given the expected small magnitude of the impacts (due to the small amount of NOx controls applied), this uncertainty will likely be small relative to other modeling uncertainties.

A wide range of human health and welfare effects are linked to ambient concentrations of $PM_{2.5}$. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis [CB]). Welfare effects potentially linked to PM and its precursors include materials damage and visibility impacts, as well as the impacts associated with deposition of nitrates and sulfates. Although methods exist for quantifying the benefits associated with many of these human health and welfare categories, not all can be evaluated at this time because of limitations in methods and/or data. Table 5-1 summarizes the annual incremental monetized health and welfare benefits associated with the illustrative implementation strategies for the revised 15/35 and alternative more stringent14/35 standards in 2020, when the standards are expected to be fully attained. Table 5-2 lists the full complement of human health and welfare effects associated with PM (and its precursors) and identifies those effects that are quantified for the primary estimate and those that remain unquantified because of current limitations in methods or available data. Note that these two tables summarize the health and welfare benefits of fully attaining the revised and alternative more stringent PM2.5 standards.

The general benefits analysis framework is as follows:

1. Given baseline and post-control emissions inventories for the emission species expected to affect ambient air quality, we use sophisticated photochemical air quality models to estimate baseline and post-control ambient concentrations of PM, visibility, and deposition of nitrates and sulfates for each year.

2. The estimated changes in ambient concentrations are then combined with monitoring data to estimate population-level potential exposures to changes in ambient concentrations for use in estimating health effects. Modeled changes in ambient data are also used to estimate changes in visibility and changes in other air quality statistics that are necessary to estimate welfare effects.

Table 5-1: Estimated Annual Monetized Benefits in 2020 of Illustrative Implementation Strategies for the Selected and Alternative $PM_{2.5}$ NAAQS, Incremental to Attainment of the Current Standards

Note: Unquantified benefits are not included in these estimates, thus total benefits are likely to be larger than indicated in this table.

	Total Full Attainment Benefits[a, b] (billions 1999$)			
	15/35 (µg/m3)		*14/35 (µg/m3)*	
Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature[c]				
Using a 3% discount rate	$17 *Confidence Intervals* ($4.1 – $36)		$30 *Confidence Intervals* ($7.3 - $63))	
Using a 7% discount rate	$15 *Confidence Intervals* ($3.5 – $31)		$26 *Confidence Intervals* ($6.4 - $54)	
Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature				
Using a 3% discount rate	$9 to $76 Confidence Intervals		$17 to $140 Confidence Intervals	
	Lower Bound Expert Result	Upper Bound Expert Result	Lower Bound Expert Result	Upper Bound Expert Result
	($0.8 - $42)	($19-$150)	($1.7 - $77)	($36 - $280)
Using a 7% discount rate	$8 to $64 Confidence Intervals		$15 to $120 Confidence Intervals	
	Lower Bound Expert Result	Upper Bound Expert Result	Lower Bound Expert Result	Upper Bound Expert Result
	($0.8 - $36)	($16 - $130)	($1.6 - $66)	($31 - $240)

[a] Results reflect the use of two different discount rates: 3% and 7%, as recommended in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b) and OMB Circular A-4 (OMB, 2003). Results are rounded to two significant digits for ease of presentation and computation.

[b] Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of benefits estimates associated with each of the twelve expert responses can be found in tables 5-13 through 5-16.

[c] Based on Pope et al 2002, used as primary estimate in recent RIAs.

3. Changes in population exposure to ambient air pollution are then input to impact functions[1] to generate changes in the incidence of health effects, or changes in other exposure metrics are input to dose-response functions to generate changes in welfare effects. Because these estimates contain uncertainty, we characterize the benefits estimates probabilistically when appropriate information is available.

4. The resulting effects changes are then assigned monetary values, taking into account adjustments to values for growth in real income out to the year of analysis (values for health and welfare effects are in general positively related to real income levels).

5. Finally, values for individual health and welfare effects are summed to obtain an estimate of the total monetary value of the benefits resulting from the changes in emissions.

The benefits discussed in this chapter represent the estimates based upon illustrative attainment strategies for the final $PM_{2.5}$ standards (and an alternative set of more stringent standards). As explained in earlier chapters, we designed illustrative sets of controls in and around areas that need additional emission reductions to reach the new standards in 2020. These strategies are evaluated after application of existing federal (such as CAIR), state, and local programs. As noted in earlier chapters, benefits (and costs) for the final $PM_{2.5}$ standards are evaluated incrementally relative to an illustrative scenario of full attainment with the current $PM_{2.5}$ standards (15 $\mu g/m^3$ annual mean and 65 $\mu g/m^3$ daily 98th percentile). Based on the nature of the air quality problems in different parts of the U.S. (see Chapter 2), we have divided the nation into three regions, the Eastern U.S., California, and the Western U.S. excluding California. Benefits will be presented separately for each region, as well as for the nation as a whole.

[1] The term "impact function" as used here refers to the combination of a) an effect estimate obtained from the epidemiological literature, b) the baseline incidence estimate for the health effect of interest in the modeled population, c) the size of that modeled population, and d) the change in the ambient air pollution metric of interest. These elements are combined in the impact function to generate estimates of changes in incidence of the health effect. The impact function is distinct from the C-R function, which strictly refers to the estimated equation from the epidemiological study relating incidence of the health effect and ambient pollution. We refer to the specific value of the relative risk or estimated coefficients in the epidemiological study as the "effect estimate." In referencing the functions used to generate changes in incidence of health effects for this RIA, we use the term "impact function" rather than C-R function because "impact function" includes all key input parameters used in the incidence calculation.

Table 5-2: Human Health and Welfare Effects of Pollutants Controlled to Simulate Attainment with $PM_{2.5}$ Standards[a]

Pollutant/Effect	*Quantified and Monetized Effects*	*Unquantified Effects*
PM/Health[b]	Premature mortality based on cohort study estimates[c] Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[d]
PM/Welfare	Visibility in Southeastern, Southwestern, and California Class I areas	Visibility in residential and non-Class I areas UVb exposure (+/-)[d] Global climate impacts (+/-)[d]
Nitrogen and Sulfate Deposition/ Welfare		Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
SO_2/Health		Hospital admissions for respiratory and cardiac diseases Respiratory symptoms in asthmatics
NO_x/Health		Lung irritation Lowered resistance to respiratory infection Hospital admissions for respiratory and cardiac diseases

[a] Reductions in certain $PM_{2.5}$ precursors such as NO_x and VOC may also lead to changes in ambient concentrations of ozone. These changes in ozone will also have health and welfare effects. However, for this RIA, because the majority of the illustrative strategies evaluated do not affect NO_x and VOC emissions, we focus on estimating the health and welfare effects associated with changes in ambient $PM_{2.5}$. For a full listing of health and welfare effects associated with ozone exposures, see the Ozone Criteria Document (U.S. EPA, 2006), and Chapter 4 of the RIA for the Clean Air Interstate Rule (U.S. EPA, 2005).

[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[c] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli et al, 2001 for a discussion of this issue). While some of the effects of short term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short term PM exposure not captured in the cohort estimates included in the primary analysis.

[d] May result in benefits or disbenefits.

As noted in previous chapters, we were not able to completely model attainment in several locations due to limitations in the data and modeling. In these areas, we extrapolate from existing information to develop estimates of the air quality changes that might result from fully attaining the alternative standards in residual nonattainment areas. To reflect different levels of confidence in the underlying data and models, benefits will be presented as two components, representing the fully modeled partial attainment component (referred to from this point forward at "modeled partial attainment", and the extrapolated residual attainment component (referred to from this point forward as "residual attainment").

EPA is currently developing a comprehensive integrated strategy for characterizing the impact of uncertainty in key elements of the benefits modeling process (e.g., emissions modeling, air quality modeling, health effects incidence estimation, valuation) on the benefits estimates. A recently completed component of this effort is an expert elicitation designed to characterize more fully our understanding of PM-related mortality resulting from both short-term and long-term exposure. [2] We include the results of the formal expert elicitation among the sources of information used in developing health impact functions for this benefits analysis. The results of the 'pilot' for this expert elicitation were presented in RIAs for both the Nonroad Diesel and Clean Air Interstate Rules (U.S. EPA, 2004a, 2005). The results of these elicitation projects, including peer review comments, are available on EPA's Web site, at http://www.epa.gov/ttn/ecas/. In addition, similar to our approach in the Nonroad Diesel and CAIR RIAs, we present a distribution of benefits estimates based on a more limited set of uncertainties, those characterized by the sampling error and variability in the underlying health and economic valuation studies used in the benefits modeling framework. We note that incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model, as discussed below). Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses that are summarized later in this chapter.

The benefits estimates generated for the final $PM_{2.5}$ NAAQS rule are subject to a number of assumptions and uncertainties, which are discussed throughout this document. For example, key assumptions underlying the data-derived concentration-response functions for the mortality category include the following:

1. Inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been specifically identified, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality are explored using the results of the expert elicitation.
2. All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because the composition of PM produced via transported precursors emitted from EGUs may

[2] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyub, 2002).

differ significantly from direct PM released from automotive engines and other industrial sources[3]. In accordance with advice from the CASAC, EPA has determined that no clear scientific grounds exist for supporting differential effects estimates by particle type, based on information in the most recent Criteria Document. We provide a decomposition of benefits by PM component species to provide additional insights into the makeup of the benefits associated with reductions in overall $PM_{2.5}$ mass (See Tables 5-32 and 5-33).

3. The C-R function for fine particles is approximately linear within the range of ambient concentrations under consideration (above the assumed threshold of 10 $\mu g/m^3$). Thus, we assume that the CR functions are applicable to estimates of health benefits associated with reducing fine particles in areas with varied concentrations of PM, including both regions that are in attainment with $PM_{2.5}$ standards and those that do not meet the standards. However, we examine the impact of this assumption by looking at alternative thresholds in a sensitivity analysis.

The first and third of these assumptions are directly addressed in the expert elicitation, providing probabilistic characterizations of the likelihood of causality and the shape of the concentration-response function. The second of these is not directly addressed by the expert elicitation, and remains a significant source of uncertainty in the state of knowledge about the health benefits associated with various emission reduction strategies.

In addition, a key assumption underlying the entire analysis is that the forecasts for future emissions and associated air quality modeling are valid. Because we are projecting emissions and air quality out to 2020, there are inherent uncertainties in all of the factors that underlie the future state of emissions and air quality levels. While it is important to keep in mind the difficulties, assumptions, and inherent uncertainties in the overall enterprise, these analyses are based on peer-reviewed scientific literature and up-to-date assessment tools, and we believe the results are highly useful in assessing the impacts of this rule.

In addition to the quantified and monetized benefits summarized above, a number of additional categories associated with $PM_{2.5}$ and its precursor emissions are not currently amenable to quantification or valuation. These include reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of acidification in lakes and streams and eutrophication in coastal areas. Additionally, we have not quantified a number of known or suspected health effects linked with PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). As a result, monetized benefits generated for the primary estimate may underestimate the total benefits attributable to attainment of alternative standards.

Benefits estimates for attaining alternative standards were generated using BenMAP, a computer program developed by EPA that integrates a number of the modeling elements used in previous RIAs (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into

[3] Even within certain components such as directly emitted PM, there may be significant differences in toxicity of component particles such as trace metals and specific carbonaceous species.

health effects incidence estimates and monetized benefits estimates. BenMAP provides estimates of both the mean impacts and the distribution of impacts (information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/benmodels.html).

In general, this chapter is organized around the benefits framework outlined above. In Section 5.1, we provide an overview of the data and methods that were used to quantify and value health and welfare endpoints and discuss how we incorporate uncertainty into our analysis. In Section 5.2, we report the results of the analysis for human health and welfare effects (the overall benefits estimated for the final PM NAAQS are summarized in Table 5-1). Details on the emissions inventory and air modeling are presented in Chapter 3.

5.1 Benefit Analysis—Data and Methods

Given changes in environmental quality (ambient air quality, visibility, nitrogen, and sulfate deposition), the next step is to determine the economic value of those changes. We follow a "damage-function" approach in calculating total benefits of the modeled changes in environmental quality. This approach estimates changes in individual health and welfare endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the individual values. Total benefits are calculated simply as the sum of the values for all nonoverlapping health and welfare endpoints. This imposes no overall preference structure and does not account for potential income or substitution effects (i.e., adding a new endpoint will not reduce the value of changes in other endpoints). The "damage-function" approach is the standard approach for most benefit-cost analyses of environmental quality programs and has been used in several recent published analyses (Banzhaf, Burtraw, and Palmer, 2002; Hubbell et al., 2004; Levy et al., 2001; Levy et al., 1999; Ostro and Chestnut, 1998).

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, as is the case for changes in visibility. In other cases, such as for changes in PM, a health and welfare impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values. Inherent in each of these steps is a high degree of uncertainty, due both to the randomness of environmental factors such as meteorology, and the difficulty in measuring and predicting model inputs such as pollutant emissions. As such, where possible, we incorporate probabilistic representations of model inputs and outputs. However, in many cases, probabilistic representations are not available. In these cases, we use the best available science and models, and characterize uncertainty using sensitivity analyses.

For the purposes of this RIA, the health impacts analysis is limited to those health effects that are directly linked to ambient levels of air pollution and specifically to those linked to $PM_{2.5}$. There may be other, indirect health impacts associated with implementing emissions controls, such as occupational health impacts for coal miners. These impacts may be positive or negative, but in general, for this set of control options, they are expected to be small relative to the direct air pollution-related impacts.

The welfare impacts analysis is limited to changes in the environment that have a direct impact on human welfare. For this analysis, we are limited by the available data to examine impacts of changes in visibility. We also provide qualitative discussions of the impact of changes in other environmental and ecological effects, for example, changes in deposition of nitrogen and sulfur to terrestrial and aquatic ecosystems, but we are unable to place an economic value on these changes.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure either the health outcomes or their values for this analysis. Thus, similar to Kunzli et al. (2000) and other recent health impact analyses, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors to improve the accuracy and robustness of benefits estimates.

5.1.1 Valuation Concepts

In valuing health impacts, we note that reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a fairly small amount for a large population. The appropriate economic measure is willingness to pay[4] (WTP) for changes in risk prior to the regulation (Freeman, 2003).[5] Adoption of WTP as the measure of value implies that the value of environmental quality improvements depends on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate. For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as the measure of benefits. These cost of illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of a health effect, because they do not include the value of avoided pain and suffering from the health effect (Harrington and Portney, 1987; Berger et al., 1987).

One distinction in environmental benefits estimation is between use values and nonuse values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman [2003]), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare directly. These effects include changes in product prices, quality, and availability; changes in the quality of outdoor

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[4] For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for $1, it can be observed that at least some people are willing to pay $1 for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions (e.g., nontoxic cleaners or bike helmets). Alternatively, surveys can be used in an attempt to directly elicit WTP for an environmental improvement.

[5] In general, economists tend to view an individual's WTP for an improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual's willingness to accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available and conservative measure of benefits. In some cases, such as the value of fatal risk reductions, we use WTA measures due to the difficulty in obtaining WTP estimates. For cases where the changes in the good are small WTP and WTA are approximately equal.

recreation and outdoor aesthetics; changes in health or life expectancy; and the costs of actions taken to avoid negative effects of environmental quality changes.

Nonuse values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit but might relate to existence values and bequest values. Nonuse values are not traded, directly or indirectly, in markets. For this reason, measuring nonuse values has proven to be significantly more difficult than measuring use values. The air quality changes produced by attainment strategies to attain the $PM_{2.5}$ NAAQS cause changes in both use and nonuse values, but the monetary benefits estimates are almost exclusively for use values.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques cannot be used. There are three main nonmarket valuation methods used to develop values for endpoints considered in this analysis: stated preference (including contingent valuation [CV]), indirect market (e.g., hedonic wage), and avoided cost methods.

The stated preference method values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to an improvement in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of stated preference-based valuation. Well-designed and well-executed stated preference studies are valid for estimating the benefits of air quality regulations.[6] Stated preference valuation studies form the complete or partial basis for valuing a number of health and welfare endpoints, including the value of mortality risk reductions, CB risk reductions, minor illness risk reductions, and visibility improvements.

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the VSL for use in estimating benefits from mortality risk reductions. No market exists where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk (see Section 5.1.5).

Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable lower-bound estimate (under most, although not all, conditions) of true economic

[6] Concerns about the reliability of value estimates from CV studies arose because research has shown that bias can be introduced easily into these studies if they are not carefully conducted. Accurately measuring WTP for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP; 2) whether the good to be valued is understood and accepted by the respondent; 3) whether the elicitation format is designed to minimize strategic responses; 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income; 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods; and 6) the extent to which WTP responses are consistent with established economic principles.

benefits when PM levels are reduced. Avoided costs methods are also used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see Section 5.1.5). In general, avoided cost methods should be used only if there is no information available using other valuation methods (OMB Circular A-4 offers some additional caution on the use of avoided cost methods).

5.1.2 Growth in WTP Reflecting National Income Growth Over Time

Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. There is substantial empirical evidence that the income elasticity[7] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. Thus, as real income increases, the WTP for environmental improvements also increases. Although many analyses assume that the income elasticity of WTP is unit elastic (i.e., a 10% higher real income level implies a 10% higher WTP to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one and thus relatively inelastic. As real income rises, the WTP value also rises but at a slower rate than real income.

The effects of real income changes on WTP estimates can influence benefits estimates in two different ways: through real income growth between the year a WTP study was conducted and the year for which benefits are estimated, and through differences in income between study populations and the affected populations at a particular time. Empirical evidence of the effect of real income on WTP gathered to date is based on studies examining the former. The Environmental Economics Advisory Committee (EEAC) of the Science Advisory Board (SAB) advised EPA to adjust WTP for increases in real income over time but not to adjust WTP to account for cross-sectional income differences "because of the sensitivity of making such distinctions, and because of insufficient evidence available at present" (U.S. EPA-SAB, 2000a). A recent advisory by another committee associated with the SAB, the Advisory Council on Clean Air Compliance Analysis, has provided conflicting advice. While agreeing with "the general principle that the willingness to pay to reduce mortality risks is likely to increase with growth in real income (U.S. EPA-SAB, 2004a, p. 52)" and that "The same increase should be assumed for the WTP for serious nonfatal health effects (U.S. EPA-SAB, 2004a, p. 52)," they note that "given the limitations and uncertainties in the available empirical evidence, the Council does not support the use of the proposed adjustments for aggregate income growth as part of the primary analysis (U.S. EPA-SAB, 2004a, p. 53)." Until these conflicting advisories have been reconciled, EPA will continue to adjust valuation estimates to reflect income growth using the methods described below, while providing sensitivity analyses for alternative income growth adjustment factors.

Based on a review of the available income elasticity literature, we adjusted the valuation of human health benefits upward to account for projected growth in real U.S. income. Faced with a dearth of estimates of income elasticities derived from time-series studies, we applied estimates derived from cross-sectional studies in our analysis. Details of the procedure can be found in

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[7] Income elasticity is a common economic measure equal to the percentage change in WTP for a 1% change in income.

Kleckner and Neumann (1999). An abbreviated description of the procedure we used to account for WTP for real income growth between 1990 and 2020 is presented below.

Reported income elasticities suggest that the severity of a health effect is a primary determinant of the strength of the relationship between changes in real income and WTP. As such, we use different elasticity estimates to adjust the WTP for minor health effects, severe and chronic health effects, and premature mortality. Note that because of the variety of empirical sources used in deriving the income elasticities, there may appear to be inconsistencies in the magnitudes of the income elasticities relative to the severity of the effects (*a priori* one might expect that more severe outcomes would show less income elasticity of WTP). We have not imposed any additional restrictions on the empirical estimates of income elasticity. One explanation for the seeming inconsistency is the difference in timing of conditions. WTP for minor illnesses is often expressed as a short term payment to avoid a single epidsode. WTP for major illnesses and mortality risk reductions are based on longer term measures of payment (such as wages or annual income). Economic theory suggests that relationships become more elastic as the length of time grows, reflecting the ability to adjust spending over a longer time period. Based on this theory, it would be expected that WTP for reducing long term risks would be more elastic than WTP for reducing short term risks. We also expect that the WTP for improved visibility in Class I areas would increase with growth in real income. The relative magnitude of the income elasticity of WTP for visibility compared with those for health effects suggests that visibility is not as much of a necessity as health, thus, WTP is more elastic with respect to income. The elasticity values used to adjust estimates of benefits in 2020 are presented in Table 5-3.

Table 5-3: Elasticity Values Used to Account for Projected Real Income Growth[a]

Benefit Category	*Central Elasticity Estimate*
Minor Health Effect	0.14
Severe and Chronic Health Effects	0.45
Premature Mortality	0.40
Visibility	0.90

[a] Derivation of estimates can be found in Kleckner and Neumann (1999) and Chestnut (1997). COI estimates are assigned an adjustment factor of 1.0.

In addition to elasticity estimates, projections of real gross domestic product (GDP) and populations from 1990 to 2020 are needed to adjust benefits to reflect real per capita income growth. For consistency with the emissions and benefits modeling, we used national population estimates for the years 1990 to 1999 based on U.S. Census Bureau estimates (Hollman, Mulder, and Kallan, 2000). These population estimates are based on application of a cohort-component model applied to 1990 U.S. Census data projections (U.S. Bureau of Census, 2000). For the years between 2000 and 2020, we applied growth rates based on the U.S. Census Bureau projections to the U.S. Census estimate of national population in 2000. We used projections of real GDP provided in Kleckner and Neumann (1999) for the years 1990 to 2010.[8] We used

[8] U.S. Bureau of Economic Analysis, Table 2A (1992$) (available at http://www.bea.doc.gov/bea/dn/0897nip2/tab2a.htm.) and U.S. Bureau of Economic Analysis, Economics and Budget Outlook. Note that projections for 2007 to 2010 are based on average GDP growth rates between 1999 and 2007.

projections of real GDP (in chained 1996 dollars) provided by Standard and Poor's (2000) for the years 2010 to 2020.[9]

Using the method outlined in Kleckner and Neumann (1999) and the population and income data described above, we calculated WTP adjustment factors for each of the elasticity estimates listed in Table 5-4. Benefits for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility) are adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor. Table 5-4 lists the estimated adjustment factors. Note that, for premature mortality, we applied the income adjustment factor to the present discounted value of the stream of avoided mortalities occurring over the lag period. Also note that because of a lack of data on the dependence of COI and income, and a lack of data on projected growth in average wages, no adjustments are made to benefits based on the COI approach or to work loss days and worker productivity. This assumption leads us to underpredict benefits in future years because it is likely that increases in real U.S. income would also result in increased COI (due, for example, to increases in wages paid to medical workers) and increased cost of work loss days and lost worker productivity (reflecting that if worker incomes are higher, the losses resulting from reduced worker production would also be higher).

Table 5-4: Adjustment Factors Used to Account for Projected Real Income Growth[a]

Benefit Category	*2020*
Minor Health Effect	1.066
Severe and Chronic Health Effects	1.229
Premature Mortality	1.201
Visibility	1.517

[a] Based on elasticity values reported in Table 5-3, U.S. Census population projections, and projections of real GDP per capita.

5.1.3 Demographic Projections

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 and Poole, Inc. The Woods and Poole (WP) database contains county-level projections of population by age, sex, and race out to 2025. Projections in each county are determined simultaneously with every other county in the United States to take into account 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 (Hollman, Mulder, and Kallan, 2000). According to WP, linking county-level growth projections together and constraining to a national-level total growth avoids potential errors introduced by forecasting each county independently. County projections are developed in a four-stage process. First, national-level variables such as income, employment,

[9] In previous analyses, we used the Standard and Poor's projections of GDP directly. This led to an apparent discontinuity in the adjustment factors between 2010 and 2011. We refined the method by applying the relative growth rates for GDP derived from the Standard and Poor's projections to the 2010 projected GDP based on the Bureau of Economic Analysis projections.

and populations are forecasted. Second, employment projections are made for 172 economic areas defined by the Bureau of Economic Analysis, using an "export-base" approach, which relies on linking industrial-sector production of nonlocally 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 of age by sex and race for each year through 2020 based on historical rates of mortality, fertility, and migration.

The WP projections of county-level population are based on historical population data from 1969 through 1999 and do not include the 2000 Census results. Given the availability of detailed 2000 Census data, we constructed adjusted county-level population projections for each future year using a two-stage process. First, we constructed ratios of the projected WP populations in a future year to the projected WP population in 2000 for each future year by age, sex, and race. Second, we multiplied the block-level 2000 Census population data by the appropriate age-, sex-, and race-specific WP ratio for the county containing the census block for each future year. This results in a set of future population projections that is consistent with the most recent detailed Census data.

As noted above, values for environmental quality improvements are expected to increase with growth in real per capita income. Accounting for real income growth over time requires projections of both real GDP and total U.S. populations. For consistency with the emissions and benefits modeling, we used national population estimates based on the U.S. Census Bureau projections.

5.1.4 Methods for Describing Uncertainty

The NRC (2002) highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates as well as the need for presenting these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA has initiated the development of a comprehensive methodology for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates

In the current analysis EPA continues to move forward on one of the key recommendations of the NRC – moving the assessment of uncertainties from its ancillary analyses into its main benefits presentation through the conduct of probabilistic analyses. In this final rule, EPA addressed key sources of uncertainty by Monte Carlo propagation of uncertainty in the C-R functions and economic valuation functions through its base estimates as well as by continuing its practice of conducting a series of ancillary sensitivity analyses examining the impact of alternate assumptions on the benefits estimates. It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters. Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards. Issues such as correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements will be addressed in future versions of the uncertainty framework.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, in characterizing the uncertainty related to the estimates of total benefits it is particularly important to attempt to characterize the uncertainties associated with this endpoint. As such the analysis for this rule incorporates the results of our recent expert elicitation to characterize uncertainty in the effect estimates used to estimate premature mortality resulting from exposures to PM into the main analysis. In collaboration with OMB, EPA completed a pilot expert elicitation in 2004, which was used to characterize uncertainty in the PM mortality C R function in the Nonroad Diesel and CAIR RIAs. EPA has recently completed a full-scale expert elicitation that incorporated peer-review comments on the pilot application, and that provides a more robust characterization of the uncertainty in the premature mortality function. This expert elicitation was designed to evaluate uncertainty in the underlying causal relationship, the form of the mortality impact function (e.g., threshold versus linear models) and the fit of a specific model to the data (e.g., confidence bounds for specific percentiles of the mortality effect estimates). Additional issues, such as the ability of long-term cohort studies to capture premature mortality resulting from short-term peak PM exposures, were also addressed in the expert elicitation.

For this final rule, EPA addressed key sources of uncertainty through Monte Carlo propagation of uncertainty in the C-R functions and economic valuation functions and through a series of sensitivity analyses examining the impact of alternate assumptions on the benefits estimates that are generated. It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters. Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards.

Our distributions of total benefits do not completely represent full uncertainty because of the uncertainty in model elements discussed above (see Table 5-5). Uncertainty about specific aspects of the health and welfare estimation models is discussed in greater detail in the following sections. The estimated distributions of total benefits may not completely capture the shape and location of the actual distribution of total benefits.

5.1.4.1 Sources of 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. As outlined both in this and preceding chapters, many inputs were used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain and, depending on its role in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to large impacts on total benefits.

Some key sources of uncertainty in each stage of the benefits analysis are the following:

- gaps in scientific data and inquiry;
- variability in estimated relationships, such as epidemiological effect estimates, introduced through differences in study design and statistical modeling;
- errors in measurement and projection for variables such as population growth rates;
- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and
- biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table 5-5.

More specifically, there are key uncertainties in many aspects of the health impact functions used in our analyses. These are discussed in detail in the following section.

Table 5-5: Primary Sources of Uncertainty in the Benefits Analysis

1. Uncertainties Associated with Impact Functions
   - The value of the PM effect estimate in each impact function.
   - Application of a single impact function to pollutant changes and populations in all locations.
   - Similarity of future-year impact functions to current impact functions.
   - Correct functional form of each impact function.
   - Extrapolation of effect estimates beyond the range of PM concentrations observed in the source epidemiological study.
   - Application of some impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with PM Concentrations
   - Responsiveness of the models to changes in precursor emissions resulting from the control policy.
   - Projections of future levels of precursor emissions, especially organic carbonaceous particle emissions.
   - Model chemistry for the formation of ambient nitrate concentrations.
   - Lack of speciation monitors in some areas requires extrapolation of observed speciation data.
   - CMAQ model performance in the Western U.S., especially California indicates significant underprediction of $PM_{2.5}$.
3. Uncertainties Associated with PM Mortality Risk
   - Differential toxicity of specific component species within the complex mixture of PM has not been determined.
   - The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures.
   - The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.
   - Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated with Possible Lagged Effects
   - The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated with Baseline Incidence Rates
   - Some baseline incidence rates are not location specific (e.g., those taken from studies) and therefore may not accurately represent the actual location-specific rates.
   - Current baseline incidence rates may not approximate well baseline incidence rates in 2020.
   - Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated with Economic Valuation
   - Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them.
   - Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates because of differences in income or other factors.
7. Uncertainties Associated with Aggregation of Monetized Benefits
   - Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

5.1.4.2 Uncertainties Associated with Health Impact Functions based on Reported Effect Estimates from the Epidemiological Literature

Within-Study Variation. Within-study variation refers to the precision with which a given study estimates the relationship between air quality changes and health effects. Health effects studies provide both a “best estimate” of this relationship plus a measure of the statistical uncertainty of the relationship. The size of this uncertainty depends on factors such as the number of subjects studied and the size of the effect being measured. The results of even the most well-designed epidemiological studies are characterized by this type of uncertainty, though well-designed studies typically report narrower uncertainty bounds around the best estimate than do studies of lesser quality. In selecting health endpoints, we generally focus on endpoints where a statistically significant relationship has been observed in at least some studies, although we may pool together results from studies with both statistically significant and insignificant estimates to avoid selection bias.

Across-Study Variation. Across-study variation refers to the fact that different published studies of the same pollutant/health effect relationship typically do not report identical findings; in some instances the differences are substantial. These differences can exist even between equally well designed and executed studies and may result in health effect estimates that vary considerably. Across-study variation can result from a variety of possible causes. Such differences might simply be associated with different measurement techniques. Sources of variation can be introduced by the air quality monitoring technique, measurement averaging times, health endpoint data sources (differences in the way medical records are kept at different institutions or questionnaire wording). One possibility is that estimates of the single true relationship between a given pollutant and a health effect differ across studies because of differences in study design, random chance, or other factors. For example, a hypothetical study conducted in New York and one conducted in Seattle may report different C-R functions for the relationship between PM and mortality, in part because of differences between these two study populations (e.g., demographics, activity patterns). Alternatively, study results may differ because these two studies are in fact estimating different relationships; that is, the same reduction in PM in New York and Seattle may result in different reductions in premature mortality. This may result differences in the relative sensitivity of these two populations to PM pollution and differences in the composition of PM in these two locations, as well as other factors. In either case, where we identified multiple studies that are appropriate for estimating a given health effect, we generated a pooled estimate of results from each of those studies.

Application of C-R Relationship Nationwide. Regardless of the use of impact functions based on effect estimates from a single epidemiological study or multiple studies, each impact function was applied uniformly throughout the United States to generate health benefit estimates. However, to the extent that pollutant/health effect relationships are region specific, applying a location-specific impact function at all locations in the United States may result in overestimates of health effect changes in some locations and underestimates of health effect changes in other locations. It is not possible, however, to know the extent or direction of the overall effect on health benefit estimates introduced by applying a single impact function to the entire United States. This may be a significant uncertainty in the analysis, but the current state of the scientific literature does not allow for a region-specific estimation of health benefits for most health outcomes.[10]

Extrapolation of Impact Functions Across Populations. Epidemiological studies often focus on specific age ranges, either due to data availability limitations (e.g., most hospital admission data come from Medicare records, which are limited to populations 65 and older), or to simplify data collection (e.g., some asthma symptom studies focus on children at summer camps, which usually have a limited age range). We have assumed for the primary analysis that most impact functions should be applied only to those populations with ages that strictly match the populations in the underlying epidemiological studies. However, in many cases, there is no biological reason why the observed health effect would not also occur in other populations within a reasonable range of the studied population. For example, Dockery et al. (1996) examined acute bronchitis in children aged 8 to 12. There is no biological reason to expect a very different response in children aged 6 or 14. By excluding populations outside the range in the studies, we may be underestimating the health impact in the overall population. In response to recommendations from the SAB-HES, where there appears to be a reasonable physiological basis for expanding the age group associated with a specific effect estimate beyond the study population to cover the full age group (e.g., expanding from a study population of 7 to 11 year olds to the full 6- to 18-year child age group), we have done so and used those expanded incidence estimates in the primary analysis.

Uncertainties in Concentration-Response Functions. The following uncertainties exist in almost all concentration-response functions for PM related health effects. For expository purposes, and because of the importance of mortality, we focus the discussion on how these uncertainties affect the PM mortality concentration-response functions.

Causality: Epidemiological studies are not designed to definitively prove causation. For the analysis of the PM NAAQS, we assumed a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the substantial body of published scientific literature (CASAC, 2005). As with all health effects included in our analysis, a weight of evidence process is used to evaluate endpoints before including them in the analysis.

Other Pollutants: PM concentrations are correlated with the concentrations of other criteria pollutants, such as ozone and CO. To the extent that there is correlation, this analysis may be assigning mortality effects to PM exposure that are actually the result of exposure to other pollutants. Recent studies (see Thurston and Ito [2001] and Bell et al. [2004]) have explored whether ozone may have mortality effects independent of PM. EPA is currently evaluating the epidemiological literature on the relationship between ozone and mortality.

Shape of the C-R Function: The shape of the true PM mortality C-R function is uncertain, but this analysis assumes the C-R function has a non-threshold log-linear form throughout the relevant range of exposures. If this is not the correct form of the C-R function, or if certain

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[10] Although we are not able to use region-specific effect estimates, we use region-specific baseline incidence rates where available. This allows us to take into account regional differences in health status, which can have a significant impact on estimated health benefits.

scenarios predict concentrations well above the range of values for which the C-R function was fitted, avoided mortality may be misestimated.

In addition there is ongoing debate as to whether there exists a threshold below which there would be no benefit to further reductions in $PM_{2.5}$. Some researchers have hypothesized the presence of a threshold relationship. The nature of the hypothesized relationship is the possibility that there exists a PM concentration level below which further reductions no longer yield premature mortality reduction benefits. EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies" (U.S. EPA, 2004b, p. 9-44). EPA's Science Advisory Board (SAB) that provides advice on benefits analysis methods[11] has been to model premature mortality associated with PM exposure as a non-threshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations.

Regional Differences: As discussed above, significant variability exists in the results of different PM/mortality studies. This variability may reflect regionally specific C-R functions resulting from regional differences in factors such as the physical and chemical composition of PM. If true regional differences exist, applying the PM-mortality C-R function to regions outside the study location could result in misestimation of effects in these regions.

Relative Toxicity of PM Component Species: In this analysis, all fine particles, regardless of their chemical composition, are assumed to be equally potent in causing premature mortality. This is an important assumption, because there may be significant differences between PM produced via transported precursors, direct PM released from automotive engines, and direct PM from other industrial sources. The analysis also assumes that all components of fine particles have equal toxicity (because the available epidemiological effect estimates are based on total $PM_{2.5}$ mass rather than the mass of individual component species). While it is reasonable to expect that the potency of components may vary across the numerous effect categories associated with particulate matter, EPA's interpretation of scientific information considered to date is that such information does not yet provide a basis for quantification beyond using fine particle mass. However, to provide information that may be useful as additional studies become available, we are providing estimates of the proportions of benefits that are attributable to specific components of $PM_{2.5}$, e.g., ammonium sulfate, ammonium nitrate, elemental carbon, organic carbon, and crustal material (which includes metals). This apportionment does not make any assumptions about the relative toxicity of the different species; rather, it divides total benefits based on the contribution of reductions in individual component species to the overall reduction in $PM_{2.5}$ mass.

[11] The advice from the 2004 SAB-HES (U.S. EPA-SAB, 2004b) is characterized by the following: "For the studies of long-term exposure, the HES notes that Krewski et al. (2000) have conducted the most careful work on this issue. They report that the associations between $PM_{2.5}$ and both all-cause and cardiopulmonary mortality were near linear within the relevant ranges, with no apparent threshold. Graphical analyses of these studies (Dockery et al., 1993, Figure 3, and Krewski et al., 2000, page 162) also suggest a continuum of effects down to lower levels. Therefore, it is reasonable for EPA to assume a no threshold model down to, at least, the low end of the concentrations reported in the studies."

Lag Time Between Change in Exposure and Health Impact: There is a time lag between changes in PM exposures and the total realization of changes in health effects. Within the context of benefits analyses, this term is often referred to as "cessation lag". For the chronic PM/mortality relationship, the length of the cessation lag is unknown. The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. There is no specific scientific evidence of the existence or structure of a health effects cessation lag for reductions in exposures to fine PM. Information about latency (the amount of time between exposure and onset of a health effect) may inform our understanding of cessation lags.

Scientific literature on adverse health effects similar to those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggests that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. The smoking-related literature also implies that lags of up to a few years or longer are plausible, although it is worth noting here that in the case of ambient air pollution we are predicting the effects of reduced exposure rather than complete cessation. The SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate. Diseases with longer progressions should be characterized by long-term lag structures, while impacts occurring in populations with existing disease may be characterized by short-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the cohort studies used. While we may be more certain about the appropriate length of cessation lag for lung cancer deaths, it is not clear what the appropriate lag structure should be for different types of cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including the use of disease-specific lag models, and the construction of a segmented lag distribution to combine differential lags across causes of death. The SAB-HES recommended that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30% of mortality reductions occurring in the first year, 50% occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20% occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004). The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. For future analyses, the specific distribution of deaths over time will need to be determined through research on causes of death and progression of diseases associated with air pollution. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths.

Cumulative Effects: We attribute the PM-mortality relationship in the underlying epidemiological studies to cumulative exposure to PM. However, the relative roles of PM exposure duration and PM exposure level in inducing premature mortality are still uncertain at this time.

5.1.5 Health Benefits Assessment Methods

The largest monetized benefits of reducing ambient concentrations of PM are attributable to reductions in health risks associated with air pollution. EPA's Criteria Documents for ozone and PM list numerous health effects known to be linked to ambient concentrations of these pollutants (EPA, 2004; 2006). As discussed above, quantification of health impacts requires several inputs, including epidemiological effect estimates (concentration-response functions), baseline incidence and prevalence rates, potentially affected populations, and estimates of changes in ambient concentrations of air pollution. Previous sections have described the population and air quality inputs. This section describes the effect estimates and baseline incidence and prevalence inputs and the methods used to quantify and monetize changes in the expected number of incidences of various health effects. These include premature mortality, nonfatal heart attacks, chronic bronchitis, acute bronchitis, hospital admissions, emergency room visits for asthma, upper and lower respiratory symptoms, asthma exacerbations, minor restricted activity days and days of work lost.

Some health effects are excluded from this analysis for three reasons: the possibility of double-counting, uncertainties in applying effect relationships based on clinical studies to the affected population, or a lack of an established relationship between the health effect and pollutant in the published epidemiological literature. Unquantifed effects are listed in Table 5-2. An improvement in ambient PM2.5 air quality may reduce the number of incidences within each unquantified effect category that the U.S. population would experience. Although these health effects are believed to be PM induced, effect estimates are not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects lends a downward bias to the monetized benefits presented in this analysis.

5.1.5.1 Selection of Health Endpoints

We base our selection of health endpoints on consistency with EPA Criteria Documents and Staff Papers, with input and advice from the EPA Science Advisory Board Health Effects Subcommittee, a scientific review panel specifically established to provide advice on the use of the scientific literature in developing benefits analyses for air pollution regulations (http://www.epa.gov/sab/). In general, we follow a weight of evidence approach, based on the biological plausibility of effects, availability of concentration-response functions from well-conducted peer-reviewed epidemiological studies, cohesiveness of results across studies, and a focus on endpoints reflecting public health impacts (like hospital admissions) rather than physiological responses (such as changes in clinical measures like Forced Expiratory Volume (FEV1)).

5.1.5.2 Sources of Information for Effect Estimates

There are several types of data that can support the determination of types and magnitude of health effects associated with air pollution exposures. These sources of data include toxicological studies (including animal and cellular studies), human clinical trials, and observational epidemiology studies. All of these data sources provide important contributions to the weight of evidence surrounding a particular health impact, however, only epidemiology studies provide direct concentration-response relationships which can be used to evaluate population-level impacts of reductions in ambient pollution levels.

However, standard environmental epidemiology studies provide only a limited representation of the uncertainty associated with a specific C-R function, measuring only the statistical error in the estimates, and usually relating more to the power of the underlying study (driven largely by population size and the frequency of the outcome measure). There are many other sources of uncertainty in the relationships between ambient pollution and population level health outcomes, including many sources of model uncertainty, such as model specification, potential confounding between factors that are both correlated with the health outcome and each other, and many other factors. As such, in recent years, EPA has begun investigating how expert elicitation methods can be used to integrate across various sources of data in developing C-R functions for regulatory benefits analyses.

Expert elicitation is useful in integrating the many sources of information about uncertainty in the C-R function, because it allows experts to synthesize these data sources using their own mental models, and provide a probabilistic representation of their synthesis of the data in the form of a probability distribution of the C-R function. Figure 5-1 shows how expert elicitation builds on both the direct empirical data on C-R relationships and other less direct evidence to develop probabilistic distributions of C-R functions. EPA has used expert elicitation to inform the regulatory process in the past (see for example the previous staff paper for the lead NAAQS, U.S. EPA, 1990). In the current analysis, we have only used expert elicitation to characterize the C-R function for the relationship between fine PM and premature mortality. However, similar methods could be used to characterize C-R functions for other health outcomes.

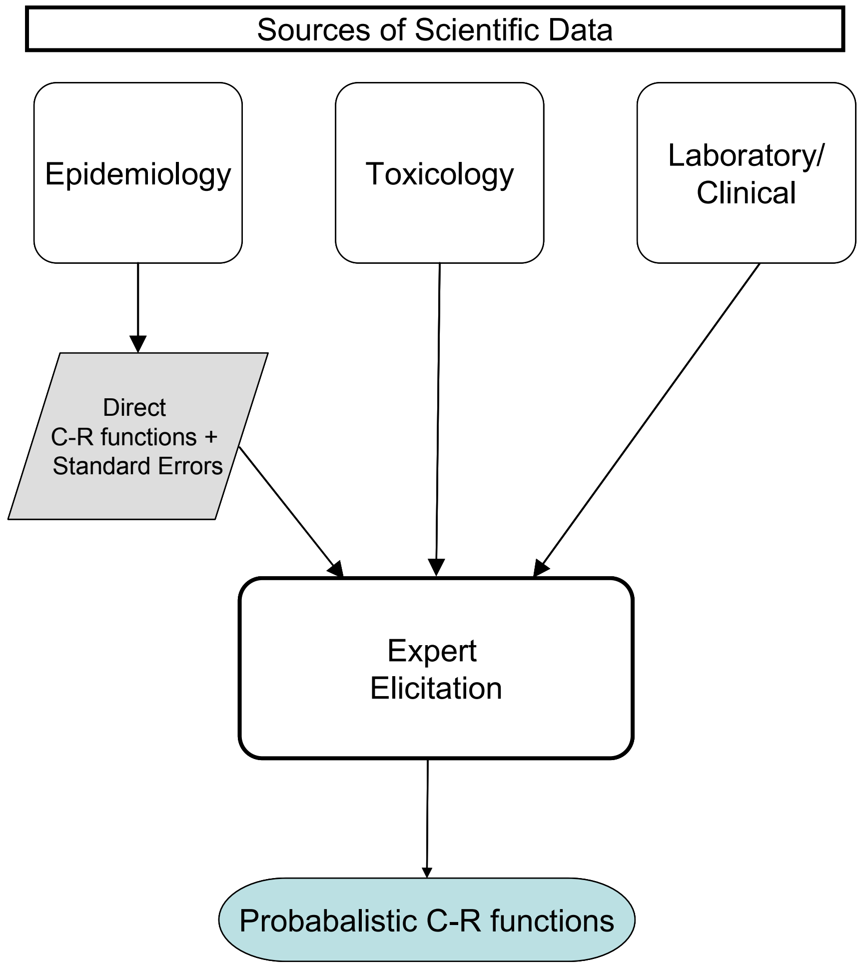

Figure 5-1. Sources and Integration of Scientific Data in Informing Development of Health Impact Functions

5.1.5.3 Information Used in Quantifying C-R Functions

For the data-derived estimates, we relied on the published scientific literature to ascertain the relationship between PM and adverse human health effects. We evaluated epidemiological studies using the selection criteria summarized in Table 5-6. These criteria include consideration of whether the study was peer-reviewed, the match between the pollutant studied and the pollutant of interest, the study design and location, and characteristics of the study population, among other considerations. The selection of C-R functions for the benefits analysis is guided by the goal of achieving a balance between comprehensiveness and scientific defensibility.

In general, the use of results from more than a single study can provide a more robust estimate of the relationship between a pollutant and a given health effect. However, there are often differences between studies examining the same endpoint, making it difficult to pool the results in a consistent manner. For example, studies may examine different pollutants or different age groups. For this reason, we consider very carefully the set of studies available examining each endpoint and select a consistent subset that provides a good balance of population coverage and match with the pollutant of interest. In many cases, either because of a lack of multiple studies, consistency problems, or clear superiority in the quality or comprehensiveness of one study over others, a single published study is selected as the basis of the effect estimate.

When several effect estimates for a pollutant and a given health endpoint have been selected, they are quantitatively combined or pooled to derive a more robust estimate of the relationship. The BenMAP Technical Appendices provides details of the procedures used to combine multiple impact functions (Abt Associates, 2005). In general, we used fixed or random effects models to pool estimates from different studies of the same endpoint. Fixed effects pooling simply weights each study's estimate by the inverse variance, giving more weight to studies with greater statistical power (lower variance). Random effects pooling accounts for both within-study variance and between-study variability, due, for example, to differences in population susceptibility. We used the fixed effects model as our null hypothesis and then determined whether the data suggest that we should reject this null hypothesis, in which case we would use the random effects model.[12] Pooled impact functions are used to estimate hospital admissions and asthma exacerbations. For more details on methods used to pool incidence estimates, see the BenMAP Technical Appendices (Abt Associates, 2005), which are available with the BenMAP software at http://www.epa.gov/ttn/ecas/benmodels.html.

Effect estimates selected for a given health endpoint were applied consistently across all locations nationwide. This applies to both impact functions defined by a single effect estimate and those defined by a pooling of multiple effect estimates. Although the effect estimate may, in fact, vary from one location to another (e.g., because of differences in population susceptibilities or differences in the composition of PM), location-specific effect estimates are generally not available.

The specific studies from which effect estimates for the primary analysis are drawn are included in Table 5-7. In all cases where effect estimates are drawn directly from epidemiological studies, standard errors are used as a partial representation of the uncertainty in the size of the effect estimate. Below we provide the basis for selecting these studies.

[12] In this analysis, the fixed effects model assumes that there is only one pollutant coefficient for the entire modeled area. The random effects model assumes that studies conducted in different locations are estimating different parameters; therefore, there may be a number of different underlying pollutant coefficients.

Table 5-6: Summary of Considerations Used in Selecting C-R Functions

Consideration	*Comments*
Peer-Reviewed Research	Peer-reviewed research is preferred to research that has not undergone the peer-review process.
Study Type	Among studies that consider chronic exposure (e.g., over a year or longer), prospective cohort studies are preferred over ecological studies because they control for important individual-level confounding variables that cannot be controlled for in ecological studies.
Study Period	Studies examining a relatively longer period of time (and therefore having more data) are preferred, because they have greater statistical power to detect effects. More recent studies are also preferred because of possible changes in pollution mixes, medical care, and lifestyle over time. However, when there are only a few studies available, studies from all years will be included.
Population Attributes	The most technically appropriate measures of benefits would be based on impact functions that cover the entire sensitive population but allow for heterogeneity across age or other relevant demographic factors. In the absence of effect estimates specific to age, sex, preexisting condition status, or other relevant factors, it may be appropriate to select effect estimates that cover the broadest population to match with the desired outcome of the analysis, which is total national-level health impacts. When available, multi-city studies are preferred to single city studies because they provide a more generalizable representation of the C-R function.
Study Size	Studies examining a relatively large sample are preferred because they generally have more power to detect small magnitude effects. A large sample can be obtained in several ways, either through a large population or through repeated observations on a smaller population (e.g., through a symptom diary recorded for a panel of asthmatic children).
Study Location	U.S. studies are more desirable than non-U.S. studies because of potential differences in pollution characteristics, exposure patterns, medical care system, population behavior, and lifestyle.
Pollutants Included in Model	When modeling the effects of ozone and PM (or other pollutant combinations) jointly, it is important to use properly specified impact functions that include both pollutants. Using single-pollutant models in cases where both pollutants are expected to affect a health outcome can lead to double-counting when pollutants are correlated.
Measure of PM	For this analysis, impact functions based on $PM_{2.5}$ are preferred to PM_{10} because of the focus on reducing emissions of $PM_{2.5}$ precursors, and because air quality modeling was conducted for this size fraction of PM. Where $PM_{2.5}$ functions are not available, PM_{10} functions are used as surrogates, recognizing that there will be potential downward (upward) biases if the fine fraction of PM_{10} is more (less) toxic than the coarse fraction.
Economically Valuable Health Effects	Some health effects, such as forced expiratory volume and other technical measurements of lung function, are difficult to value in monetary terms. These health effects are not quantified in this analysis.
Nonoverlapping Endpoints	Although the benefits associated with each individual health endpoint may be analyzed separately, care must be exercised in selecting health endpoints to include in the overall benefits analysis because of the possibility of double-counting of benefits.

Adult Premature Mortality – Epidemiological Basis. Both long- and short-term exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. The size of the mortality risk estimates from epidemiological 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.

Although a number of uncertainties remain to be addressed by continued research (NRC, 1998), a substantial body of published scientific literature documents the correlation between elevated PM concentrations and increased mortality rates (US EPA, 2004). Time-series methods have been used to relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Cohort methods have been used to examine the potential relationship between community-level PM exposures over multiple years (i.e., long-term exposures) and community-level annual mortality rates. Researchers have found statistically significant associations between PM and premature mortality using both types of studies. In general, the risk estimates based on the cohort studies are larger than those derived from time-series studies. Cohort analyses are thought to better capture the full public health impact of exposure to air pollution over time, because they capture the effects of long-term exposures and possibly some component of short-term exposures (Kunzli et al., 2001; NRC, 2002). This section discusses some of the issues surrounding the estimation of premature mortality. To demonstrate the sensitivity of the benefits estimates to the specific sources of information regarding the impact of PM2.5 exposures on the risk of premature death, we are providing estimates in our results tables based on studies derived from the epidemiological literature and from the recent EPA sponsored expert elicitation. The epidemiological studies from which these estimates are drawn are described below. The expert elicitation project and the derivation of effect estimates from the expert elicitation results are described in the next section.

Over a dozen studies have found significant associations between various measures of long-term exposure to PM and elevated rates of annual mortality, beginning with Lave and Seskin (1977). Most of the published studies found positive (but not always statistically significant) associations with available PM indices such as total suspended particles (TSP). However, exploration of alternative model specifications sometimes raised questions about causal relationships (e.g., Lipfert, Morris, and Wyzga [1989]). These early "ecological cross-sectional" studies (e.g., Lave and Seskin [1977]; Ozkaynak and Thurston [1987]) were criticized for a number of methodological limitations, particularly for inadequate control at the individual level for variables that are potentially important in causing mortality, such as wealth, smoking, and diet. Over the last 10 years, several studies using "prospective cohort" designs have been published that appear to be consistent with the earlier body of literature. These new "prospective cohort" studies reflect a significant improvement over the earlier work because they include individual-level information with respect to health status and residence. The most extensive analyses have been based on data from two prospective cohort groups, often referred to as the Harvard "Six-Cities Study" (Dockery et al., 1993; Laden et al, 2006) and the "American Cancer Society or ACS study" (Pope et al., 1995; Pope et al, 2002; Pope et al, 2004); these studies have found consistent relationships between fine particle indicators and premature mortality across multiple locations in the United States. A third major data set comes from the California-based 7th Day Adventist Study (e.g., Abbey et al., 1999), which reported associations between long-term PM exposure and mortality in men. Results from this cohort, however, have been inconsistent, and the air quality results are not geographically representative of most of the United States, and the lifestyle of the population is not reflective of much of the U.S. population. Analysis is also available for a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000; Lipfert et al, 2003, 2006). The characteristics of this group differ from the cohorts in the Six-Cities, ACS, and 7th Day Adventist studies with respect to income, race, health status, and smoking status. Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators. Because of the selective nature of the population in the veteran's cohort, we have chosen not to include any effect estimates from the Lipfert et al. (2000) study in our benefits assessment.[13]

[13] EPA recognizes that the ACS cohort also is not representative of the demographic mix in the general population. The ACS cohort is almost entirely white and has higher income and education levels relative to the general population. EPA's approach to this problem is to match populations based on the potential for demographic characteristics to modify the effect of air pollution on mortality risk. Thus, for the various ACS-based models, we are careful to apply the effect estimate only to ages matching those in the original studies, because age has a potentially large modifying impact on the effect estimate, especially when younger individuals are excluded from the study population. For the Lipfert analysis, the applied population should be limited to that matching the sample used in the analysis. This sample was all male, veterans, and diagnosed hypertensive. There are also a number of differences between the composition of the sample and the general population, including a higher percentage of African Americans (35%) and a much higher percentage of smokers (81% former smokers, 57% current smokers) than the general population (12% African American, 24% current smokers).

Table 5-7: Endpoints and Studies Used to Calculate Total Monetized Health Benefits

Endpoint	*Pollutant*	*Study*	*Study Population*
Premature Mortality			
Premature mortality —cohort study, all-cause	$PM_{2.5}$ (annual)	Pope et al. (2002) Laden et al. (2006)	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$ (annual)	Expert Elicitation (IEc, 2006)	>24 years
Premature mortality — all-cause	$PM_{2.5}$ (annual)	Woodruff et al. (1997)	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$ (annual)	Abbey et al. (1995)	>26 years
Nonfatal heart attacks	$PM_{2.5}$ (daily)	Peters et al. (2001)	Adults
Hospital Admissions			
Respiratory	$PM_{2.5}$ (daily)	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD) Ito (2003)—ICD 490-496 (COPD)	>64 years
	$PM_{2.5}$ (daily)	Moolgavkar (2000)—ICD 490-496 (COPD)	20–64 years
	$PM_{2.5}$ (daily)	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$ (daily)	Sheppard (2003)—ICD 493 (asthma)	<65 years
Cardiovascular	$PM_{2.5}$ (daily)	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$ (daily)	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	$PM_{2.5}$	Norris et al. (1999)	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)	8–12 years
Upper respiratory symptoms	PM_{10}	Pope et al. (1991)	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001) (cough, wheeze and shortness of breath) Vedal et al. (1998) (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)	18–65 years
MRADs	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the SAB-HES, we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group.

Given their consistent results and broad geographic coverage, and importance in informing the NAAQS development process, the Six-Cities and ACS data have been particularly important in benefits analyses. The credibility of these two studies is further enhanced by the fact that the initial published studies (Pope et al, 1995 and Dockery et al 1993) were subject to extensive reexamination and reanalysis by an independent team of scientific experts commissioned by HEI (Krewski et al., 2000). The final results of the reanalysis were then independently peer reviewed by a Special Panel of the HEI Health Review Committee. The results of these reanalyses confirmed and expanded those of the original investigators. While the HEI reexamination lends credibility to the original studies, it also highlights sensitivities concerning the relative impact of various pollutants, such as SO2, the potential role of education in mediating the association between pollution and mortality, and the influence of spatial correlation modeling.

Further confirmation and extension of the findings of the 1993 Six City Study and the 1995 ACS study were recently completed using more recent air quality and a longer follow-up period for the ACS cohort was recently published (Pope et al, 2002, 2004; Laden et al, 2006). The follow up to the Harvard Six City Study both confirmed the effect size from the first analysis and provided additional confirmation that reductions in $PM_{2.5}$ are likely to result in reductions in the risk of premature death. This additional evidence stems from the observed reductions in $PM_{2.5}$ in each city during the extended follow-up period. Laden et al. (2006) found that mortality rates consistently went down at a rate proportionate to the observed reductions in $PM_{2.5}$.

The extended analyses of the ACS cohort data (Pope et al., 2002, 2004) provides additional refinements to the analysis of PM-related mortality by a) extending the follow-up period for the ACS study subjects to 16 years, which triples the size of the mortality data set; b) substantially increasing exposure data, including additional measurement of cohort exposure to $PM_{2.5}$ following implementation of the $PM_{2.5}$ standard in 1999; c) controlling for a variety of personal risk factors including occupational exposure and diet; and d) using advanced statistical methods to evaluate specific issues that can adversely affect risk estimates including the possibility of spatial autocorrelation of survival times in communities located near each other.

The NRC (2002) also recommended that EPA review the database of cohort studies and consider developing a weighted mean estimate based on selected studies. Because of the differences in the study designs and populations considered in the ACS and Harvard Six-cities studies, we have elected to not pool the results of the studies, instead presenting a range of estimates reflecting the different sources of impact estimates.

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA consulted with the SAB-HES. That panel recommended using long-term prospective cohort studies in estimating mortality risk reduction (U.S. EPA,1999b). This recommendation has been confirmed by a recent report from the National Research Council, which stated that "it is essential to use the cohort studies in benefits analysis to capture all important effects from air pollution exposure" (NRC, 2002, p. 108). More specifically, the SAB recommended emphasis on the ACS study because it includes a much larger sample size and longer exposure interval and covers more locations (e.g., 50 cities compared to the Six-Cities Study) than other studies of its kind. Because of the refinements in the extended follow-up analysis, the SAB-HES recommends using the Pope et al. (2002) study as the basis for the primary mortality estimate for adults and suggests that alternate estimates of mortality generated using other cohort and time-series studies could be included as part of the sensitivity analysis (U.S. EPA-SAB, 2004b).

The SAB-HES also recommended using the specific estimated relative risks from the Pope et al. (2002) study based on the average exposure to $PM_{2.5}$, measured by the average of two $PM_{2.5}$ measurements, over the periods 1979–1983 and 1999–2000. In addition to relative risks for all-cause mortality, the Pope et al. (2002) study provides relative risks for cardiopulmonary, lung cancer, and all-other cause mortality. Because of concerns regarding the statistical reliability of the all-other cause mortality relative risk estimates, we calculated mortality impacts for the primary analysis based on the all-cause relative risk. Based on our most recently available SAB guidance, we provide mortality impacts based on the ACS study as the best estimate for comparing across the current and previous RIAs. This provides historical continuity with past analyses and serves as one point of reference in interpreting the results of the expert elicitation (see discussion below).

In recent RIAs (see for example the CAIR and Nonroad Diesel RIAs), we have included an estimate of mortality impacts based on application of the C-R function derived from the Harvard Six-cities study. In those analyses, the Six-cities estimate was included as a sensitivity analysis in an appendix to the RIA. Following the NAS advice to begin moving sensitivity and uncertainty analyses into the main body of the RIA, we are including a separate estimate based on the Six-cities study to complement the estimate based on the ACS study. This also reflects the weight that was placed on both the ACS and Harvard Six-city studies by experts participating in the $PM_{2.5}$ mortality expert elicitation.

As noted above, since the most recent SAB review, an extended followup of the Harvard Six-cities study has been published (Laden et al., 2006). We use this specific estimate to represent the Six-cities study because it reflects the most up-to-date science and because it was cited by many of the experts in their elicitation responses. We note that because of the recent publication date of the Laden et al (2006) study, it has not undergone the CASAC and SAB-HES review received by the Pope et al (2002) and earlier Six-cities publications (see Dockery et al, 1993). However, it is clear from the expert elicitation that the results published in Laden et al (2006) are potentially influential, and in fact, the expert elicitation results encompass within their range the estimates from both the Pope et al (2002) and Laden et al (2006) studies. As part of the NAAQS review process, EPA conducted a provisional assessment of "new" science published since the closing date for the PM Criteria Document. The provisional assessment found that "new" studies generally strengthen the evidence that acute and chronic exposures to fine particles are associated with health effects. The provisional assessment found that the results reported in the studies do not dramatically diverge from previous findings, and, taken in context with the findings of the Criteria Document, the new information and findings do not materially change any of the broad scientific conclusions regarding the health effects of PM exposure made in the Criteria Document. The Laden et al (2006) study was included in this provisional assessment and therefore can be considered to be covered under the broad findings of the provisional assessment.

A number of additional analyses have been conducted on the ACS cohort data (Jarrett et al., 2005; Krewski et al., 2005; Pope et al., 2004). These studies have continued to find a strong significant relationship between $PM_{2.5}$ and mortality outcomes. Specifically, much of the recent research has suggested a stronger relationship between cardiovascular mortality and lung cancer mortality with $PM_{2.5}$, and a less significant relationship between respiratory-related mortality and $PM_{2.5}$.

EPA's is committed to seeking the advice of its Science Advisory Board to review how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies, and if so, the appropriateness of using Laden et al 2006, the most recently published update, as the estimate for the Six Cities based model.

Adult Premature Mortality – Expert Elicitation Study

Among the recommendations made by the National Research Council (NRC) in its 2002 review of EPA's method for assessing health benefits of air pollution regulations was a recommendation for EPA to consider the use of formally elicited expert judgments as a means of characterizing uncertainty in inputs to health benefits analyses. As part of its efforts to improve the characterization of uncertainties in its benefits estimates, EPA has conducted a study of the concentration-response (C-R) relationship between changes in $PM_{2.5}$ exposures and mortality using formally elicited expert judgments. The goal of the study was to elicit from a sample of health experts probabilistic distributions describing uncertainty in estimates of the reduction in mortality among the adult U.S. population resulting from reductions in ambient annual average $PM_{2.5}$ levels. These distributions were obtained through a formal interview protocol using methods designed to elicit subjective expert judgments.

In 2003 and 2004, EPA conducted a pilot-scale elicitation study with five experts to explore the effectiveness of expert judgment techniques for characterizing uncertainty and to explore the use of the expert judgment results in the context of economic benefits analysis (Industrial Economics, 2004). EPA previously applied the results of the pilot-scale study as part of its uncertainty analysis in the regulatory analysis accompanying the Clean Air Interstate Rule (CAIR) (U.S. EPA, 2005). EPA has recently completed a full-scale expert elicitation analysis of the PM2.5-mortality relationship that included numerous refinements based on insights from conducting the pilot study and on comments from peer reviewers of the pilot (Industrial Economics, 2006). This analysis applies the results of the full-scale study.

The full-scale study involved personal interviews with twelve health experts who have conducted research on the relationship between PM2.5 exposures and mortality. These experts were selected through a peer-nomination process and included experts in epidemiology, toxicology, and medicine. The elicitation interview consisted of a protocol of carefully structured questions, both qualitative and quantitative, about the nature of the $PM_{2.5}$-mortality relationship.[14] The

[14] In addition to the elicitation interviews, the twelve experts participated in pre- and post-elicitation workshops. The pre-elicitation workshop was designed to prepare the experts by familiarizing them with the protocol, providing them information about probabilistic judgments, and allowing them to discuss key issues and relevant evidence. At this workshop, the experts were also provided with "briefing book" materials, including a CD containing relevant studies and background information pages with data on air quality in the US, population

questions requiring qualitative responses probed experts' beliefs concerning key evidence and critical sources of uncertainty and enabled them to establish a conceptual basis supporting their quantitative judgments. Questions covered topics such as potential biological mechanisms linking $PM_{2.5}$ exposures with mortality; the role of study design in capturing PM/mortality effects; key scientific evidence on the magnitude of the PM/mortality relationship; sources of potential error or bias in epidemiological results; the likelihood of a causal relationship between $PM_{2.5}$ and mortality, and the shape of the C-R function. The main quantitative question in the protocol asked experts to provide the 5th, 25th, 50th, 75th, and 95th percentiles of a probabilistic distribution for the percent change in U.S. annual, adult all-cause mortality resulting from a 1 $\mu g/m^3$ change in annual average $PM_{2.5}$ exposure, assuming a range of baseline PM2.5 levels between 4 and 30 $\mu g/m^3$. This quantitative question was designed to yield results appropriate for application in EPA's quantitative health benefit analyses.

The results of the full-scale study consist of twelve individual distributions for the coefficient or slope of the C-R function relating changes in annual average $PM_{2.5}$ exposures to annual, adult all-cause mortality. The results have not been combined in order to preserve the breadth and diversity of opinion on the expert panel. In applying these results in a benefits analysis context, EPA incorporates information about each expert's judgments concerning the shape of the C-R function (including the potential for a population threshold $PM_{2.5}$ concentration below which there is no effect on mortality), the distribution of the slope of the C-R function, and the likelihood that the $PM_{2.5}$-mortality relationship is or is not causal (unless the expert incorporated this last element directly in his slope distribution - see Industrial Economics, 2006).

Based on the responses of the 12 experts (designated A through L), we constructed a corresponding set of 12 health impact functions for premature mortality. For those experts providing log-linear non-threshold functions, construction of a health impact function was straightforward, and directly matched the construction of health impact functions based on the epidemiology literature.[15] In these cases, the expert's function can be translated into a health impact function of the form:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta PM} - 1\right),$$

Where y_0 is the baseline incidence, equal to the baseline incidence rate time the potentially affected population, β is the effect estimate provided by the expert, and ΔPM is the change in $PM_{2.5}$.

Some experts specified a piecewise log-linear function, in which case we developed health impact functions that incorporate ambient concentration levels. For example, Expert B specified

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demographics, health status, summaries of published effect estimates, and data on other factors potentially useful to experts in developing their judgments (air conditioning use, housing stock, PM composition, educational attainment). The post-elicitation workshop was designed to anonymously share and discuss results of the expert interviews; discuss key areas where expert opinion varied; and clarify any questions that may have arisen during the interviews. Experts were given the opportunity to revise their judgments in response to discussions at this workshop; however, experts were not encouraged to reach a consensus opinion.

[15] Note that in the expert elicitation protocol, we specified the relevant range of exposure as between 4 and 30 $\mu g/m^3$. As such, when applying the expert elicitation based functions, benefits are only estimated for starting concentrations greater than 4 $\mu g/m^3$.

a piecewise function with two segments, representing the concentration-response function for ambient concentrations between 4 and 10 μg/m^3 and between 10 and 30 μg/m^3. In this case, the expert's function can be translated into a health impact function of the form:

$$\Delta y = \begin{cases} y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) if\ Q_0 < 10 \\ y_{02} \cdot \left(e^{\beta_2 \cdot \Delta PM} - 1\right) if\ Q_0 \geq 10 \end{cases},$$

Where Q_0 is the baseline concentration of $PM_{2.5}$, y_{01} is the baseline incidence for populations living in areas with baseline concentrations of $PM_{2.5}$ less than 10 μg/m^3, y_{02} is the baseline incidence for populations living in areas with baseline concentrations of $PM_{2.5}$ greater than or equal to10 μg/m^3, and β_1 and β_2 are the effect estimates corresponding to the segments of the C-R function relating to ambient concentrations between 4 and 10 μg/m^3 and 10 and 30 μg/m^3, respectively.

A third form specified by one expert (Expert K) included both a piecewise log-linear function and a probabilistic threshold. Expert K did not provide a full set of information about the shape of the distribution of the threshold, providing only the probability that a threshold existed between 0 and 5 μg/m^3 (equal to 0.4) and the probability that a threshold existed between 5 and 10 μg/m^3 (equal to 0.1). The probability that a threshold above 10 existed was set to zero, and the probability that there was no threshold was specified as 0.50. We assumed that the probability distribution across the range 0 to 5 was uniform, such that the probability of a threshold between 0 and 1, 1 and 2, etc. was equal. Likewise, we assumed that the probability distribution across the range 5 to 10 was uniform. Expert K also provided a two segment piecewise log-linear function, with the segments defined over the ranges 4 to 16 μg/m^3, and 16 to 30 μg/m^3. Using this information, we translated Expert K's responses into the following three conditional health impact functions:

$$\text{(K1)} \quad \Delta y = \begin{cases} y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) if\ Q_0 < 16 \\ y_{02} \cdot \left(e^{\beta_2 \cdot \Delta PM} - 1\right) if\ Q_0 \geq 16 \end{cases}$$

$$\text{(K2)} \quad \Delta y = \begin{cases} y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.0 if\ 0 \leq Q_0 < 1 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.2\ if\ 1 \leq Q_0 < 2 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.4\ if\ 2 \leq Q_0 < 3 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.6\ if\ 3 \leq Q_0 < 4 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.8 if\ 4 \leq Q_0 < 5 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) if\ 5 \leq Q_0 < 16 \\ y_{02} \cdot \left(e^{\beta_2 \cdot \Delta PM} - 1\right) if\ Q_0 \geq 16 \end{cases}$$

$$
\text{(K3)} \quad \Delta y = \begin{cases} y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.0 \, if \; 0 \le Q_0 < 6 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.2 \; if \; 6 \le Q_0 < 7 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.4 \; if \; 7 \le Q_0 < 8 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.6 \; if \; 8 \le Q_0 < 9 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 0.8 \, if \; 9 \le Q_0 < 10 \\ y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) \times 1.0 \, if \; 10 \le Q_0 < 16 \\ y_{02} \cdot \left(e^{\beta_2 \cdot \Delta PM} - 1\right) if \; Q_0 \ge 16 \end{cases}
$$

Function K1 is associated with a no threshold segmented log-linear specification with a knot at 16 μg/m^3. Function K2 represents the segmented log-linear function with a threshold between 0 and 5 μg/m^3, with the cumulative probability of a threshold at or below the initial concentration Q_0 increasing as Q_0 decreases (this will result in a declining expected value of the impact at lower initial concentrations). Likewise, function K3 represented the segmented log-linear function with a threshold between 5 and 10 μg/m^3. The results of applying the three conditional functions are then combined using Monte Carlo analysis with weights of 0.5, 0.4, and 0.1 assigned to conditional functions K1, K2, and K3, respectively.

In addition to specifying a function form, each expert provided a representation of the distribution (or distributions for those who specified piecewise functions) of the effect size (in terms of the percent change in premature mortality associated with a one microgram change in annual mean $PM_{2.5}$). Six of the experts simply chose a normal distribution, which is completely specified with two parameters, the mean and standard deviation (see Figure 5-2 for example). In one case, the expert specified a triangular distribution, which is represented by a minimum, maximum, and most likely value (see Figure 5-3). In another case, the expert specified a Weibull distribution, which has three parameters representing scale, location, and shape (see Figure 5-4). Four of the experts did not choose a parametric distribution, preferring instead to provide only effect estimates at particular percentiles of their distributions. In these cases, we constructed custom distributions to represent their percentiles. For these custom distributions, we assume a continuous and smooth transition of the distribution between the reported percentiles (see Figure 5-5 for example).

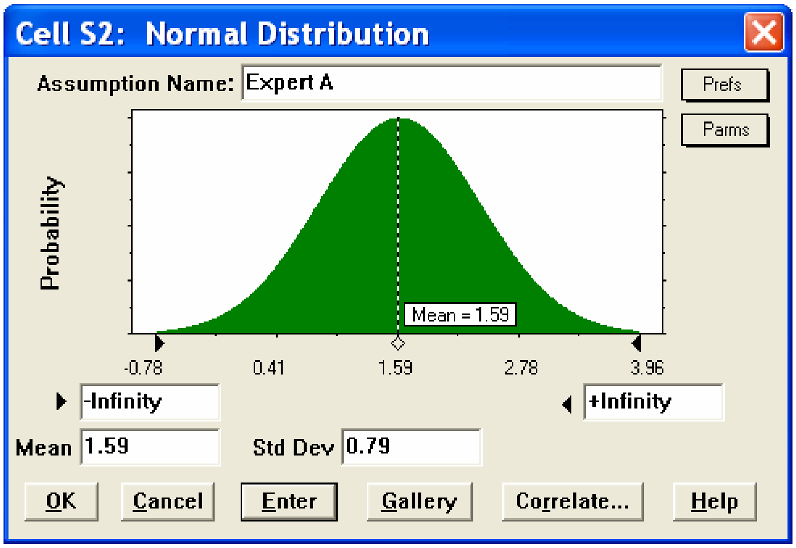

Figure 5-2. Example Normal Distribution for Expert A

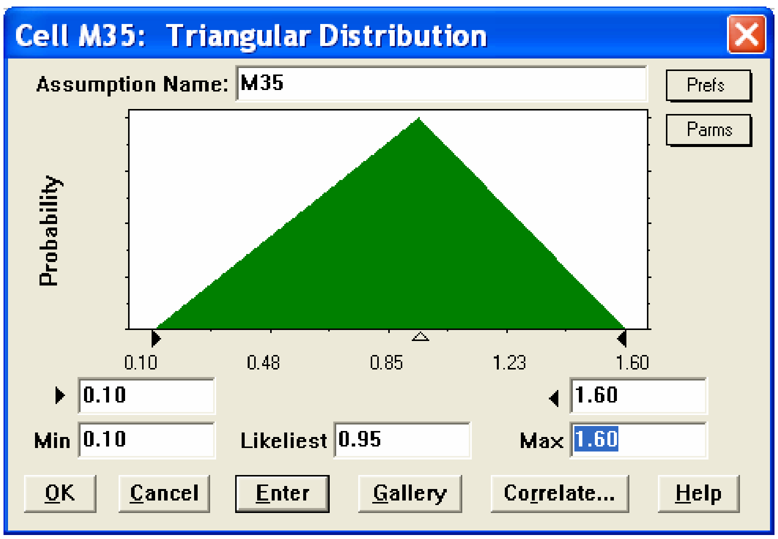

Figure 5-3. Example Triangular Distribution for Expert D

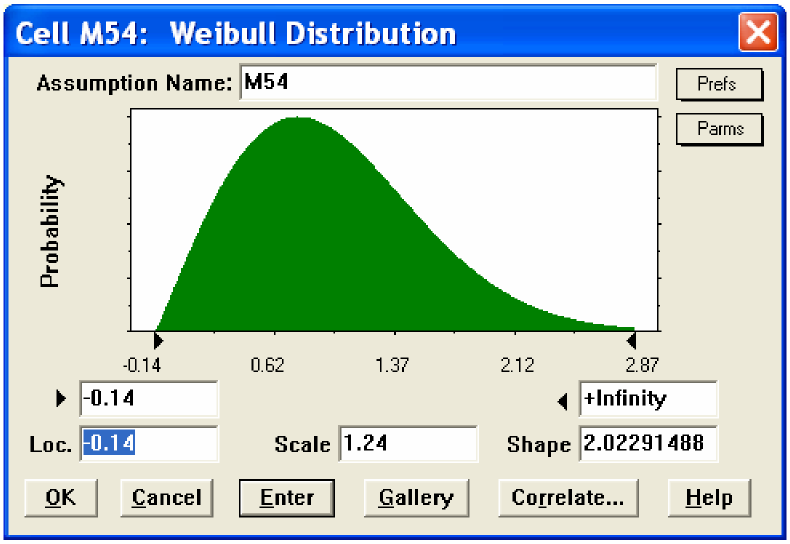

Figure 5-4. Example Weibull Distribution for Expert J

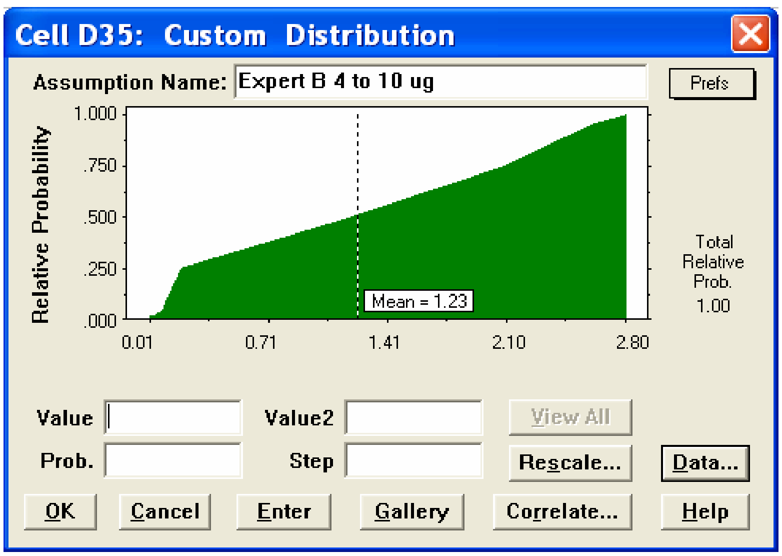

Figure 5-5. Example Custom Distribution for Expert B

In one special case, Expert E provided a normal distribution that implied a negative tail at the 2.5th percentile (the lower bound of a typical 95 percent confidence interval), but also specified a minimum value at zero. In this case, we treated the distribution as a truncated normal. In the case, the mean of the resulting incidence distribution will be shifted upwards relative to a full normal, to adjust for the mass of the distribution that would have been below zero (see Figure 5-6). Note that in the figure, the mean of the normal distribution specified by Expert C is 1.2, while the mean of the implied truncated normal will be 1.34.

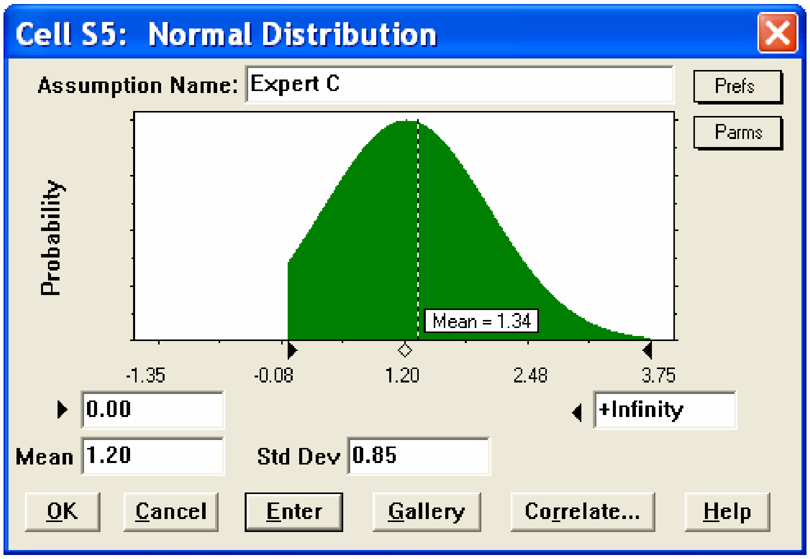

Figure 5-6. Truncated Normal Distribution for Expert C

In some cases, experts included in their reported distributions the likelihood that the relationship between $PM_{2.5}$ and mortality was not causal, e.g., that reducing $PM_{2.5}$ would not actually reduce the risk of premature death. In these cases, the distributions are unconditional, and included zero with some probability to reflect views on less than certain causality. In most cases, the experts chose to specify a conditional distribution, such that the distribution of the effect estimate is conditional on there being a causal relationship. In these cases, the final estimated distribution of avoided incidence of premature mortality will be the expected value of the unconditional distribution. In practice, we implement this by estimating each expert's conditional distribution and then, using Monte Carlo sampling, construct an unconditional distribution using the expert's reported probability of a causal relationship. To illustrate how these various components of an expert's results are combined to produce an estimate of the distribution of reduced mortality associated with a reduction in ambient $PM_{2.5}$, we provide an example calculation using the results from the partial attainment scenario for the 15/35 standards in California for Expert K. This example calculation is graphical displayed in Figure 5-7. In Figure 5-7, the initial application of Expert K's conditional concentration-response functions provides 3 distributions associated with reductions in $PM_{2.5}$ concentrations in the range of starting concentrations from 4 to 16 $\mu g/m^3$. These distributions are assigned weights based on the expert's judgments about the likelihood of a threshold existing in the ranges 0 to 5, 5 to 10, or not at all. These weights are used to develop a new distribution for the change in mortality for starting concentrations between 4 and 16. These are then added to the distribution of the change in mortality associated with reductions in $PM_{2.5}$ in the range of starting concentrations from 16 to 30 $\mu g/m^3$. This gives an overall distribution of reductions in mortality for the full range of starting concentrations, conditional on the existence of a causal relationship. This conditional distribution is then combined with the expert's judgment about causality (35 percent likelihood of a causal relationship), to derive the unconditional distribution of changes in mortality, which, as can be seen in the figure, is composed of a mass of probability at zero (reflecting the likelihood of no causal relationship), and a probability density function (PDF) over the remaining 35 percent of probability characterized by the conditional distribution. As expected, the unconditional

Initial Distributions:

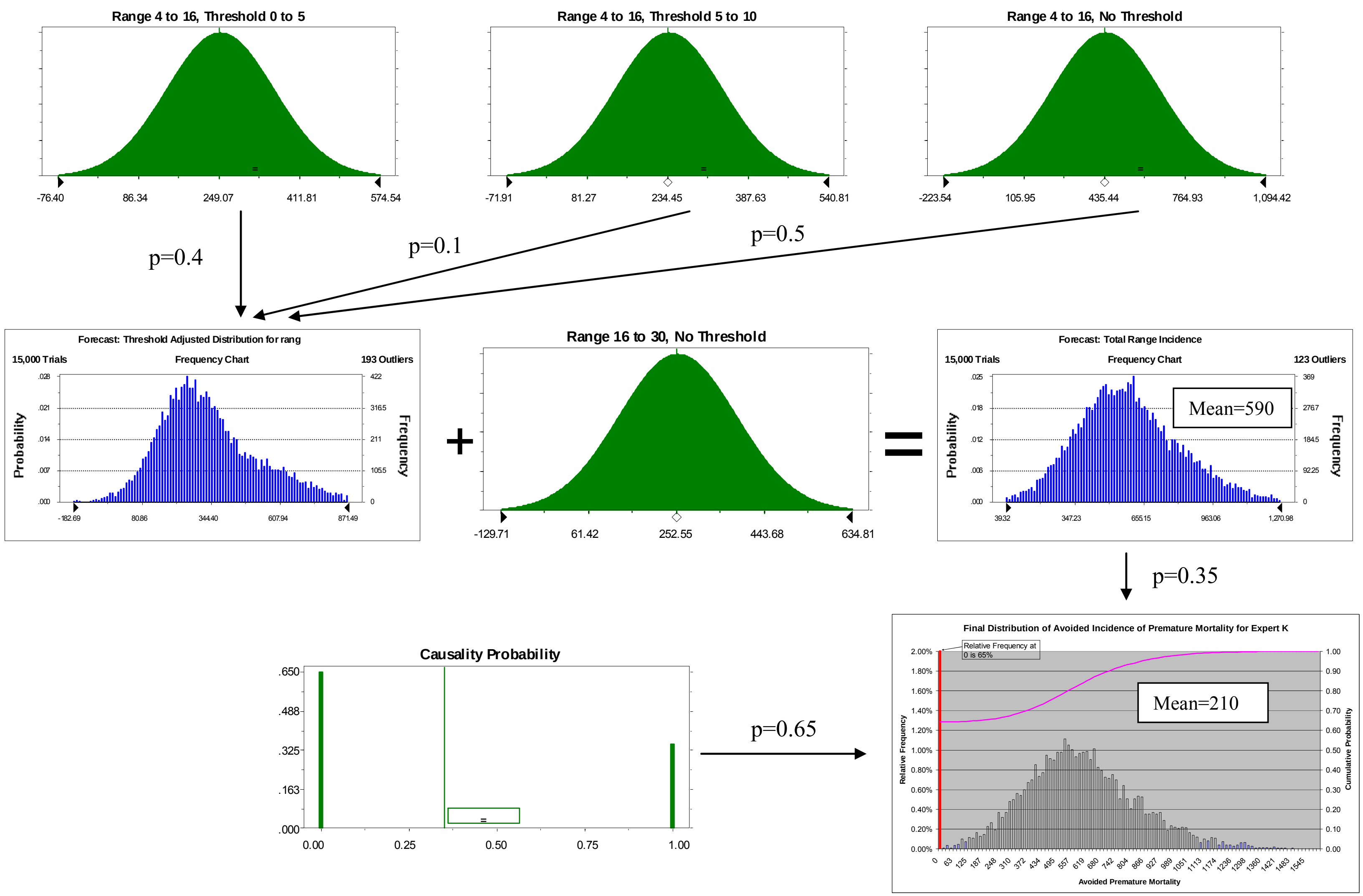

Figure 5-7. Example Calculations Expert K for California 15/35 Partial Attainment Scenario

distribution has a mean change in mortality that is 35 percent of the mean of the conditional distribution.

Infant Mortality. Recently published studies have strengthened the case for an association between PM exposure and respiratory inflammation and infection leading to premature mortality in children under 5 years of age. Specifically, the SAB-HES noted the release of the WHO Global Burden of Disease Study focusing on ambient air, which cites several recently published time-series studies relating daily PM exposure to mortality in children (U.S. EPA-SAB, 2004b). The SAB-HES also cites the study by Belanger et al. (2003) as corroborating findings linking PM exposure to increased respiratory inflammation and infections in children. Recently, a study by Chay and Greenstone (2003) found that reductions in TSP caused by the recession of 1981–1982 were related to reductions in infant mortality at the county level. With regard to the cohort study conducted by Woodruff et al. (1997), the SAB-HES notes several strengths of the study, including the use of a larger cohort drawn from a large number of metropolitan areas and efforts to control for a variety of individual risk factors in infants (e.g., maternal educational level, maternal ethnicity, parental marital status, and maternal smoking status). Based on these findings, the SAB-HES recommends that EPA incorporate infant mortality into the primary benefits estimate and that infant mortality be evaluated using an impact function developed from the Woodruff et al. (1997) study (U.S. EPA-SAB, 2004b). A more recent study by Woodruff et al. (2006) continues to find associations between $PM_{2.5}$ and infant mortality. The study also found the most significant relationships with respiratory-related causes of death. We have not yet sought comment from the SAB on this more recent study and as such continue to rely on the earlier 1997 analysis.

Chronic Bronchitis. CB is characterized by mucus in the lungs and a persistent wet cough for at least 3 months a year for several years in a row. CB affects an estimated 5% of the U.S. population (American Lung Association, 1999). A limited number of studies have estimated the impact of air pollution on new incidences of CB. Schwartz (1993) and Abbey et al. (1995) provide evidence that long-term PM exposure gives rise to the development of CB in the United States. Because attainment strategies for the PM NAAQS are expected to reduce primarily $PM_{2.5}$, this analysis uses only the Abbey et al. (1995) study, because it is the only study focusing on the relationship between $PM_{2.5}$ and new incidences of CB.

Nonfatal Myocardial Infarctions (heart attacks). Nonfatal heart attacks have been linked with short-term exposures to $PM_{2.5}$ in the United States (Peters et al., 2001) and other countries (Poloniecki et al., 1997). We used a recent study by Peters et al. (2001) as the basis for the impact function estimating the relationship between $PM_{2.5}$ and nonfatal heart attacks. A more recent study by Zanobetti and Schwartz (2005) used a similar method to Peters et al. (2001), but focused on adults 65 and older, and used PM10 as the PM indicator. They found a significant relationship between nonfatal heart attacks and PM10, although the magnitude of the effect was much lower than Peters et al. This may reflect the use of PM10, the more limited age range, or the less precise diagnosis of heart attack used in defining the outcome measure. Other studies, such as Domenici et al. (2006), Samet et al. (2000), and Moolgavkar (2000), show a consistent relationship between all cardiovascular hospital admissions, including those for nonfatal heart attacks, and PM. Given the lasting impact of a heart attack on long-term health costs and earnings, we provide a separate estimate for nonfatal heart attacks. The estimate used in the PM NAAQS analysis is based on the single available U.S. $PM_{2.5}$ effect estimate from Peters et al.

(2001). The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the United States. Several epidemiologic studies (Liao et al., 1999; Gold et al., 2000; Magari et al., 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other coronary heart diseases (Carthenon et al., 2002; Dekker et al., 2000; Liao et al., 1997; Tsuji et al., 1996). As such, significant impacts of PM on heart rate variability are consistent with an increased risk of heart attacks.

Hospital and Emergency Room Admissions. Because of the availability of detailed hospital admission and discharge records, there is an extensive body of literature examining the relationship between hospital admissions and air pollution. Because of this, many of the hospital admission endpoints use pooled impact functions based on the results of a number of studies. In addition, some studies have examined the relationship between air pollution and emergency room visits. Since most emergency room visits do not result in an admission to the hospital (the majority of people going to the emergency room are treated and return home), we treat hospital admissions and emergency room visits separately, taking account of the fraction of emergency room visits that are admitted to the hospital.

The two main groups of hospital admissions estimated in this analysis are respiratory admissions and cardiovascular admissions. There is not much evidence linking PM with other types of hospital admissions. The only type of emergency room visits that have been consistently linked to PM in the United States are asthma-related visits.

To estimate avoided incidences of $PM_{2.5}$ related cardiovascular hospital admissions in populations aged 65 and older, we use effect estimates from studies by Moolgavkar (2003) and Ito (2003). However, only Moolgavkar (2000) provided a separate effect estimate for populations 20 to 64.[16] Total cardiovascular hospital admissions are thus the sum of the pooled estimates from Moolgavkar (2003) and Ito (2003) for populations over 65 and the Moolgavkar (2000) based impacts for populations aged 20 to 64. Cardiovascular hospital admissions include admissions for myocardial infarctions. To avoid double-counting benefits from reductions in myocardial infarctions when applying the impact function for cardiovascular hospital admissions, we first adjusted the baseline cardiovascular hospital admissions to remove admissions for myocardial infarctions.

To estimate total avoided incidences of respiratory hospital admissions, we used impact functions for several respiratory causes, including chronic obstructive pulmonary disease (COPD), pneumonia, and asthma. As with cardiovascular admissions, additional published studies show a statistically significant relationship between PM_{10} and respiratory hospital admissions. We used only those focusing on $PM_{2.5}$. Both Moolgavkar (2000) and Ito (2003)

[16] Note that the Moolgavkar (2000) study has not been updated to reflect the more stringent GAM convergence criteria. However, given that no other estimates are available for this age group, we chose to use the existing study. Updates have been provided for the 65 and older population, and showed little difference. Given the very small (<5%) difference in the effect estimates for people 65 and older with cardiovascular hospital admissions between the original and reanalyzed results, we do not expect the difference in the effect estimates for the 20 to 64 population to differ significantly. As such, the choice to use the earlier, uncorrected analysis will likely not introduce much bias.

provide effect estimates for COPD in populations over 65, allowing us to pool the impact functions for this group. Only Moolgavkar (2000) provides a separate effect estimate for populations 20 to 64. Total COPD hospital admissions are thus the sum of the pooled estimate for populations over 65 and the single study estimate for populations 20 to 64. Only Ito (2003) estimated pneumonia and only for the population 65 and older. In addition, Sheppard (2003) provided an effect estimate for asthma hospital admissions for populations under age 65. Total avoided incidences of PM-related respiratory-related hospital admissions is the sum of COPD, pneumonia, and asthma admissions.

To estimate the effects of PM air pollution reductions on asthma-related ER visits, we use the effect estimate from a study of children 18 and under by Norris et al. (1999). As noted earlier, there is another study by Schwartz examining a broader age group (less than 65), but the Schwartz study focused on PM_{10} rather than $PM_{2.5}$. We selected the Norris et al. (1999) effect estimate because it better matched the pollutant of interest. Because children tend to have higher rates of hospitalization for asthma relative to adults under 65, we will likely capture the majority of the impact of $PM_{2.5}$ on asthma emergency room visits in populations under 65, although there may still be significant impacts in the adult population under 65.

Acute Health Events and Work Loss Days. As indicated in Table 5-1, in addition to mortality, chronic illness, and hospital admissions, a number of acute health effects not requiring hospitalization are associated with exposure to ambient levels of PM. The sources for the effect estimates used to quantify these effects are described below.

Around 4% of U.S. children between the ages of 5 and 17 experience episodes of acute bronchitis annually (American Lung Association, 2002c). Acute bronchitis is characterized by coughing, chest discomfort, slight fever, and extreme tiredness, lasting for a number of days. According to the MedlinePlus medical encyclopedia,[17] with the exception of cough, most acute bronchitis symptoms abate within 7 to 10 days. Incidence of episodes of acute bronchitis in children between the ages of 5 and 17 were estimated using an effect estimate developed from Dockery et al. (1996).

Incidences of lower respiratory symptoms (e.g., wheezing, deep cough) in children aged 7 to 14 were estimated using an effect estimate from Schwartz and Neas (2000).

Because asthmatics have greater sensitivity to stimuli (including air pollution), children with asthma can be more susceptible to a variety of upper respiratory symptoms (e.g., runny or stuffy nose; wet cough; and burning, aching, or red eyes). Research on the effects of air pollution on upper respiratory symptoms has thus focused on effects in asthmatics. Incidences of upper respiratory symptoms in asthmatic children aged 9 to 11 are estimated using an effect estimate developed from Pope et al. (1991).

Exposure to air pollution can result in restrictions in activity levels. These restrictions range from relatively minor changes in daily activities to serious limitations that can result in missed days of work (either from personal symptoms or from caring for a sick family member). We include two types of restricted activity days, minor restricted activity days (MRAD) and work

[17] See http://www.nlm.nih.gov/medlineplus/ency/article/000124.htm, accessed January 2002.

loss days (WLD). MRAD result when individuals reduce most usual daily activities and replace them with less strenuous activities or rest, yet not to the point of missing work or school. For example, a mechanic who would usually be doing physical work most of the day will instead spend the day at a desk doing paper and phone work because of difficulty breathing or chest pain. The effect of $PM_{2.5}$ on MRAD was estimated using an effect estimate derived from Ostro and Rothschild (1989). Work loss days due to $PM_{2.5}$ were estimated using an effect estimate developed from Ostro (1987).

In analyzing attainment strategies for the PM NAAQS, we have followed the SAB-HES recommendations regarding asthma exacerbations in developing the primary estimate. To prevent double-counting, we focused the estimation on asthma exacerbations occurring in children and excluded adults from the calculation.[18] Asthma exacerbations occurring in adults are assumed to be captured in the general population endpoints such as work loss days and MRADs. Consequently, if we had included an adult-specific asthma exacerbation estimate, we would likely double-count incidence for this endpoint. However, because the general population endpoints do not cover children (with regard to asthmatic effects), an analysis focused specifically on asthma exacerbations for children (6 to 18 years of age) could be conducted without concern for double-counting.

To characterize asthma exacerbations in children, we selected two studies (Ostro et al., 2001; Vedal et al., 1998) that followed panels of asthmatic children. Ostro et al. (2001) followed a group of 138 African-American children in Los Angeles for 13 weeks, recording daily occurrences of respiratory symptoms associated with asthma exacerbations (e.g., shortness of breath, wheeze, and cough). This study found a statistically significant association between $PM_{2.5}$, measured as a 12-hour average, and the daily prevalence of shortness of breath and wheeze endpoints. Although the association was not statistically significant for cough, the results were still positive and close to significance; consequently, we decided to include this endpoint, along with shortness of breath and wheeze, in generating incidence estimates (see below). Vedal et al. (1998) followed a group of elementary school children, including 74 asthmatics, located on the west coast of Vancouver Island for 18 months including measurements of daily peak expiratory flow (PEF) and the tracking of respiratory symptoms (e.g., cough, phlegm, wheeze, chest tightness) through the use of daily diaries. Association between PM_{10} and

[18] Estimating asthma exacerbations associated with air pollution exposures is difficult, due to concerns about double-counting of benefits. Concerns over double-counting stem from the fact that studies of the general population also include asthmatics, so estimates based solely on the asthmatic population cannot be directly added to the general population numbers without double-counting. In one specific case (upper respiratory symptoms in children), the only study available is limited to asthmatic children, so this endpoint can be readily included in the calculation of total benefits. However, other endpoints, such as lower respiratory symptoms and MRADs, are estimated for the total population that includes asthmatics. Therefore, to simply add predictions of asthma-related symptoms generated for the population of asthmatics to these total population-based estimates could result in double-counting, especially if they evaluate similar endpoints. The SAB-HES, in commenting on the analytical blueprint for 812, acknowledged these challenges in evaluating asthmatic symptoms and appropriately adding them into the primary analysis (U.S. EPA-SAB, 2004b). However, despite these challenges, the SAB-HES recommends the addition of asthma-related symptoms (i.e., asthma exacerbations) to the primary analysis, provided that the studies use the panel study approach and that they have comparable design and baseline frequencies in both asthma prevalence and exacerbation rates. Note also, that the SAB-HES, while supporting the incorporation of asthma exacerbation estimates, does not believe that the association between ambient air pollution, including ozone and PM, and the new onset of asthma is sufficiently strong to support inclusion of this asthma-related endpoint in the primary estimate.

respiratory symptoms for the asthmatic population was only reported for two endpoints: cough and PEF. Because it is difficult to translate PEF measures into clearly defined health endpoints that can be monetized, we only included the cough-related effect estimate from this study in quantifying asthma exacerbations. We employed the following pooling approach in combining estimates generated using effect estimates from the two studies to produce a single asthma exacerbation incidence estimate. First, we pooled the separate incidence estimates for shortness of breath, wheeze, and cough generated using effect estimates from the Ostro et al. study, because each of these endpoints is aimed at capturing the same overall endpoint (asthma exacerbations) and there could be overlap in their predictions. The pooled estimate from the Ostro et al. study is then pooled with the cough-related estimate generated using the Vedal study. The rationale for this second pooling step is similar to the first; both studies are attempting to quantify the same overall endpoint (asthma exacerbations).

Additional epidemiological studies are available for characterizing asthma-related health endpoints (the full list of epidemiological studies considered for modeling asthma-related incidence is presented in Table 5-8). However, based on recommendations from the SAB-HES, we decided not to use these additional studies in generating the primary estimate. In particular, the Yu et al. (2000) estimates show a much higher baseline incidence rate than other studies, which may lead to an overstatement of the expected impacts in the overall asthmatic population. The Whittemore and Korn (1980) study did not use a well-defined endpoint, instead focusing on a respondent-defined “asthma attack.” Other studies looked at respiratory symptoms in asthmatics but did not focus on specific exacerbations of asthma.

Treatment of Potential Thresholds in Health Impact Functions

Unless specifically noted, our premature mortality benefits estimates are based on an assumed cutpoint in the premature mortality concentration-response function at 10 $\mu g/m^3$, and an assumed cutpoint of 10 $\mu g/m^3$ for the concentration-response functions for morbidity associated with short term exposure to PM2.5. The 10 $\mu g/m^3$ threshold reflects comments from CASAC (U.S. EPA Science Advisory Board, 2005). To consider the impact of a threshold in the response function for the chronic mortality endpoint on the primary benefits estimates, we also constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, we adjusted the mortality function slopes accordingly.[19] This sensitivity analysis allows us to determine the change (reduction) in avoided mortality cases and associated monetary benefits associated with alternative cutpoints. Five cutpoints (including the base case assumption) were included in this sensitivity analysis: (a) 14 $\mu g/m^3$ (assumes no impacts below the alternative annual NAAQS), (b) 12 $\mu g/m^3$ (c) 10 $\mu g/m^3$ (reflects comments from CASAC - 2005), (d) 7.5 $\mu g/m^3$ (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the Pope 2002 study used as the basis for modeling chronic mortality) and (e) background or 3 $\mu g/m^3$ (reflects NRC recommendation to consider effects all the way to background).

[19] Note, that the adjustment to the mortality slopes was only done for the 10 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$ cutpoints since the 7.5 $\mu g/m^3$ and background cutpoints are at or below the lowest measured exposure levels reported in the Pope 2002, for the combined exposure dataset. See Appendix H for a complete discussion of the slope adjustment procedure.

Table 5-8: Studies Examining Health Impacts in the Asthmatic Population Evaluated for Use in the Benefits Analysis

Endpoint	*Definition*	*Pollutant*	*Study*	*Study Population*
Asthma Attack Indicators				
Shortness of breath	Prevalence of shortness of breath; incidence of shortness of breath	$PM_{2.5}$	Ostro et al. (2001)	African-American asthmatics, 8–13
Cough	Prevalence of cough; incidence of cough	$PM_{2.5}$	Ostro et al. (2001)	African-American asthmatics, 8–13
Wheeze	Prevalence of wheeze; incidence of wheeze	$PM_{2.5}$	Ostro et al. (2001)	African-American asthmatics, 8–13
Asthma exacerbation	≥1 mild asthma symptom: wheeze, cough, chest tightness, shortness of breath	PM_{10}, $PM_{1.0}$	Yu et al. (2000)	Asthmatics, 5–13
Cough	Prevalence of cough	PM_{10}	Vedal et al. (1998)	Asthmatics, 6–13
Other Symptoms/Illness Endpoints				
Upper respiratory symptoms	≥1 of the following: runny or stuffy nose; wet cough; burning, aching, or red eyes	PM_{10}	Pope et al. (1991)	Asthmatics, 9–11
Moderate or worse asthma	Probability of moderate (or worse) rating of overall asthma status	$PM_{2.5}$	Ostro et al. (1991)	Asthmatics, all ages
Acute bronchitis	≥1 episodes of bronchitis in the past 12 months	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9–15
Phlegm	"Other than with colds, does this child usually seem congested in the chest or bring up phlegm?"	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9–15
Asthma attacks	Respondent-defined asthma attack	$PM_{2.5}$, ozone	Whittemore and Korn (1980)	Asthmatics, all ages

Baseline Health Effect Incidence Rates

The 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 an estimate of the absolute number of avoided cases. For example, a typical result might be that a 10 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by 3%. To then to convert this relative change into a number of cases, the baseline incidence of the health effect is necessary. The baseline incidence rate provides an estimate of the incidence rate (number of cases of the health effect per year, usually per 10,000 or 100,000 general population) in the assessment location corresponding 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 (e.g., if the baseline incidence rate is number of cases per year per 100,000 population, it must be multiplied by the number of 100,000s in the population).

Some epidemiological studies examine the association between pollution levels and adverse health effects in a specific subpopulation, such as asthmatics or diabetics. In these cases, it is necessary to develop not only baseline incidence rates, but also prevalence rates for the defining condition (e.g., asthma). For both baseline incidence and prevalence data, we use age-specific rates where available. Impact functions are applied to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits.

In most cases, because of a lack of data or methods, we have not attempted to project incidence rates to future years, instead assuming that the most recent data on incidence rates is the best prediction of future incidence rates. In recent years, better data on trends in incidence and prevalence rates for some endpoints, such as asthma, have become available. We are working to develop methods to use these data to project future incidence rates. However, for our primary benefits analysis, we continue to use current incidence rates. The one exception is in the case of premature mortality. In this case, we have projected mortality rates such that future mortality rates are consistent with our projections of population growth (Abt Associates, 2005). Compared with previous analyses, this will result in a reduction in the mortality related impacts of air pollution in future years.

Table 5-9 summarizes the baseline incidence data and sources used in the benefits analysis. We use the most geographically disaggregated data available. For premature mortality, county-level data are available. For hospital admissions, regional rates are available. However, for all other endpoints, a single national incidence rate is used, due to a lack of more spatially disaggregated data. In these cases, we used national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, 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 5-9: Baseline Incidence Rates and Population Prevalence Rates for Use in Impact Functions, General Population

		Rates	
Endpoint	*Parameter*	*Value*	*Source*[a]
Mortality	Daily or annual mortality rate	Age-, cause-, and county-specific rate	CDC Wonder (1996–1998)
Hospitalizations	Daily hospitalization rate	Age-, region-, and cause-specific rate	1999 NHDS public use data files[b]
Asthma ER Visits	Daily asthma ER visit rate	Age- and region-specific visit rate	2000 NHAMCS public use data files[c]; 1999 NHDS public use data files[b]
Chronic Bronchitis	Annual prevalence rate per person • Aged 18–44 • Aged 45–64 • Aged 65 and older	 0.0367 0.0505 0.0587	1999 NHIS (American Lung Association, 2002b, Table 4)
	Annual incidence rate per person	0.00378	Abbey et al. (1993, Table 3)
Nonfatal Myocardial Infarction (heart attacks)	Daily nonfatal myocardial infarction incidence rate per person, 18+ • Northeast • Midwest • South • West	 0.0000159 0.0000135 0.0000111 0.0000100	1999 NHDS public use data files[b]; adjusted by 0.93 for probability of surviving after 28 days (Rosamond et al., 1999)
Asthma Exacerbations	Incidence (and prevalence) among asthmatic African-American children • daily wheeze • daily cough • daily dyspnea	 0.076 (0.173) 0.067 (0.145) 0.037 (0.074)	Ostro et al. (2001)
	Prevalence among asthmatic children • daily wheeze • daily cough • daily dyspnea	 0.038 0.086 0.045	Vedal et al. (1998)
Acute Bronchitis	Annual bronchitis incidence rate, children	0.043	American Lung Association (2002c, Table 11)
Lower Respiratory Symptoms	Daily lower respiratory symptom incidence among children[d]	0.0012	Schwartz et al. (1994, Table 2)
Upper Respiratory Symptoms	Daily upper respiratory symptom incidence among asthmatic children	0.3419	Pope et al. (1991, Table 2)
Work Loss Days	Daily WLD incidence rate per person (18–65) • Aged 18–24 • Aged 25–44 • Aged 45–64	 0.00540 0.00678 0.00492	1996 HIS (Adams, Hendershot, and Marano, 1999, Table 41); U.S. Bureau of the Census (2000)

(continued)

Table 5-9: Baseline Incidence Rates and Population Prevalence Rates for Use in Impact Functions, General Population (continued)

		Rates	
Endpoint	*Parameter*	*Value*	*Source*[a]
Minor Restricted-Activity Days	Daily MRAD incidence rate per person	0.02137	Ostro and Rothschild (1989, p. 243)

a The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS—National Hospital Discharge Survey; NHAMCS—National Hospital Ambulatory Medical Care Survey.

b See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/.

c See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/.

d Lower respiratory symptoms are defined as two or more of the following: cough, chest pain, phlegm, and wheeze.

Baseline age, cause, and county-specific mortality rates were obtained from the U.S. Centers for Disease Control and Prevention (CDC) for the years 1996 through 1998. CDC maintains an online data repository of health statistics, CDC Wonder, accessible at http://wonder.cdc.gov/. The mortality rates provided are derived from U.S. death records and U.S. Census Bureau postcensal population estimates. Mortality rates were averaged across 3 years (1996 through 1998) to provide more stable estimates. When estimating rates for age groups that differed from the CDC Wonder groupings, we assumed that rates were uniform across all ages in the reported age group. For example, to estimate mortality rates for individuals ages 30 and up, we scaled the 25- to 34-year-old death count and population by one-half and then generated a population-weighted mortality rate using data for the older age groups.

To estimate age- and county-specific mortality rates in years 2000 through 2020, we calculated adjustment factors, based on a series of Census Bureau projected national mortality rates, to adjust the CDC Wonder age- and county-specific mortality rates in 1996-1998 to corresponding rates for each future year. For the analysis year 2020, these adjustment factors ranged across age categories from 0.76 to 0.86

For the set of endpoints affecting the asthmatic population, in addition to baseline incidence rates, prevalence rates of asthma in the population are needed to define the applicable population. Table 5-9 lists the baseline incidence rates and their sources for asthma symptom endpoints. Table 5-10 lists the prevalence rates used to determine the applicable population for asthma symptom endpoints. Note that these reflect current asthma prevalence and assume no change in prevalence rates in future years. As noted above, we are investigating methods for projecting asthma prevalence rates in future years. However, it should be noted that current trends in asthma prevalence do not lead us to expect that asthma prevalence rates will be more than 4% overall in 2020, or that large changes will occur in asthma prevalence rates for individual age categories (Mansfield et al., 2005).

Table 5-10: Asthma Prevalence Rates Used to Estimate Asthmatic Populations in Impact Functions

	Asthma Prevalence Rates	
Population Group	*Value*	*Source*
All Ages	0.0386	American Lung Association (2002a, Table 7)—based on 1999 HIS
< 18	0.0527	American Lung Association (2002a, Table 7)—based on 1999 HIS
5–17	0.0567	American Lung Association (2002a, Table 7)—based on 1999 HIS
18–44	0.0371	American Lung Association (2002a, Table 7)—based on 1999 HIS
45–64	0.0333	American Lung Association (2002a, Table 7)—based on 1999 HIS
65+	0.0221	American Lung Association (2002a, Table 7)—based on 1999 HIS
Male, 27+	0.021	2000 HIS public use data files[a]
African American, 5 to 17	0.0726	American Lung Association (2002a, Table 9)—based on 1999 HIS
African American, <18	0.0735	American Lung Association (2002a, Table 9)—based on 1999 HIS

[a] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHIS/2000/.

Selecting Unit Values for Monetizing Health Endpoints

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 affects 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 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. For example, suppose a measure is able to reduce 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). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. 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 use the cost of treating or mitigating the effect as a primary estimate. 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 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. Table 5-11 summarizes the value estimates per health effect that we used in this analysis. Values are presented both for a 1990 base income level and adjusted for income growth out to 2020. Note that the unit values for hospital admissions are the weighted averages of the ICD-9 code-specific values for the group of ICD-9 codes included in the hospital admission categories. A discussion of the valuation methods for

Table 5-11: Unit Values Used for Economic Valuation of Health Endpoints (1999$)

Health Endpoint	*Central Estimate of Value Per Statistical Incidence*		*Derivation of Distributions of Estimates*
	1990 Income Level	*2020 Income Level*	
Premature Mortality (Value of a Statistical Life)	$5,500,000	$6,600,000	Point estimate is the mean of a normal distribution with a 95% confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$340,000	$420,000	The WTP to avoid a case of pollution-related CB is calculated as $WTP_x = WTP_{13} * e^{-\beta*(13-x)}$, where x is the severity of an average CB case, WTP_{13} is the WTP for a severe case of CB, and is the parameter relating WTP to severity, based on the regression results reported in Krupnick and Cropper (1992). The distribution of WTP for an average severity-level case of CB was generated by Monte Carlo methods, drawing from each of three distributions: (1) WTP to avoid a severe case of CB is assigned a 1/9 probability of being each of the first nine deciles of the distribution of WTP responses in Viscusi et al. (1991); (2) the severity of a pollution-related case of CB (relative to the case described in the Viscusi study) is assumed to have a triangular distribution, with the most likely value at severity level 6.5 and endpoints at 1.0 and 12.0; and (3) the constant in the elasticity of WTP with respect to severity is normally distributed with mean = 0.18 and standard deviation = 0.0669 (from Krupnick and Cropper [1992]). This process and the rationale for choosing it is described in detail in the *Costs and Benefits of the Clean Air Act, 1990 to 2010* (EPA, 1999)., where x is the severity of an average CB case, WTP13 is the WTP for a severe case of CB, and is the parameter relating WTP to severity, based on the regression results reported in Krupnick and Cropper (1992). The distribution of WTP for an average severity-level case of CB was generated by Monte Carlo methods, drawing from each of three distributions: (1) WTP to avoid a severe case of CB is assigned a 1/9 probability of being each of the first nine deciles of the distribution of WTP responses in Viscusi et al. (1991); (2) the severity of a pollution-related case of CB (relative to the case described in the Viscusi study) is assumed to have a triangular distribution, with the most likely value at severity level 6.5 and endpoints at 1.0 and 12.0; and (3) the constant in the elasticity of WTP with respect to severity is normally distributed with mean = 0.18 and standard deviation = 0.0669 (from Krupnick and Cropper [1992]). This process and the rationale for choosing it is described in detail in the Costs and Benefits of the Clean Air Act, 1990 to 2010 (U.S. EPA, 1999).

(continued)

Table 5-11: Unit Values Used for Economic Valuation of Health Endpoints (1999$) (continued)

Health Endpoint	*Central Estimate of Value Per Statistical Incidence* 1990 Income Level	2020 Income Level	*Derivation of Distributions of Estimates*
Nonfatal Myocardial Infarction (heart attack)			No distributional information available. Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990). Direct medical costs are based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990).
3% discount rate			Lost earnings:
Age 0–24	$66,902	$66,902	Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings:
Age 25–44	$74,676	$74,676	age of onset: at 3% at 7%
Age 45–54	$78,834	$78,834	25-44 $8,774 $7,855
Age 55–65	$140,649	$140,649	45-54 $12,932 $11,578
Age 66 and over	$66,902	$66,902	55-65 $74,746 $66,920
7% discount rate			Direct medical expenses: An average of:
Age 0–24	$65,293	$65,293	1. Wittels et al. (1990) ($102,658—no discounting)
Age 25–44	$73,149	$73,149	2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
Age 45–54	$76,871	$76,871	
Age 55–65	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	
Hospital Admissions			
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$6,634	$6,634	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Emergency Room Visits for Asthma	$286	$286	No distributional information available. Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997) and (2) $260.67, from Stanford et al. (1999).

(continued)

Table 5-11: Unit Values Used for Economic Valuation of Health Endpoints (1999$) (continued)

Health Endpoint	*Central Estimate of Value Per Statistical Incidence*		Derivation of Distributions of Estimates
	1990 Income Level	*2020 Income Level*	
Respiratory Ailments Not Requiring Hospitalization			
Upper Respiratory Symptoms (URS)	$25	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. In the absence of information surrounding the frequency with which each of the seven types of URS occurs within the URS symptom complex, we assumed a uniform distribution between $10 and $45.
Lower Respiratory Symptoms (LRS)	$16	$18	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS. In the absence of information surrounding the frequency with which each of the 11 types of LRS occurs within the LRS symptom complex, we assumed a uniform distribution between $8 and $25.
Asthma Exacerbations	$42	$45	Asthma exacerbations are valued at $45 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986). This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma exacerbation is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study. The value is assumed have a uniform distribution between $17 and $73.
Acute Bronchitis	$360	$380	Assumes a 6-day episode, with the distribution of the daily value specified as uniform with the low and high values based on those recommended for related respiratory symptoms in Neumann et al. (1994). The low daily estimate of $10 is the sum of the mid-range values recommended by IEc (1994) for two symptoms believed to be associated with acute bronchitis: coughing and chest tightness. The high daily estimate was taken to be twice the value of a minor respiratory restricted-activity day, or $110.
Work Loss Days (WLDs)	Variable (U.S. median=$110)		No distribution available. Point estimate is based on county-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.

(continued)

Table 5-11: Unit Values Used for Economic Valuation of Health Endpoints (1999$) (continued)

Health Endpoint	*Central Estimate of Value Per Statistical Incidence*		Derivation of Distributions of Estimates
	1990 Income Level	*2020 Income Level*	
Minor Restricted Activity Days (MRADs)	$51	$54	Median WTP estimate to avoid one MRAD from Tolley et al. (1986). Distribution is assumed to be triangular with a minimum of $22 and a maximum of $83, with a most likely value of $55. Range is based on assumption that value should exceed WTP for a single mild symptom (the highest estimate for a single symptom—for eye irritation—is $16.00) and be less than that for a WLD. The triangular distribution acknowledges that the actual value is likely to be closer to the point estimate than either extreme.

premature mortality and CB is provided here because of the relative importance of these effects. Discussions of the methods used to value nonfatal myocardial infarctions (heart attacks) and school absence days are provided because these endpoints have only recently been added to the analysis and the valuation methods are still under development. In the following discussions, unit values are presented at 1990 levels of income for consistency with previous analyses. Equivalent future-year values can be obtained from Table 5-11. COI estimates are converted to constant 1999 dollar equivalents using the medical CPI.

Valuing Reductions in Premature Mortality Risk. Following the advice of the EEAC of the SAB, EPA currently uses the VSL approach in calculating the primary estimate of mortality benefits, because we believe this calculation provides the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk (EPA, 2000a). The VSL approach is a summary measure for the value of small changes in mortality risk experienced by a large number of people. The mean value of avoiding one statistical death is assumed to be $5.5 million in 1999 dollars. This represents a central value consistent with the range of values suggested by recent meta-analyses of the wage-risk VSL literature. The distribution of VSL is characterized by a confidence interval from $1 to $10 million, based on two meta-analyses of the wage-risk VSL literature. The $1 million lower confidence limit represents the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis. The $10 million upper confidence limit represents the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis. The mean estimate of $5.5 million is consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006) meta-analysis. Because the majority of the studies in these meta-analyses are based on datasets from the early 1990s or previous decades, we continue to assume that the VSL estimates provided by those meta-analyses are in 1990 income equivalents. Future research might provide income-adjusted VSL values for individual studies that can be incorporated into the meta-analyses. This would allow for a more reliable base-year estimate for use in adjusting VSL for aggregate changes in income over time.

As indicated in the previous section on quantification of premature mortality benefits, we assumed for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the 20 years following exposure. To take this into account in the valuation of reductions in premature mortality, we applied an annual 3% discount rate to the value of premature mortality occurring in future years.[20]

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economics and public policy analysis community. EPA strives to use the best economic science in its analyses. Given the mixed theoretical finding and empirical evidence regarding adjustments to VSL for risk and population characteristics, we use a single VSL for all reductions in mortality risk.

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[20] The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the federal government. EPA adopted a 3% discount rate for its base estimate in this case to reflect reliance on a "social rate of time preference" discounting concept. We have also calculated benefits and costs using a 7% rate consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements. In this case, the benefit and cost estimates were not significantly affected by the choice of discount rate. Further discussion of this topic appears in EPA's *Guidelines for Preparing Economic Analyses* (EPA, 2000b).

Although there are several differences between the labor market studies EPA uses to derive a VSL estimate and the PM air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. Table 5-12 lists some of these differences and the expected effect on the VSL estimate for air pollution-related mortality. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $5.5 million value while acknowledging the significant limitations and uncertainties in the available literature.

Table 5-12: Expected Impact on Estimated Benefits of Premature Mortality Reductions of Differences Between Factors Used in Developing Applied VSL and Theoretically Appropriate VSL

Attribute	*Expected Direction of Bias*
Age	Uncertain, perhaps overestimate
Life Expectancy/Health Status	Uncertain, perhaps overestimate
Attitudes Toward Risk	Underestimate
Income	Uncertain
Voluntary vs. Involuntary	Uncertain, perhaps underestimate
Catastrophic vs. Protracted Death	Uncertain, perhaps underestimate

The SAB-EEAC has reviewed many potential VSL adjustments and the state of the economics literature. The SAB-EEAC advised EPA to "continue to use a wage-risk-based VSL as its primary estimate, including appropriate sensitivity analyses to reflect the uncertainty of these estimates," and that "the only risk characteristic for which adjustments to the VSL can be made is the timing of the risk" (U.S. EPA, 2000a). In developing our primary estimate of the benefits of premature mortality reductions, we have followed this advice and discounted over the lag period between exposure and premature mortality.

Uncertainties Specific to Premature Mortality Valuation. The economic benefits associated with premature mortality are the largest category of monetized benefits of the final PM NAAQS. In addition, in prior analyses, EPA has identified valuation of mortality benefits as the largest contributor to the range of uncertainty in monetized benefits (see U.S. EPA, 1999).[21] Because of the uncertainty in estimates of the value of premature mortality avoidance, it is important to adequately characterize and understand the various types of economic approaches available for mortality valuation. Such an assessment also requires an understanding of how alternative valuation approaches reflect that some individuals may be more susceptible to air pollution-induced mortality or reflect differences in the nature of the risk presented by air pollution relative to the risks studied in the relevant economics literature.

[21] This conclusion was based on a assessment of uncertainty based on statistical error in epidemiological effect estimates and economic valuation estimates. Additional sources of model error such as those examined in the PM mortality expert elicitation may result in different conclusions about the relative contribution of sources of uncertainty.

The health science literature on air pollution indicates that several human characteristics affect the degree to which mortality risk affects an individual. For example, some age groups appear to be more susceptible to air pollution than others (e.g., the elderly and children). Health status prior to exposure also affects susceptibility. An ideal benefits estimate of mortality risk reduction would reflect these human characteristics, in addition to an individual's WTP to improve one's own chances of survival plus WTP to improve other individuals' survival rates. The ideal measure would also take into account the specific nature of the risk reduction commodity that is provided to individuals, as well as the context in which risk is reduced. To measure this value, it is important to assess how reductions in air pollution reduce the risk of dying from the time that reductions take effect onward and how individuals value these changes. Each individual's survival curve, or the probability of surviving beyond a given age, should shift as a result of an environmental quality improvement. For example, changing the current probability of survival for an individual also shifts future probabilities of that individual's survival. This probability shift will differ across individuals because survival curves depend on such characteristics as age, health state, and the current age to which the individual is likely to survive.

Although a survival curve approach provides a theoretically preferred method for valuing the benefits of reduced risk of premature mortality associated with reducing air pollution, the approach requires a great deal of data to implement. The economic valuation literature does not yet include good estimates of the value of this risk reduction commodity. As a result, in this study we value avoided premature mortality risk using the VSL approach.

Other uncertainties specific to premature mortality valuation include the following:

- *Across-study variation:* There is considerable uncertainty as to whether the available literature on VSL provides adequate estimates of the VSL saved by air pollution reduction. Although there is considerable variation in the analytical designs and data used in the existing literature, the majority of the studies involve the value of risks to a middle-aged working population. Most of the studies examine differences in wages of risky occupations, using a hedonic wage approach. Certain characteristics of both the population affected and the mortality risk facing that population are believed to affect the average WTP to reduce the risk. The appropriateness of a distribution of WTP based on the current VSL literature for valuing the mortality-related benefits of reductions in air pollution concentrations therefore depends not only on the quality of the studies (i.e., how well they measure what they are trying to measure), but also on the extent to which the risks being valued are similar and the extent to which the subjects in the studies are similar to the population affected by changes in pollution concentrations.

- *Level of risk reduction:* The transferability of estimates of the VSL from the wage-risk studies to the context of the PM NAAQS analysis rests on the assumption that, within a reasonable range, WTP for reductions in mortality risk is linear in risk reduction. For example, suppose a study provides a result that the average WTP for a reduction in mortality risk of 1/100,000 is $50, but that the actual mortality risk reduction resulting from a given pollutant reduction is 1/10,000. If WTP for reductions in mortality risk is linear in risk reduction, then a WTP of $50 for a reduction of 1/100,000 implies a WTP of $500 for a risk reduction of 1/10,000 (which is 10 times the risk reduction valued in the study). Under the assumption of linearity, the estimate of the VSL does not depend on the particular amount of risk reduction being valued. This assumption has been shown to be reasonable provided the change in the risk being valued is within the range of risks evaluated in the underlying studies (Rowlatt et al., 1998).

- *Voluntariness of risks evaluated:* Although job-related mortality risks may differ in several ways from air pollution-related mortality risks, the most important difference may be that job-related risks are incurred voluntarily, or generally assumed to be, whereas air pollution-related risks are incurred involuntarily. Some evidence suggests that people will pay more to reduce involuntarily incurred risks than risks incurred voluntarily. If this is the case, WTP estimates based on wage-risk studies may understate WTP to reduce involuntarily incurred air pollution-related mortality risks.

- *Sudden versus protracted death:* A final important difference related to the nature of the risk may be that some workplace mortality risks tend to involve sudden, catastrophic events, whereas air pollution-related risks tend to involve longer periods of disease and suffering prior to death. Some evidence suggests that WTP to avoid a risk of a protracted death involving prolonged suffering and loss of dignity and personal control is greater than the WTP to avoid a risk (of identical magnitude) of sudden death. To the extent that the mortality risks addressed in this assessment are associated with longer periods of illness or greater pain and suffering than are the risks addressed in the valuation literature, the WTP measurements employed in the present analysis would reflect a downward bias.

- *Self-selection and skill in avoiding risk:* Recent research (Shogren and Stamland, 2002) suggests that VSL estimates based on hedonic wage studies may overstate the average value of a risk reduction. This is based on the fact that the risk-wage trade-off revealed in hedonic studies reflects the preferences of the marginal worker (i.e., that worker who demands the highest compensation for his risk reduction). This worker must have either higher risk, lower risk tolerance, or both. However, the risk estimate used in hedonic studies is generally based on average risk, so the VSL may be upwardly biased because the wage differential and risk measures do not match.

- *Baseline risk and age:* Recent research (Smith, Pattanayak, and Van Houtven, 2006) finds that because individuals reevaluate their baseline risk of death as they age, the marginal value of risk reductions does not decline with age as predicted by some lifetime consumption models. This research supports findings in recent stated preference studies that suggest only small reductions in the value of mortality risk reductions with increasing age.

Valuing Reductions in the Risk of Chronic Bronchitis. The best available estimate of WTP to avoid a case of CB comes from Viscusi, Magat, and Huber (1991). The Viscusi, Magat, and Huber study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting the Viscusi, Magat, and Huber (1991) estimate of the WTP to avoid a severe case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the

Krupnick and Cropper (1992) study. Details of this adjustment procedure are provided in the Benefits TSD for the Nonroad Diesel rulemaking (Abt Associates, 2003).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: the WTP to avoid a case of severe CB, as described by Viscusi, Magat, and Huber; the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi, Magat, and Huber); and the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean) of this distribution, which is about $331,000 (2000$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB.

Valuing Reductions in Nonfatal Myocardial Infarctions (Heart Attacks). The Agency has recently incorporated into its analyses the impact of air pollution on the expected number of nonfatal heart attacks, although it has examined the impact of reductions in other related cardiovascular endpoints. We were not able to identify a suitable WTP value for reductions in the risk of nonfatal heart attacks. Instead, we use a COI unit value with two components: the direct medical costs and the opportunity cost (lost earnings) associated with the illness event. Because the costs associated with a myocardial infarction extend beyond the initial event itself, we consider costs incurred over several years. Using age-specific annual lost earnings estimated by Cropper and Krupnick (1990) and a 3% discount rate, we estimated a present discounted value in lost earnings (in 2000$) over 5 years due to a myocardial infarction of $8,774 for someone between the ages of 25 and 44, $12,932 for someone between the ages of 45 and 54, and $74,746 for someone between the ages of 55 and 65. The corresponding age-specific estimates of lost earnings (in 2000$) using a 7% discount rate are $7,855, $11,578, and $66,920, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for populations under 25 or over 65. As such, we do not include lost earnings in the cost estimates for these age groups.

We found three possible sources in the literature of estimates of the direct medical costs of myocardial infarction:

- Wittels et al. (1990) estimated expected total medical costs of myocardial infarction over 5 years to be $51,211 (in 1986$) for people who were admitted to the hospital and survived hospitalization. (There does not appear to be any discounting used.) Wittels et al. was used to value coronary heart disease in the 812 Retrospective Analysis of the Clean Air Act. Using the CPI-U for medical care, the Wittels estimate is $109,474 in year 2000$. This estimated cost is based on a medical cost model, which incorporated therapeutic options, projected outcomes, and prices (using "knowledgeable cardiologists" as consultants). The model used medical data and medical decision algorithms to estimate the probabilities of certain events and/or medical procedures being used. The authors note that the average length of hospitalization for acute myocardial infarction has decreased over time (from an average of 12.9 days in 1980 to an average of 11 days in 1983). Wittels et al. used 10 days as the average in their study. It is unclear how much further the length of stay for myocardial infarction may have decreased from 1983 to the present. The average length of stay for ICD code 410 (myocardial infarction) in the year-2000 Agency for Healthcare Research and Quality (AHRQ) HCUP database is 5.5 days. However, this may include patients who died in the hospital (not included among our nonfatal myocardial infarction cases), whose length of stay was therefore substantially shorter than it would be if they had not died.

- Eisenstein et al. (2001) estimated 10-year costs of $44,663 in 1997$, or $49,651 in 2000$ for myocardial infarction patients, using statistical prediction (regression) models to estimate inpatient costs. Only inpatient costs (physician fees and hospital costs) were included.

- Russell et al. (1998) estimated first-year direct medical costs of treating nonfatal myocardial infarction of $15,540 (in 1995$) and $1,051 annually thereafter. Converting to year 2000$, that would be $23,353 for a 5-year period (without discounting) or $29,568 for a 10-year period.

In summary, the three different studies provided significantly different values (see Table 5-13).

Table 5-13: Alternative Direct Medical Cost of Illness Estimates for Nonfatal Heart Attacks

Study	*Direct Medical Costs (2000$)*	*Over an x-Year Period, for x =*
Wittels et al. (1990)	$109,474[a]	5
Russell et al. (1998)	$22,331[b]	5
Eisenstein et al. (2001)	$49,651[b]	10
Russell et al. (1998)	$27,242[b]	10

[a] Wittels et al. (1990) did not appear to discount costs incurred in future years.
[b] Using a 3% discount rate. Discounted values as reported in the study.

As noted above, the estimates from these three studies are substantially different, and we have not adequately resolved the sources of differences in the estimates. Because the wage-related opportunity cost estimates from Cropper and Krupnick (1990) cover a 5-year period, we used estimates for medical costs that similarly cover a 5-year period (i.e., estimates from Wittels et al. (1990) and Russell et al. (1998). We used a simple average of the two 5-year estimates, or $65,902, and added it to the 5-year opportunity cost estimate. The resulting estimates are given in Table 5-14.

Table 5-14: Estimated Costs Over a 5-Year Period (in 2000$) of a Nonfatal Myocardial Infarction

Age Group	*Opportunity Cost*	*Medical Cost[a]*	*Total Cost*
0–24	$0	$65,902	$65,902
25–44	$8,774[b]	$65,902	$74,676
45–54	$12,253[b]	$65,902	$78,834
55–65	$70,619[b]	$65,902	$140,649
> 65	$0	$65,902	$65,902

[a] An average of the 5-year costs estimated by Wittels et al. (1990) and Russell et al. (1998).
[b] From Cropper and Krupnick (1990), using a 3% discount rate.

5.1.6 Human Welfare Impact Assessment

PM and PM precursor emissions have numerous documented effects on environmental quality that affect human welfare. These welfare effects include direct damages to property, either through impacts on material structures or by soiling of surfaces, direct economic damages in the form of lost productivity of crops and trees, indirect damages through alteration of ecosystem functions, and indirect economic damages through the loss in value of recreational experiences or the existence value of important resources. EPA's Criteria Documents for PM, NOx, and SO2 list numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (U.S. EPA, 2005; 1993) This section describes individual effects and how we quantify and monetize them. These effects include changes in nitrogen and sulfate deposition, and visibility.

Visibility Benefits

Changes in the level of ambient PM caused by the reduction in emissions associated with attainment strategies for the PM NAAQS will change the level of visibility throughout the United States. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Great Smokey Mountains National Park. This section discusses the measurement of the economic benefits of improved visibility.

It is difficult to quantitatively define a visibility endpoint that can be used for valuation. Increases in PM concentrations cause increases in light extinction, a measure of how much the components of the atmosphere absorb light. More light absorption means that the clarity of visual images and visual range is reduced, *ceteris paribus.* Light absorption is a variable that can be accurately measured. Sisler (1996) created a unitless measure of visibility, the *deciview*, based directly on the degree of measured light absorption. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10% in available light. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." Air quality models were used to predict the change in visibility, measured in deciviews, of the areas affected by the control options.[22]

EPA considers benefits from two categories of visibility changes: residential visibility and recreational visibility. In both cases economic benefits are believed to consist of use values and nonuse values. Use values include the aesthetic benefits of better visibility, improved road and air safety, and enhanced recreation in activities like hunting and birdwatching. Nonuse values are based on people's beliefs that the environment ought to exist free of human-induced haze.

[22] A change of less than 10% in the light extinction budget represents a measurable improvement in visibility but may not be perceptible to the eye in many cases. Some of the average regional changes in visibility are less than one deciview (i.e., less than 10% of the light extinction budget) and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility that, when considered together, amount to perceptible changes in visibility.

Nonuse values may be more important for recreational areas, particularly national parks and monuments.

Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas and also in recreational areas not listed as federal Class I areas.[23] For the purposes of this analysis, recreational visibility improvements are defined as those that occur specifically in federal Class I areas. A key distinction between recreational and residential benefits is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the United States are assumed to derive some benefit from improvements in Class I areas. Values are assumed to be higher if the Class I area is located close to their home.[24]

Only two existing studies provide defensible monetary estimates of the value of visibility changes. One is a study on residential visibility conducted in 1990 (McClelland et al., 1993) and the other is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990a; 1990b). Although there are a number of other studies in the literature, they were conducted in the early 1980s and did not use methods that are considered defensible by current standards. Both the Chestnut and Rowe and McClelland et al. studies use the CV method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CV surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CV study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas.[25] This study serves as an essential input to our estimates of the benefits of recreational visibility improvements in the primary benefits estimates. Consistent with SAB advice, EPA has designated the McClelland et al. study as significantly less reliable for regulatory benefit-cost analysis, although it does provide useful estimates on the order of magnitude of residential visibility benefits (U.S. EPA-SAB, 1999). Residential visibility benefits are not calculated for this analysis.

The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. Respondents in five states were asked about their WTP to protect national parks or NPS-managed wilderness areas within a particular region. The survey used photographs reflecting different visibility levels in the specified recreational areas. The visibility levels in these photographs were later converted to deciviews for the current analysis. The survey data collected were used to estimate a WTP equation for improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

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[23] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

[24] For details of the visibility estimates discussed in this chapter, please refer to the Benefits TSD for the Nonroad Diesel rulemaking (Abt Associates, 2003).

[25] An SAB advisory letter indicates that "many members of the Council believe that the Chestnut and Rowe study is the best available" (EPA-SAB-COUNCIL-ADV-00-002, 1999, p. 13). However, the committee did not formally approve use of these estimates because of concerns about the peer-reviewed status of the study. EPA believes the study has received adequate review and has been cited in numerous peer-reviewed publications (Chestnut and Dennis, 1997).

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the United States. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. A complete description of the benefits transfer method used to infer values for visibility changes in Class I areas outside the study regions is provided in the Benefits TSD for the Nonroad Diesel rulemaking (Abt Associates, 2003).

The Chestnut and Rowe study (Chestnut and Rowe, 1990a; 1990b), although representing the best available estimates, has a number of limitations. These include the following:

- The age of the study (late 1980s) will increase the uncertainty about the correspondence of the estimated values to those that might be provided by current or future populations.
- The survey focused only on populations in five states, so the application of the estimated values to populations outside those states requires that preferences of populations in the five surveyed states be similar to those of nonsurveyed states.
- There is an inherent difficulty in separating values expressed for visibility improvements from an overall value for improved air quality. The Chestnut and Rowe study attempted to control for this by informing respondents that "other households are being asked about visibility, human health, and vegetation protections in urban areas and at national parks in other regions." However, most of the respondents did not feel that they were able to segregate visibility at national parks entirely from residential visibility and health effects.
- It is not clear exactly what visibility improvements the respondents to the Chestnut and Rowe survey were valuing. For the purpose of the benefits analysis for this rule, EPA assumed that respondents provided values for changes in annual average visibility. Because most policies will result in a shift in the distribution of visibility (usually affecting the worst days more than the best days), the annual average may not be the most relevant metric for policy analysis.
- The WTP question asked about changes in average visibility. However, the survey respondents were shown photographs of only summertime conditions, when visibility is generally at its worst. It is possible that the respondents believed those visibility conditions held year-round, in which case they would have been valuing much larger overall improvements in visibility than what otherwise would be the case.
- The survey did not include reminders of possible substitutes (e.g., visibility at other parks) or budget constraints. These reminders are considered to be best practice for stated preference surveys.
- The Chestnut and Rowe survey focused on visibility improvements in and around national parks and wilderness areas. The survey also focused on visibility improvements of national parks in the southwest United States. Given that national parks and wilderness areas exhibit unique characteristics, it is not clear whether the WTP estimate obtained from Chestnut and Rowe can be transferred to other national parks and wilderness areas, without introducing additional uncertainty.

In general, the survey design and implementation reflect the period in which the survey was conducted. Since that time, many improvements to the stated preference methodology have been developed. As future survey efforts are completed, EPA will incorporate values for visibility improvements reflecting the improved survey designs.

The estimated relationship from the Chestnut and Rowe study is only directly applicable to the populations represented by survey respondents. EPA used benefits transfer methodology to extrapolate these results to the population affected by the reductions in precursor emissions associated with attainment strategies for the PM NAAQS. A general WTP equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from attainment strategies for the PM NAAQS. The method for developing calibrated WTP functions is based on the approach developed by Smith et al. (2002). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut, 1997). The benefits estimates here incorporate Chestnut's estimate that a 1% increase in income is associated with a 0.9% increase in WTP for a given change in visibility. A more detailed explanation of the visibility benefits methodology is provided in Appendix I.

Using the methodology outlined above, EPA estimates that the total WTP for the visibility improvements in Southeastern Class I areas brought about by attainment strategies for the PM NAAQS is $530 million in 2020 for attainment of the 15/35 option and $1,200 million for attainment of the 14/35 option. This value includes the value to households living in the same state as the Class I area as well as values for all households in the United States living outside the state containing the Class I area, and the value accounts for growth in real income.

One major source of uncertainty for the visibility benefits estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for WTP for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small or outside the range covered in the Chestnut and Rowe study could also affect the results.

Agricultural, Forestry, and Other Vegetation-Related Benefits

Certain illustrative attainment strategies which reduce NO_x emissions will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen oversaturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen represent additional agricultural benefits.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in the deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification, which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

Benefits from Reductions in Materials Damage

The control options that we modeled are expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Particulate matter also has corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefits analyses have been able to provide quantitative estimates of household soiling damage. Consistent with SAB advice, we determined that the existing data (based on consumer expenditures from the early 1970s) are too out of date to provide a reliable estimate of current household soiling damages (U.S. EPA, 1998).

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits.

Benefits from Reduced Ecosystem Damage

The effects of air pollution on the health and stability of ecosystems are potentially very important but are at present poorly understood and difficult to measure. Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999).

Direct functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP-based measure of benefits depends on the availability of these functions and on estimates of the value of environmental responses. Because neither appropriate functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

If better models of ecological effects can be defined, EPA believes that progress can be made in estimating WTP measures for ecosystem functions. These estimates would be superior to avoided cost estimates in placing economic values on the welfare changes associated with air pollution damage to ecosystem health. For example, if nitrogen or sulfate loadings can be linked to measurable and definable changes in fish populations or definable indexes of biodiversity, then stated preference studies can be designed to elicit individuals' WTP for changes in these effects. This is an important area for further research and analysis and will require close collaboration among air quality modelers, natural scientists, and economists.

5.2 Benefits Analysis—Results and Probabilistic Uncertainty Analysis

5.2.1 Results of National Assessment

Applying the impact and valuation functions described previously in this chapter to the estimated changes in PM yields estimates of the changes in health and environmental endpoints (e.g., premature mortalities, cases, admissions, and change in light extinction) and the associated monetary values for those changes. As noted earlier, benefits are provided for three regions of the U.S. (Eastern, Western excluding CA, and CA). Benefits are also separately provided for the modeled scenarios (which result in only partial attainment for a limited number of areas) and for residual attainment based on "rolling back" $PM_{2.5}$ design values to the level of the standards (see Chapter 4). Because of the differences in the sources of effect estimates for mortality versus morbidity (mortality includes both epidemiology and expert elicitation based impact functions), mortality estimates are presented separately from morbidity.

Estimates of mortality and morbidity impacts are presented in Tables 5-16 through 5-19. For mortality, results based on concentration response functions from the American Cancer Society Study (ACS), Six Cities, and Expert Elicitation are being provided in each table to give an indication of the sensitivity of the benefits estimates to alternative assumptions. Following the recommendations of the NRC report (NRC, 2002), we identify those estimates which are based on empirical data, and those which are based on expert judgments. EPA intends to ask its Science Advisory Board to evaluation how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies, and if so, the appropriateness of using Laden et al 2006, the most recently published update, as the estimate for the Six Cities based model.

Monetized values for both health and welfare endpoints are presented in Tables 5-20 through 5-26, along with total aggregate monetized benefits in Table 5-27. Figures 5-8 and 5-9 provide a graphical view of the results of the benefits analysis. The graphs show the relative proportions of total benefits in each area accounted for by the modeled and residual benefits and also shows the relative magnitudes of benefits across the three regions of the U.S. Finally, the graphs allow for comparison across the sources of data for the mortality concentration-response function.

All of the monetary benefits are in constant-year 1999 dollars. For each endpoint and total benefits, we provide both the mean estimate and the 95% confidence interval. Note that in the case of the premature mortality estimates derived from the expert elicitation, we report the 95% credible interval, which encompasses a broader representation of uncertainty relative to the statistical confidence intervals provided for the effect estimates derived from the epidemiology literature.

Table 5-16: Illustrative Strategy to Attain 15/35: Estimated Reduction in Premature Mortality (Incremental to 15/65 Attainment Strategy) 90th Percentile Confidence Intervals Provided in Parentheses[a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	360 (140 – 600)	17 (7 – 27)	80 (30 – 120)	15 (6 – 24)	520 (200 – 830)	1,600 (610 – 2,490)	960 (370 – 1,500)	1,600 (620 – 2,500)	2,500 (1,000 – 4,100)
Harvard Six-City Study[c]	800 (450 – 1,200)	38 (21 – 55)	200 (90 – 300)	30 (18 – 50)	1,200 (640 – 1,700)	3,500 (1,900 – 5,000)	2,200 (1,180 – 3,100)	3,600 (1,900 – 5,100)	5,700 (3,100 – 8,300)
Woodruff et al., 1997 (infant mortality)	1 (1 – 2)	0.02 (0.01 – 0.03)	0.7 (0.4 – 1.1)	0.3 (0.2 – 0.5)	1 (1 – 2)	4.8 (2.3 – 7.2)	3 (1 – 5)	5 (3 – 8)	8 (4 – 12)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	1,700 (300 – 3,100)	41 (8 – 75)	1,400 (300 – 2,500)	370 (70 – 660)	1,600 (300 – 2,800)	5,100 (900 – 9,100)	4,600 (900 – 8,400)	5,500 (1,000 – 9,900)	10,000 (1,900 – 18,000)
Expert B	1,400 (200 – 2,800)	34 (5 – 67)	1,100 (100 – 2,200)	290 (30 – 600)	1,300 (200 – 2,500)	4,100 (600 – 8,200)	3,700 (400 – 7,600)	4,400 (600 – 8,900)	8,100 (1,000 – 16,000)
Expert C	1,400 (230 – 2,800)	34 (6 – 67)	1,100 (190 – 2,200)	300 (50 – 600)	1,300 (210 – 2,500)	4,200 (700 – 8,200)	3,800 (630 – 7,500)	4,500 (760 – 8,900)	8,400 (1,400 – 16,000)
Expert D	920 (190 – 1,500)	23 (5 – 36)	750 (150 – 1,200)	200 (41 – 320)	850 (170 – 1,400)	2,800 (570 – 4,400)	2,500 (510 – 4,000)	3,000 (610 – 4,800)	5,500 (1,100 – 8,800)
Expert E	2,100 (1,100 – 3,200)	52 (26 – 78)	1,700 (870 – 2,600)	460 (230 – 690)	2,000 (980 – 2,900)	6,400 (3,200 – 9,500)	5,800 (2,900 – 8,700)	6,900 (3,500 – 10,000)	13,000 (6,400 – 19,000)
Expert F	1,200 (820 – 1,700)	30 (20 – 41)	1,000 (660 – 1,400)	270 (180 – 360)	1,100 (760 – 1,600)	3,700 (2,500 – 5,100)	3,400 (2,200 – 4,600)	4,000 (2,700 – 5,500)	7,400 (4,900 – 10,000)
Expert G	750 (0 – 1,400)	18 (0 – 34)	610 (0 – 1,100)	160 (0 – 300)	690 (0 – 1,300)	2,300 (0 – 4,200)	2,000 (0 – 3,800)	2,400 (0 – 4,500)	4,500 (0 – 8,300)
Expert H	920 (0 – 2,200)	22 (0 – 53)	750 (0 – 1,800)	200 (0 – 470)	850 (0 – 2,000)	2,800 (0 – 6,500)	2,500 (0 – 6,000)	3,000 (0 – 7,100)	5,500 (0 – 13,000)
Expert I	1,300 (200 – 2,300)	32 (5 – 55)	1,100 (200 – 1,800)	280 (40 – 490)	1,200 (200 – 2,100)	3,900 (600 – 6,800)	3,600 (600 – 6,200)	4,300 (700 – 7,300)	7,900 (1,200 – 13,000)
Expert J	1,200 (310 – 2,300)	28 (7 – 56)	900 (250 – 1,800)	250 (66 – 490)	1,100 (280 – 2,100)	3,500 (930 – 6,800)	3,200 (840 – 6,200)	3,800 (1,000 – 7,300)	7,000 (1,800 – 14,000)
Expert K	190 (0 – 960)	5 (0 – 23)	160 (0 – 780)	41 (0 – 210)	200 (0 – 940)	580 (0 – 2,880)	540 (0 – 2,700)	630 (0 – 3,100)	1,200 (0 – 5,800)
Expert L	910 (100 – 1,700)	25 (5 – 42)	660 (0 – 1,400)	180 (10 – 380)	920 (200 – 1,600)	2,900 (500 – 5,200)	2,500 (300 – 4,700)	3,100 (500 – 5,600)	5,600 (800 – 10,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.
[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs
[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-17: Illustrative Strategy to Attain 15/35: Estimated Reductions in Morbidity (Incremental to 15/65 Attainment Strategy) 90th Percentile Confidence Intervals Provided in Parentheses[a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Morbidity Functions Derived from Epidemiology Literature									
Chronic bronchitis (age >25 and over)	360 (66 – 650)	8 (1 – 14)	240 (45 – 440)	87 (16 – 160)	440 (81 – 800)	1,500 (280 – 2,700)	1,000 (190 – 1,900)	1,600 (300 – 2,900)	2,600 (490 – 4,800)
Nonfatal myocardial infarction (age >17)	800 (420 – 1,100)	38 (20 – 55)	140 (76 – 200)	30 (16 – 44)	1,000 (560 – 1,500)	3,000 (1,600 – 4,300)	1,900 (1,100 – 2,800)	3,100 (1,700 – 4,400)	5,000 (2,700 – 7,200)
Hospital admissions—respiratory (all ages)	86 (43 – 130)	4 (2 – 6)	13 (7 – 20)	3 (1 – 4)	104 (52 – 160)	320 (160 – 480)	200 (100 – 310)	330 (160 – 490)	530 (260 – 800)
Hospital admissions—cardiovascular (age >17)	190 (120 – 260)	9 (6 – 12)	30 (19 – 42)	6 (4 – 9)	220 (140 – 300)	650 (400 – 887)	440 (280 – 600)	660 (410 – 910)	1,100 (690 – 1,500)
Emergency room visits for asthma (age <19)	290 (170 – 410)	7 (4 – 11)	25 (15 – 35)	6 (3 – 8)	210 (130 – 300)	690 (410 – 970)	530 (310 – 740)	700 (417 – 990)	1,200 (730 – 1,700)
Acute bronchitis (age 8–12)	870 (–30 – 1,800)	17 (–1 – 34)	650 (–20 – 1,300)	280 (–10 – 560)	1,240 (–40 – 2,500)	4,300 (–150 – 8,500)	2,800 (–90 – 5,600)	4,500 (–160 – 9,100)	7,300 (–260 – 15,000)
Lower respiratory symptoms (age 7–14)	4,900 (2,400 – 7,500)	180 (86 – 270)	1,400 (660 – 2,100)	300 (150 – 460)	11,600 (5,600 – 17,600)	38,000 (18,000 – 57,000)	18,000 (8,600 – 27,000)	38,000 (19,000 – 57,000)	56,000 (27,000 – 84,000)
Upper respiratory symptoms (asthmatic children age 9–18)	3,600 (1,100 – 6,100)	130 (41 – 220)	1,000 (320 – 1,700)	220 (70 – 370)	8,500 (2,700 – 14,300)	28,000 (8,800 – 47,000)	13,000 (4,100 – 22,000)	28,000 (8,900 – 48,000)	41,000 (13,000 – 70,000)
Asthma exacerbation (asthmatic children age 6–18)	4,400 (500 – 13,000)	160 (18 – 0)	1,200 (130 – 3,500)	270 (30 – 780)	10,400 (1,200 – 30,200)	34,000 (3,800 – 99,000)	16,000 (1,800 – 47,000)	35,000 (3,800 – 100,000)	51,000 (5,600 – 150,000)
Work loss days (age 18–65)	33,000 (29,000 – 37,000)	1,300 (1,100 – 1,400)	7,900 (6,900 – 8,900)	1,800 (1,600 – 2,000)	73,500 (64,000 – 82,900)	230,000 (200,000 – 260,000)	110,000 (100,000 – 130,000)	230,000 (200,000 – 260,000)	350,000 (300,000 – 390,000)
Minor restricted-activity days (age 18–65)	200,000 (170,000 – 230,000)	8,000 (6,000 – 9,000)	46,000 (39,000 – 53,000)	10,000 (9,000 – 12,000)	430,000 (360,000 – 500,000)	1,300,000 (1,100,000 – 1,500,000)	680,000 (570,000 – 780,000)	1,400,000 (1,100,000 – 1,600,000)	2,000,000 (1,700,000 – 2,300,000)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-18: Illustrative Strategy to Attain 14/35: Estimated Reduction in Premature Mortality (Incremental to 15/65 Attainment Strategy) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		Western U.S. Excluding CA		California		National Total		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	2,100 (820 – 3,400)	70 (29 – 120)	77 (30 – 120)	15 (6 – 24)	500 (200 – 810)	1,600 (650 – 2,600)	2,700 (1,000 – 4,300)	1,700 (680 – 2,800)	4,400 (1,700 – 7,100)
Harvard Six-City Study[c]	4,700 (2,600 – 6,900)	170 (90 – 250)	170 (95 – 250)	34 (18 – 49)	1,100 (620 – 1,700)	3,700 (2,000 – 5,400)	6,000 (3,300 – 8,800)	3,900 (2,100 – 5,700)	9,900 (5,400 – 14,000)
Woodruff et al 1997 (infant mortality)	8 (4 – 11)	0.2 (0.1 – 0.3)	0.7 (0.3 – 1.1)	0 (0 – 1)	1.3 (1.0 – 1.9)	5 (2 – 8)	10 (5 – 14)	6 (3 – 8)	15 (7 – 23)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	10,000 (1,900 – 18,000)	180 (30 – 330)	1,400 (250 – 2,400)	370 (67 – 660)	1,500 (300 – 2,800)	5,300 (1,000 – 9,600)	13,000 (2,400 – 24,000)	5,900 (1,100 – 10,600)	19,000 (3,500 – 34,000)
Expert B	8,100 (1,000 – 17,000)	150 (20 – 300)	1,000 (100 – 2,200)	290 (29 – 600)	1,200 (200 – 2,500)	4,300 (600 – 8,600)	10,000 (1,200 – 21,000)	4,700 (600 – 9,500)	15,000 (1,900 – 31,000)
Expert C	8,400 (1,400 – 17,000)	150 (25 – 300)	1,100 (190 – 2,200)	300 (50 – 600)	1,300 (210 – 2,500)	4,400 (730 – 8,600)	11,000 (1,800 – 21,000)	4,900 (810 – 9,500)	16,000 (2,600 – 31,000)
Expert D	5,500 (1,100 – 8,800)	100 (20 – 160)	740 (150 – 1,200)	200 (41 – 320)	830 (170 – 1,300)	2,900 (590 – 4,600)	7,100 (1,400 – 11,000)	3,200 (650 – 5,100)	10,000 (2,100 – 16,000)
Expert E	13,000 (6,400 – 19,000)	230 (110 – 300)	1,700 (850 – 2,500)	460 (230 – 690)	1,900 (960 – 2,900)	6,700 (3,400 – 10,000)	16,000 (8,200 – 25,000)	7,400 (3,700 – 11,000)	24,000 (12,000 – 35,000)
Expert F	7,300 (4,900 – 10,000)	130 (90 – 180)	980 (650 – 1,300)	270 (180 – 360)	1,100 (740 – 1,500)	3,900 (2,600 – 5,300)	9,400 (6,300 – 13,000)	4,300 (2,900 – 5,800)	14,000 (9,100 – 19,000)
Expert G	4,500 (0 – 8,300)	80 (0 – 150)	600 (0 – 1,100)	160 (0 – 300)	670 (0 – 1,200)	2,400 (0 – 4,400)	5,700 (0 – 11,000)	2,600 (0 – 4,800)	8,300 (0 – 15,000)
Expert H	5,500 (0 – 13,000)	100 (0 – 230)	740 (0 – 1,700)	200 (1 – 470)	830 (0 – 2,000)	2,900 (0 – 6,800)	7,100 (0 – 17,000)	3,200 (0 – 7,600)	10,000 (0 – 24,000)
Expert I	7,900 (1,200 – 14,000)	140 (20 – 240)	1,000 (160 – 1,800)	280 (44 – 490)	1,200 (200 – 2,000)	4,100 (600 – 7,100)	10,000 (1,600 – 17,000)	4,600 (700 – 7,800)	15,000 (2,300 – 25,000)
Expert J	7,000 (1,800 – 14,000)	120 (33 – 240)	930 (240 – 1,800)	250 (66 – 490)	1,000 (270 – 2,000)	3,700 (970 – 7,100)	8,900 (2,300 – 17,000)	4,000 (1,070 – 7,800)	13,000 (3,400 – 25,000)
Expert K	1,100 (0 – 5,700)	21 (0 – 100)	150 (0 – 760)	41 (0 – 210)	190 (0 – 920)	610 (0 – 3,000)	1,500 (0 – 7,400)	670 (0 – 3,300)	2,200 (0 – 11,000)
Expert L	5,400 (700 – 10,000)	110 (20 – 180)	650 (0 – 1,400)	180 (13 – 380)	890 (200 – 1,500)	3,100 (500 – 5,400)	7,000 (900 – 13,000)	3,300 (600 – 5,900)	10,000 (1,400 – 19,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-19: Illustrative Strategy to Attain 14/35: Estimated Reductions in Morbidity (Incremental to 15/65 Attainment Strategy) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Morbidity Impact Function Derived frm Epidemiology Literature									
Chronic bronchitis (age >25 and over)	2,200 (410 – 4,100)	40 (7 – 70)	240 (44 – 430)	87 (16 – 160)	430 (79 – 780)	1,600 (290 – 2,800)	2,900 (540 – 5,300)	1,700 (320 – 3,100)	4,600 (850 – 8,300)
Nonfatal myocardial infarction (age >17)	4,200 (2,300 – 6,100)	150 (80 – 220)	140 (77 – 200)	30 (16 – 44)	1,000 (540 – 1,500)	3,200 (1,800 – 4,600)	5,300 (2,900 – 7,800)	3,400 (1,900 – 4,900)	8,700 (4,800 – 13,000)
Hospital admissions—respiratory (all ages)	500 (250 – 750)	18 (9 – 27)	13 (7 – 20)	3 (1 – 4)	100 (50 – 150)	340 (170 – 510)	620 (310 – 930)	360 (180 – 540)	980 (490 – 1,500)
Hospital admissions—cardiovascular (age >17)	1,100 (680 – 1,500)	37 (24 – 51)	31 (19 – 42)	6 (4 – 9)	210 (130 – 291)	690 (430 – 940)	1,300 (830 – 1,800)	730 (460 – 1,000)	2,100 (1,300 – 2,800)
Emergency room visits for asthma (age <19)	2,200 (1,300 – 3,000)	76 (45 – 110)	25 (15 – 36)	6 (3 – 8)	210 (120 – 290)	740 (438 – 1,040)	2,400 (1,400 – 3,400)	820 (486 – 1,200)	3,200 (1,900 – 4,500)
Acute bronchitis (age 8–12)	5,900 (–200 – 12,000)	110 (–4 – 220)	640 (–20 – 1,300)	280 (–10 – 560)	1,200 (–40 – 2,400)	4,500 (–160 – 9,000)	7,700 (–260 – 16,000)	4,900 (–170 – 9,800)	13,000 (–440 – 25,000)
Lower respiratory symptoms (age 7–14)	34,000 (16,000 – 51,000)	1,200 (600 – 1,800)	1,400 (670 – 2,100)	300 (150 – 460)	11,000 (5,400 – 17,100)	40,000 (20,000 – 61,000)	46,000 (22,400 – 70,000)	42,000 (20,000 – 63,000)	88,000 (43,000 – 130,000)
Upper respiratory symptoms (asthmatic children age 9–18)	25,000 (7,800 – 42,000)	900 (270 – 1,500)	1,000 (320 – 1,700)	220 (70 – 370)	8,300 (2,600 – 13,900)	30,000 (9,400 – 50,000)	34,000 (11,000 – 57,000)	31,000 (9,800 – 52,000)	65,000 (20,000 – 110,000)
Asthma exacerbation (asthmatic children age 6–18)	30,000 (3,400 – 89,000)	1,000 (120 – 3,000)	1,200 (140 – 3,600)	270 (30 – 780)	10,100 (1,100 – 29,300)	36,000 (4,100 – 106,000)	42,000 (4,600 – 120,000)	38,000 (4,200 – 110,000)	79,000 (8,900 – 230,000)
Work loss days (age 18–65)	220,000 (190,000 – 250,000)	7,000 (6,000 – 8,000)	8,000 (7,000 – 9,000)	1,800 (1,600 – 2,000)	71,300 (62,100 – 80,400)	240,000 (210,000 – 280,000)	300,000 (260,000 – 340,000)	250,000 (220,000 – 290,000)	550,000 (480,000 – 620,000)
Minor restricted-activity days (age 18–65)	1,300,000 (1,100,000 – 1,500,000)	44,000 (37,000 – 51,000)	47,000 (40,000 – 54,000)	10,000 (8,800 – 12,000)	420,000 (350,000 – 480,000)	1,400,000 (1,200,000 – 1,700,000)	1,800,000 (1,500,000 – 2,000,000)	1,500,000 (1,300,000 – 1,700,000)	3,300,000 (2,700,000 – 3,800,000)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-20: Illustrative Strategy to Attain 15/35: Estimated Monetary Value of Reductions in Risk of Premature Mortality (3 Percent Discount Rate, in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	$2,100 ($470 – $4,400)	$97 ($22 – $200)	$440 ($99 – $920)	$87 ($19 – $180)	$3,000 ($670 – $6,200)	$9,000 ($2,000 – $19,000)	$5,500 ($1,200 – $12,000)	$9,200 ($2,000 – $19,000)	$15,000 ($3,300 – $31,000)
Harvard Six-City Study[c]	$4,800 ($1,200 – $9,200)	$220 ($57 – $430)	$1,000 ($260 – $1,900)	$200 ($51 – $380)	$6,800 ($1,800 – $13,000)	$20,000 ($5,300 – $39,000)	$13,000 ($3,300 – $24,000)	$21,000 ($5,400 – $40,000)	$33,000 ($8,600 – $64,000)
Woodruff et al 1997 (infant mortality)	$6 ($1 – $11)	$0 ($0 – $0)	$4 ($1 – $8)	$2 ($0 – $4)	$8 ($2 – $15)	$28 ($7 – $55)	$17 ($4 – $35)	$30 ($7 – $59)	$47 ($12 – $94)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	$9,800 ($1,300 – $22,000)	$240 ($32 – $540)	$8,000 ($1,100 – $18,000)	$2,100 ($280 – $4,800)	$9,000 ($1,200 – $20,000)	$29,000 ($4,000 – $67,000)	$27,000 ($3,600 – $61,000)	$32,000 ($4,300 – $72,000)	$59,000 ($7,900 – $130,000)
Expert B	$7,800 ($650 – $21,000)	$200 ($21 – $510)	$6,100 ($390 – $17,000)	$1,700 ($120 – $4,500)	$7,400 ($740 – $19,000)	$24,000 ($2,300 – $62,000)	$21,000 ($1,800 – $57,000)	$26,000 ($2,400 – $68,000)	$47,000 ($4,200 – $120,000)
Expert C	$8,100 ($980 – $20,000)	$200 ($24 – $480)	$6,600 ($800 – $16,000)	$1,800 ($210 – $4,200)	$7,500 ($900 – $18,000)	$24,000 ($3,000 – $59,000)	$22,000 ($2,700 – $54,000)	$26,000 ($3,200 – $63,000)	$48,000 ($5,900 – $120,000)
Expert D	$5,300 ($800 – $11,000)	$130 ($19 – $270)	$4,300 ($650 – $9,100)	$1,200 ($170 – $2,400)	$4,900 ($730 – $10,000)	$16,000 ($2,400 – $34,000)	$15,000 ($2,200 – $31,000)	$17,000 ($2,600 – $36,000)	$32,000 ($4,800 – $67,000)
Expert E	$12,000 ($3,100 – $24,000)	$300 ($76 – $600)	$10,000 ($2,500 – $20,000)	$2,700 ($670 – $5,300)	$11,000 ($2,800 – $22,000)	$37,000 ($9,300 – $73,000)	$34,000 ($8,500 – $67,000)	$40,000 ($10,000 – $79,000)	$74,000 ($19,000 – $150,000)
Expert F	$7,200 ($1,900 – $13,000)	$170 ($47 – $330)	$5,800 ($1,600 – $11,000)	$1,500 ($420 – $2,900)	$6,600 ($1,800 – $12,000)	$22,000 ($5,900 – $40,000)	$19,000 ($5,300 – $37,000)	$23,000 ($6,300 – $44,000)	$43,000 ($12,000 – $80,000)
Expert G	$4,300 ($0 – $11,000)	$110 ($0 – $260)	$3,500 ($0 – $8,700)	$940 ($0 – $2,300)	$4,000 ($0 – $9,800)	$13,000 ($0 – $32,000)	$12,000 ($0 – $29,000)	$14,000 ($0 – $35,000)	$26,000 ($0 – $64,000)
Expert H	$5,300 ($17 – $15,000)	$130 ($0 – $370)	$4,300 ($14 – $12,000)	$1,200 ($4 – $3,300)	$4,900 ($16 – $14,000)	$16,000 ($52 – $46,000)	$15,000 ($47 – $42,000)	$17,000 ($56 – $49,000)	$32,000 ($100 – $91,000)
Expert I	$7,600 ($900 – $17,000)	$190 ($22 – $410)	$6,200 ($730 – $14,000)	$1,600 ($190 – $3,600)	$7,000 ($830 – $15,000)	$23,000 ($2,700 – $50,000)	$21,000 ($2,500 – $46,000)	$25,000 ($2,900 – $54,000)	$45,000 ($5,400 – $100,000)
Expert J	$6,800 ($1,100 – $16,000)	$160 ($28 – $390)	$5,500 ($930 – $13,000)	$1,500 ($250 – $3,500)	$6,200 ($1,100 – $15,000)	$20,000 ($3,500 – $48,000)	$18,000 ($3,100 – $44,000)	$22,000 ($3,700 – $52,000)	$40,000 ($6,900 – $95,000)
Expert K	$1,100 ($0 – $6,000)	$27 ($0 – $150)	$900 ($0 – $4,800)	$240 ($0 – $1,300)	$1,100 ($0 – $6,000)	$3,400 ($0 – $18,000)	$3,100 ($0 – $17,000)	$3,600 ($0 – $20,000)	$6,800 ($0 – $36,000)
Expert L	$5,300 ($480 – $13,000)	$140 ($20 – $330)	$3,800 ($110 – $10,000)	$1,100 ($59 – $2,800)	$5,300 ($720 – $12,000)	$17,000 ($2,100 – $40,000)	$14,000 ($1,300 – $36,000)	$18,000 ($2,200 – $43,000)	$32,000 ($3,500 – $79,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-21: Illustrative Strategy to Attain 15/35: Estimated Monetary Value of Reductions in Risk of Premature Mortality (7 Percent Discount Rate, in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		Western U.S. Excluding CA		California		National Total		
	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	National Total Full Attainment
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	$1,800 ($390 – $3,700)	$82 ($18 – $170)	$370 ($83 – $770)	$73 ($16 – $150)	$2,500 ($560 – $5,200)	$7,600 ($1,700 – $16,000)	$4,700 ($1,000 – $9,700)	$7,700 ($1,700 – $16,000)	$12,000 ($2,800 – $26,000)
Harvard Six-City Study[c]	$4,000 ($1,000 – $7,800)	$180 ($48 – $360)	$840 ($220 – $1,600)	$160 ($43 – $320)	$5,700 ($1,500 – $11,000)	$17,000 ($4,400 – $33,000)	$11,000 ($2,700 – $20,000)	$17,000 ($4,500 – $34,000)	$28,000 ($7,300 – $54,000)
Woodruff et al 1997 (infant mortality)	$5 ($1 – $10)	$0 ($0 – $0)	$4 ($1 – $7)	$2 ($0 – $3)	$6 ($2 – $13)	$23 ($6 – $46)	$15 ($4 – $29)	$25 ($6 – $50)	$40 ($10 – $79)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	$8,300 ($1,100 – $19,000)	$200 ($27 – $460)	$6,700 ($900 – $15,000)	$1,800 ($240 – $4,100)	$7,600 ($1,000 – $17,000)	$25,000 ($3,400 – $56,000)	$23,000 ($3,000 – $51,000)	$27,000 ($3,600 – $61,000)	$49,000 ($6,700 – $110,000)
Expert B	$6,600 ($550 – $18,000)	$170 ($17 – $430)	$5,200 ($320 – $14,000)	$1,400 ($100 – $3,800)	$6,200 ($630 – $16,000)	$20,000 ($1,900 – $53,000)	$18,000 ($1,500 – $48,000)	$22,000 ($2,100 – $57,000)	$40,000 ($3,600 – $110,000)
Expert C	$6,900 ($830 – $17,000)	$170 ($20 – $400)	$5,500 ($670 – $13,000)	$1,500 ($180 – $3,600)	$6,300 ($760 – $15,000)	$20,000 ($2,500 – $49,000)	$19,000 ($2,300 – $45,000)	$22,000 ($2,700 – $53,000)	$41,000 ($5,000 – $98,000)
Expert D	$4,500 ($670 – $9,400)	$110 ($16 – $230)	$3,600 ($540 – $7,600)	$970 ($140 – $2,000)	$4,100 ($620 – $8,600)	$14,000 ($2,000 – $28,000)	$12,000 ($1,800 – $26,000)	$15,000 ($2,200 – $31,000)	$27,000 ($4,000 – $56,000)
Expert E	$10,000 ($2,600 – $21,000)	$250 ($64 – $500)	$8,400 ($2,100 – $17,000)	$2,200 ($560 – $4,400)	$9,500 ($2,400 – $19,000)	$31,000 ($7,800 – $61,000)	$28,000 ($7,100 – $56,000)	$34,000 ($8,500 – $66,000)	$62,000 ($16,000 – $120,000)
Expert F	$6,000 ($1,600 – $11,000)	$150 ($40 – $280)	$4,900 ($1,300 – $9,100)	$1,300 ($350 – $2,400)	$5,500 ($1,500 – $10,000)	$18,000 ($4,900 – $34,000)	$16,000 ($4,400 – $31,000)	$20,000 ($5,300 – $37,000)	$36,000 ($9,800 – $67,000)
Expert G	$3,700 ($0 – $9,000)	$89 ($0 – $220)	$3,000 ($0 – $7,300)	$790 ($0 – $1,900)	$3,300 ($0 – $8,300)	$11,000 ($0 – $27,000)	$10,000 ($0 – $25,000)	$12,000 ($0 – $29,000)	$22,000 ($0 – $54,000)
Expert H	$4,500 ($14 – $13,000)	$110 ($0 – $310)	$3,600 ($12 – $10,000)	$970 ($3 – $2,800)	$4,100 ($13 – $12,000)	$13,000 ($44 – $38,000)	$12,000 ($40 – $35,000)	$15,000 ($47 – $41,000)	$27,000 ($87 – $77,000)
Expert I	$6,400 ($760 – $14,000)	$160 ($18 – $340)	$5,200 ($620 – $11,000)	$1,400 ($160 – $3,000)	$5,900 ($700 – $13,000)	$19,000 ($2,300 – $42,000)	$18,000 ($2,100 – $38,000)	$21,000 ($2,500 – $45,000)	$38,000 ($4,600 – $84,000)
Expert J	$5,700 ($960 – $14,000)	$140 ($23 – $330)	$4,600 ($780 – $11,000)	$1,200 ($210 – $2,900)	$5,200 ($880 – $12,000)	$17,000 ($2,900 – $40,000)	$16,000 ($2,600 – $37,000)	$18,000 ($3,100 – $44,000)	$34,000 ($5,800 – $80,000)
Expert K	$930 ($0 – $5,000)	$23 ($0 – $120)	$760 ($0 – $4,100)	$200 ($0 – $1,100)	$950 ($0 – $5,000)	$2,800 ($0 – $15,000)	$2,600 ($0 – $14,000)	$3,100 ($0 – $16,000)	$5,700 ($0 – $31,000)
Expert L	$4,400 ($410 – $11,000)	$120 ($17 – $280)	$3,200 ($91 – $8,800)	$890 ($50 – $2,400)	$4,500 ($600 – $10,000)	$14,000 ($1,700 – $33,000)	$12,000 ($1,100 – $30,000)	$15,000 ($1,800 – $36,000)	$27,000 ($2,900 – $66,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-22: Illustrative Strategy to Attain 15/35: Estimated Monetary Value of Morbidity Reductions (in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Morbidity Impact Function Derived frm Epidemiology Literature									
Chronic bronchitis (age >25 and over)	$140 ($11 – $510)	$3 ($0 – $11)	$97 ($8 – $340)	$35 ($3 – $120)	$180 ($14 – $630)	$600 ($47 – $2,100)	$420 ($33 – $1,500)	$640 ($50 – $2,300)	$1,100 ($83 – $3,700)
Nonfatal myocardial infarction (age >17) 3% Discount Rate	$63 ($17 – $140)	$3 ($1 – $7)	$11 ($3 – $24)	$2 ($1 – $5)	$87 ($24 – $190)	$250 ($70 – $540)	$160 ($43 – $350)	$260 ($71 – $560)	$420 ($110 – $910)
Nonfatal myocardial infarction (age >17) 7% Discount Rate	$61 ($15 – $140)	$3 ($1 – $7)	$11 ($3 – $24)	$2 ($1 – $5)	$84 ($22 – $190)	$240 ($64 – $540)	$160 ($40 – $350)	$250 ($66 – $550)	$410 ($110 – $890)
Hospital admissions—respiratory (all ages)	$1.4 ($0.7 – $2.1)	$0.1 ($0.0 – $0.1)	$0.2 ($0.1 – $0.3)	$0.1 ($0.0 – $0.1)	$1.7 ($0.8 – $2.5)	$5.1 ($2.5 – $7.7)	$3.3 ($1.6 – $4.9)	$5.2 ($2.6 – $7.8)	$8.5 ($4.2 – $13.0)
Hospital admissions—cardiovascular (age >17)	$3.9 ($2.5 – $5.4)	$0.2 ($0.1 – $0.3)	$0.6 ($0.4 – $0.9)	$0.1 ($0.1 – $0.2)	$4.6 ($2.9 – $6.3)	$14.0 ($8.4 – $19.0)	$9.0 ($5.7 – $13.0)	$14.0 ($8.7 – $19.0)	$23.0 ($14.0 – $32.0)
Emergency room visits for asthma (age <19)	$0.08 ($0.04 – $0.12)	$0.00 ($0.00 – $0.00)	$0.01 ($0.00 – $0.01)	$0.00 ($0.00 – $0.00)	$0.06 ($0.03 – $0.09)	$0.19 ($0.10 – $0.29)	$0.14 ($0.08 – $0.22)	$0.19 ($0.11 – $0.29)	$0.34 ($0.19 – $0.51)
Acute bronchitis (age 8–12)	$0.32 (–$0.01 – $0.81)	$0.01 ($0.00 – $0.02)	$0.24 (–$0.01 – $0.60)	$0.10 ($0.00 – $0.26)	$0.46 (–$0.02 – $1.10)	$1.60 (–$0.06 – $3.90)	$1.00 (–$0.04 – $2.60)	$1.70 (–$0.06 – $4.20)	$2.70 (–$0.10 – $6.70)
Lower respiratory symptoms (age 7–14)	$0.08 ($0.03 – $0.15)	$0.00 ($0.00 – $0.01)	$0.02 ($0.01 – $0.04)	$0.00 ($0.00 – $0.01)	$0.19 ($0.07 – $0.35)	$0.61 ($0.23 – $1.10)	$0.29 ($0.11 – $0.54)	$0.62 ($0.23 – $1.10)	$0.90 ($0.34 – $1.70)
Upper respiratory symptoms (asthmatic children age 9–18)	$0.10 ($0.03 – $0.21)	$0.00 ($0.00 – $0.01)	$0.03 ($0.01 – $0.06)	$0.01 ($0.00 – $0.01)	$0.23 ($0.06 – $0.48)	$0.75 ($0.20 – $1.60)	$0.35 ($0.09 – $0.75)	$0.76 ($0.20 – $1.60)	$1.10 ($0.29 – $2.40)
Asthma exacerbation (asthmatic children age 6–18)	$0.19 ($0.02 – $0.61)	$0.01 ($0.00 – $0.02)	$0.05 ($0.01 – $0.17)	$0.01 ($0.00 – $0.04)	$0.43 ($0.05 – $1.40)	$1.40 ($0.15 – $4.70)	$0.67 ($0.07 – $2.20)	$1.40 ($0.16 – $4.70)	$2.10 ($0.23 – $7.00)
Work loss days (age 18–65)	$3 ($3 – $4)	$0.13 ($0.11 – $0.15)	$0.9 ($0.8 – $1.0)	$0.19 ($0.17 – $0.22)	$9 ($8 – $10)	$29 ($25 – $33)	$14 ($12 – $15)	$29 ($26 – $33)	$43 ($37 – $48)
Minor restricted-activity days (age 18–65)	$5 ($0 – $10)	$0.19 ($0.02 – $0.37)	$1.2 ($0.1 – $2.2)	$0.26 ($0.02 – $0.51)	$11 ($1 – $21)	$33 ($3 – $65)	$17 ($2 – $33)	$34 ($3 – $66)	$51 ($5 – $99)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-23: Illustrative Strategy to Attain 14/35: Estimated Monetary Value of Reductions in Risk of Premature Mortality (3 Percent Discount Rate, in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		Western U.S. Excluding CA		California		National Total		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	$12,000 ($2,700 – $25,000)	$430 ($96 – $900)	$450 ($100 – $930)	$87 ($19 – $180)	$2,900 ($650 – $6,000)	$9,500 ($2,100 – $20,000)	$15,000 ($3,400 – $32,000)	$10,000 ($2,200 – $21,000)	$26,000 ($5,700 – $53,000)
Harvard Six-City Study[c]	$27,000 ($7,100 – $53,000)	$980 ($250 – $1,900)	$1,000 ($260 – $2,000)	$200 ($51 – $380)	$6,600 ($1,700 – $13,000)	$21,000 ($5,600 – $42,000)	$35,000 ($9,100 – $68,000)	$23,000 ($5,900 – $44,000)	$57,000 ($15,000 – $110,000)
Woodruff et al., 1997 (infant mortality)	$43 ($11 – $86)	$1 ($0 – $2)	$4 ($1 – $8)	$2 ($0 – $4)	$7 ($2 – $15)	$29 ($7 – $58)	$55 ($14 – $110)	$32 ($8 – $63)	$87 ($21 – $170)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	$59,000 ($7,900 – $130,000)	$1,100 ($140 – $2,400)	$7,800 ($1,100 – $18,000)	$2,100 ($280 – $4,800)	$8,800 ($1,200 – $20,000)	$31,000 ($4,200 – $70,000)	$75,000 ($10,000 – $170,000)	$34,000 ($4,600 – $77,000)	$110,000 ($15,000 – $250,000)
Expert B	$47,000 ($3,900 – $130,000)	$860 ($91 – $2,200)	$6,000 ($380 – $17,000)	$1,700 ($120 – $4,500)	$7,200 ($720 – $19,000)	$25,000 ($2,400 – $65,000)	$60,000 ($5,000 – $160,000)	$27,000 ($2,600 – $72,000)	$87,000 ($7,700 – $230,000)
Expert C	$49,000 ($5,900 – $120,000)	$870 ($110 – $2,100)	$6,500 ($790 – $16,000)	$1,800 ($210 – $4,200)	$7,300 ($880 – $18,000)	$25,000 ($3,100 – $61,000)	$62,000 ($7,500 – $150,000)	$28,000 ($3,400 – $68,000)	$90,000 ($11,000 – $220,000)
Expert D	$32,000 ($4,800 – $67,000)	$570 ($85 – $1,200)	$4,300 ($640 – $8,900)	$1,200 ($170 – $2,400)	$4,800 ($710 – $10,000)	$17,000 ($2,500 – $35,000)	$41,000 ($6,100 – $86,000)	$19,000 ($2,800 – $39,000)	$59,000 ($8,900 – $120,000)
Expert E	$74,000 ($18,000 – $150,000)	$1,300 ($330 – $2,600)	$9,800 ($2,500 – $19,000)	$2,700 ($670 – $5,300)	$11,000 ($2,800 – $22,000)	$39,000 ($9,700 – $76,000)	$95,000 ($24,000 – $190,000)	$43,000 ($11,000 – $84,000)	$140,000 ($34,000 – $270,000)
Expert F	$43,000 ($12,000 – $80,000)	$770 ($210 – $1,400)	$5,700 ($1,500 – $11,000)	$1,500 ($420 – $2,900)	$6,400 ($1,700 – $12,000)	$23,000 ($6,100 – $42,000)	$55,000 ($15,000 – $100,000)	$25,000 ($6,700 – $46,000)	$79,000 ($22,000 – $150,000)
Expert G	$26,000 ($0 – $64,000)	$460 ($0 – $1,100)	$3,500 ($0 – $8,500)	$940 ($0 – $2,300)	$3,900 ($0 – $9,600)	$14,000 ($0 – $34,000)	$33,000 ($0 – $82,000)	$15,000 ($0 – $37,000)	$48,000 ($0 – $120,000)
Expert H	$32,000 ($100 – $91,000)	$570 ($2 – $1,600)	$4,300 ($14 – $12,000)	$1,200 ($4 – $3,300)	$4,800 ($15 – $14,000)	$17,000 ($55 – $48,000)	$41,000 ($130 – $120,000)	$18,000 ($60 – $53,000)	$59,000 ($190 – $170,000)
Expert I	$45,000 ($5,400 – $100,000)	$810 ($96 – $1,800)	$6,100 ($720 – $13,000)	$1,600 ($190 – $3,600)	$6,800 ($810 – $15,000)	$24,000 ($2,900 – $52,000)	$58,000 ($6,900 – $130,000)	$26,000 ($3,100 – $58,000)	$85,000 ($10,000 – $190,000)
Expert J	$40,000 ($6,800 – $96,000)	$720 ($120 – $1,700)	$5,400 ($920 – $13,000)	$1,500 ($250 – $3,500)	$6,000 ($1,000 – $14,000)	$21,000 ($3,600 – $50,000)	$52,000 ($8,800 – $120,000)	$23,000 ($4,000 – $55,000)	$75,000 ($13,000 – $180,000)
Expert K	$6,600 ($0 – $35,000)	$120 ($0 – $640)	$880 ($0 – $4,800)	$240 ($0 – $1,300)	$1,100 ($0 – $5,800)	$3,500 ($0 – $19,000)	$8,600 ($0 – $46,000)	$3,900 ($0 – $21,000)	$12,000 ($0 – $67,000)
Expert L	$31,000 ($2,900 – $78,000)	$630 ($90 – $1,400)	$3,700 ($110 – $10,000)	$1,100 ($59 – $2,800)	$5,200 ($700 – $12,000)	$18,000 ($2,200 – $42,000)	$40,000 ($3,700 – $100,000)	$19,000 ($2,300 – $46,000)	$60,000 ($6,100 – $150,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-24: Illustrative Strategy to Attain 14/35: Estimated Monetary Value of Reductions in Risk of Premature Mortality (7 Percent Discount Rate, in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		Western U.S. Excluding CA		California		National Total		National Total Full Attainment
	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	Modeled Partial Attainment	Residual Attainment	
Mortality Impact Functions Derived from Epidemiology Literature									
ACS Study[b]	$10,000 ($2,300 – $21,000)	$360 ($81 – $760)	$380 ($84 – $780)	$73 ($16 – $150)	$2,400 ($540 – $5,100)	$8,000 ($1,800 – $17,000)	$13,000 ($2,900 – $27,000)	$8,500 ($1,900 – $18,000)	$21,000 ($4,800 – $45,000)
Harvard Six-City Study[c]	$23,000 ($6,000 – $45,000)	$820 ($210 – $1,600)	$850 ($220 – $1,600)	$160 ($43 – $320)	$5,500 ($1,400 – $11,000)	$18,000 ($4,700 – $35,000)	$29,000 ($7,600 – $57,000)	$19,000 ($5,000 – $37,000)	$48,000 ($13,000 – $94,000)
Woodruff et al., 1997 (infant mortality)	$36 ($9 – $72)	$1 ($0 – $2)	$3 ($1 – $7)	$2 ($0 – $3)	$6 ($2 – $12)	$24 ($6 – $48)	$46 ($11 – $92)	$27 ($7 – $53)	$73 ($18 – $140)
Mortality Impact Functions Derived from Expert Elicitation									
Expert A	$49,000 ($6,600 – $110,000)	$880 ($120 – $2,000)	$6,600 ($890 – $15,000)	$1,800 ($240 – $4,100)	$7,400 ($990 – $17,000)	$26,000 ($3,500 – $59,000)	$63,000 ($8,500 – $140,000)	$29,000 ($3,900 – $65,000)	$92,000 ($12,000 – $210,000)
Expert B	$39,000 ($3,300 – $110,000)	$730 ($76 – $1,900)	$5,100 ($320 – $14,000)	$1,400 ($100 – $3,800)	$6,000 ($610 – $16,000)	$21,000 ($2,000 – $55,000)	$50,000 ($4,200 – $140,000)	$23,000 ($2,200 – $61,000)	$74,000 ($6,500 – $200,000)
Expert C	$41,000 ($4,900 – $99,000)	$730 ($88 – $1,800)	$5,500 ($660 – $13,000)	$1,500 ($180 – $3,600)	$6,100 ($740 – $15,000)	$21,000 ($2,600 – $52,000)	$52,000 ($6,300 – $130,000)	$24,000 ($2,900 – $57,000)	$76,000 ($9,200 – $180,000)
Expert D	$27,000 ($4,000 – $56,000)	$480 ($72 – $1,000)	$3,600 ($530 – $7,500)	$970 ($140 – $2,000)	$4,000 ($600 – $8,400)	$14,000 ($2,100 – $30,000)	$34,000 ($5,100 – $72,000)	$16,000 ($2,300 – $33,000)	$50,000 ($7,500 – $100,000)
Expert E	$62,000 ($16,000 – $120,000)	$1,100 ($280 – $2,200)	$8,300 ($2,100 – $16,000)	$2,200 ($560 – $4,400)	$9,300 ($2,300 – $18,000)	$32,000 ($8,200 – $64,000)	$80,000 ($20,000 – $160,000)	$36,000 ($9,000 – $71,000)	$120,000 ($29,000 – $230,000)
Expert F	$36,000 ($9,700 – $67,000)	$640 ($170 – $1,200)	$4,800 ($1,300 – $9,000)	$1,300 ($350 – $2,400)	$5,400 ($1,500 – $10,000)	$19,000 ($5,100 – $35,000)	$46,000 ($12,000 – $86,000)	$21,000 ($5,700 – $39,000)	$67,000 ($18,000 – $130,000)
Expert G	$22,000 ($0 – $54,000)	$390 ($0 – $960)	$2,900 ($0 – $7,200)	$790 ($0 – $1,900)	$3,300 ($0 – $8,100)	$11,000 ($0 – $28,000)	$28,000 ($0 – $69,000)	$13,000 ($0 – $31,000)	$41,000 ($0 – $100,000)
Expert H	$27,000 ($86 – $77,000)	$480 ($2 – $1,400)	$3,600 ($12 – $10,000)	$970 ($3 – $2,800)	$4,000 ($13 – $11,000)	$14,000 ($46 – $40,000)	$34,000 ($110 – $98,000)	$16,000 ($51 – $44,000)	$50,000 ($160 – $140,000)
Expert I	$38,000 ($4,500 – $84,000)	$680 ($81 – $1,500)	$5,100 ($610 – $11,000)	$1,400 ($160 – $3,000)	$5,700 ($680 – $13,000)	$20,000 ($2,400 – $44,000)	$49,000 ($5,800 – $110,000)	$22,000 ($2,600 – $48,000)	$71,000 ($8,500 – $160,000)
Expert J	$34,000 ($5,700 – $80,000)	$610 ($100 – $1,400)	$4,500 ($770 – $11,000)	$1,200 ($210 – $2,900)	$5,100 ($860 – $12,000)	$18,000 ($3,000 – $42,000)	$44,000 ($7,400 – $100,000)	$20,000 ($3,400 – $46,000)	$63,000 ($11,000 – $150,000)
Expert K	$5,600 ($0 – $30,000)	$100 ($0 – $540)	$740 ($0 – $4,000)	$200 ($0 – $1,100)	$930 ($0 – $4,900)	$3,000 ($0 – $16,000)	$7,200 ($0 – $39,000)	$3,300 ($0 – $18,000)	$10,000 ($0 – $56,000)
Expert L	$26,000 ($2,500 – $66,000)	$530 ($76 – $1,200)	$3,200 ($91 – $8,700)	$890 ($50 – $2,400)	$4,300 ($590 – $10,000)	$15,000 ($1,800 – $35,000)	$34,000 ($3,100 – $85,000)	$16,000 ($2,000 – $39,000)	$50,000 ($5,100 – $120,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-25: Illustrative Strategy to Attain 14/35: Estimated Monetary Value of Morbidity Reductions (in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Modeled Partial Attainment	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Morbidity Impact Function Derived frm Epidemiology Literature									
Chronic bronchitis (age >25 and over)	$900 ($70 – $3,200)	$16 ($1 – $58)	$95 ($7 – $340)	$35 ($3 – $120)	$170 ($13 – $610)	$630 ($50 – $2,200)	$1,200 ($91 – $4,100)	$680 ($54 – $2,400)	$1,900 ($150 – $6,600)
Nonfatal myocardial infarction (age >17) 3% Discount Rate	$350 ($92 – $760)	$12 ($3 – $28)	$11 ($3 – $25)	$2 ($1 – $5)	$84 ($23 – $180)	$270 ($75 – $580)	$440 ($120 – $970)	$280 ($79 – $620)	$730 ($200 – $1,600)
Nonfatal myocardial infarction (age >17) 7% Discount Rate	$330 ($85 – $750)	$12 ($3 – $27)	$11 ($3 – $24)	$2 ($1 – $5)	$82 ($21 – $180)	$260 ($69 – $570)	$430 ($110 – $950)	$280 ($72 – $600)	$700 ($180 – $1,600)
Hospital admissions—respiratory (all ages)	$8.0 ($4.0 – $12.0)	$0.3 ($0.1 – $0.4)	$0.2 ($0.1 – $0.3)	$0.1 ($0.0 – $0.1)	$1.6 ($0.8 – $2.4)	$5.4 ($2.7 – $8.2)	$10.0 ($4.9 – $15.0)	$5.8 ($2.9 – $8.7)	$16.0 ($7.8 – $23.0)
Hospital admissions—cardiovascular (age >17)	$22.0 ($14.0 – $31.0)	$0.8 ($0.5 – $1.1)	$0.6 ($0.4 – $0.9)	$0.1 ($0.1 – $0.2)	$4.4 ($2.8 – $6.1)	$14.0 ($9.0 – $20.0)	$27.0 ($17.0 – $38.0)	$15.0 ($10.0 – $21.0)	$43.0 ($27.0 – $59.0)
Emergency room visits for asthma (age <19)	$0.59 ($0.32 – $0.90)	$0.02 ($0.01 – $0.03)	$0.01 ($0.00 – $0.01)	$0.00 ($0.00 – $0.00)	$0.06 ($0.03 – $0.09)	$0.20 ($0.11 – $0.31)	$0.66 ($0.36 – $1.00)	$0.23 ($0.12 – $0.34)	$0.88 ($0.48 – $1.30)
Acute bronchitis (age 8–12)	$2.10 (–$0.08 – $5.40)	$0.04 ($0.00 – $0.10)	$0.23 (–$0.01 – $0.59)	$0.10 ($0.00 – $0.26)	$0.44 (–$0.02 – $1.10)	$1.60 (–$0.06 – $4.10)	$2.80 (–$0.10 – $7.10)	$1.80 (–$0.07 – $4.50)	$4.60 (–$0.17 – $12.00)
Lower respiratory symptoms (age 7–14)	$0.55 ($0.21 – $1.00)	$0.02 ($0.01 – $0.04)	$0.02 ($0.01 – $0.04)	$0.00 ($0.00 – $0.01)	$0.18 ($0.07 – $0.34)	$0.65 ($0.25 – $1.20)	$0.75 ($0.28 – $1.40)	$0.68 ($0.26 – $1.30)	$1.40 ($0.54 – $2.70)
Upper respiratory symptoms (asthmatic children age 9–18)	$0.67 ($0.17 – $1.40)	$0.02 ($0.01 – $0.05)	$0.03 ($0.01 – $0.06)	$0.01 ($0.00 – $0.01)	$0.22 ($0.06 – $0.47)	$0.81 ($0.21 – $1.70)	$0.90 ($0.24 – $1.90)	$0.84 ($0.22 – $1.80)	$1.80 ($0.45 – $3.70)
Asthma exacerbation (asthmatic children age 6–18)	$1.30 ($0.14 – $4.20)	$0.04 ($0.00 – $0.14)	$0.05 ($0.01 – $0.17)	$0.01 ($0.00 – $0.04)	$0.42 ($0.05 – $1.40)	$1.50 ($0.16 – $5.00)	$1.70 ($0.19 – $5.80)	$1.60 ($0.17 – $5.20)	$3.30 ($0.36 – $11.00)
Work loss days (age 18–65)	$23 ($20 – $26)	$0.8 ($0.7 – $0.9)	$0.9 ($0.8 – $1.0)	$0.2 ($0.2 – $0.2)	$9 ($8 – $10)	$31 ($27 – $35)	$33 ($28 – $37)	$32 ($28 – $36)	$65 ($56 – $73)
Minor restricted-activity days (age 18–65)	$32 ($3 – $63)	$1.1 ($0.1 – $2.1)	$1.2 ($0.1 – $2.3)	$0.3 ($0.0 – $0.5)	$10 ($1 – $20)	$36 ($3 – $69)	$44 ($4 – $86)	$37 ($3 – $72)	$81 ($7 – $160)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-26: Monetary Benefits Associated with Improvements in Visibility in Selected Federal Class I Areas in 2020 Incremental to 15/65 Attainment Strategy (in millions of 1999$)[a]

Suite of Standards	*California*	*Southwest*	*Southeast*	*Total*
15/35	$320	$120	$91	$530
14/35	$320	$130	$770	$1,200

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-27: Ranges of Total Monetized Benefits (Health and Visibility) Associated with Full Attainment of 15/35 and 14/35 Standards Incremental to Attainment of Current 15/65 Standards in 2020 (in millions of 1999$) 90th Percentile Confidence Intervals Provided in Parentheses [a]

	3% Discount Rate		7% Discount Rate	
Source of Mortality Effect Estimate	**15/35**	**14/35**	**15/35**	**14/35**
Data Derived				
ACS Study[b]	$17,000	$30,000	$15,000	$26,000
	($4,100 - $36,000)	($7,300 - $63,000)	($3,500 - $31,000)	($6,400 - $54,000)
Harvard Six-City Study[c]	$35,000	$62,000	$30,000	$52,000
	($9,400 - $70,000)	($17,000 - $120,000)	($8,100 - $59,000)	($14,000 - $100,000)
Expert Elicitation Derived				
Expert A	$61,000	$110,000	$51,000	$96,000
	($8,700 - $140,000)	($16,000 - $260,000)	($7,400 - $120,000)	($14,000 - $220,000)
Expert B	$49,000	$91,000	$42,000	$78,000
	($5,000 - $130,000)	($9,300 - $240,000)	($4,300 - $110,000)	($8,100 - $210,000)
Expert C	$51,000	$94,000	$43,000	$80,000
	($6,700 - $120,000)	($13,000 - $230,000)	($5,800 - $100,000)	($11,000 - $190,000)
Expert D	$34,000	$64,000	$29,000	$54,000
	($5,600 - $72,000)	($11,000 - $130,000)	($4,800 - $62,000)	($9,100 - $110,000)
Expert E	$76,000	$140,000	$64,000	$120,000
	($19,000 - $150,000)	($36,000 - $280,000)	($16,000 - $130,000)	($31,000 - $240,000)
Expert F	$45,000	$84,000	$38,000	$71,000
	($12,000 - $86,000)	($23,000 - $160,000)	($11,000 - $73,000)	($20,000 - $140,000)
Expert G	$28,000	$52,000	$24,000	$45,000
	($800 - $69,000)	($1,700 - $130,000)	($790 - $59,000)	($1,600 - $110,000)
Expert H	$34,000	$63,000	$29,000	$54,000
	($900 - $96,000)	($1,900 - $180,000)	($880 - $82,000)	($1,800 - $150,000)
Expert I	$48,000	$89,000	$40,000	$75,000
	($6,200 - $110,000)	($12,000 - $200,000)	($5,300 - $89,000)	($10,000 - $170,000)
Expert J	$42,000	$79,000	$36,000	$67,000
	($7,700 - $100,000)	($14,000 - $190,000)	($6,600 - $86,000)	($12,000 - $160,000)
Expert K	$9,000	$17,000	$7,900	$15,000
	($800 - $42,000)	($1,700 - $77,000)	($790 - $36,000)	($1,600 - $66,000)
Expert L	$35,000	$64,000	$29,000	$54,000
	($4,300 - $84,000)	($7,700 - $160,000)	($3,700 - $72,000)	($6,800 - $130,000)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

[b] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[c] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

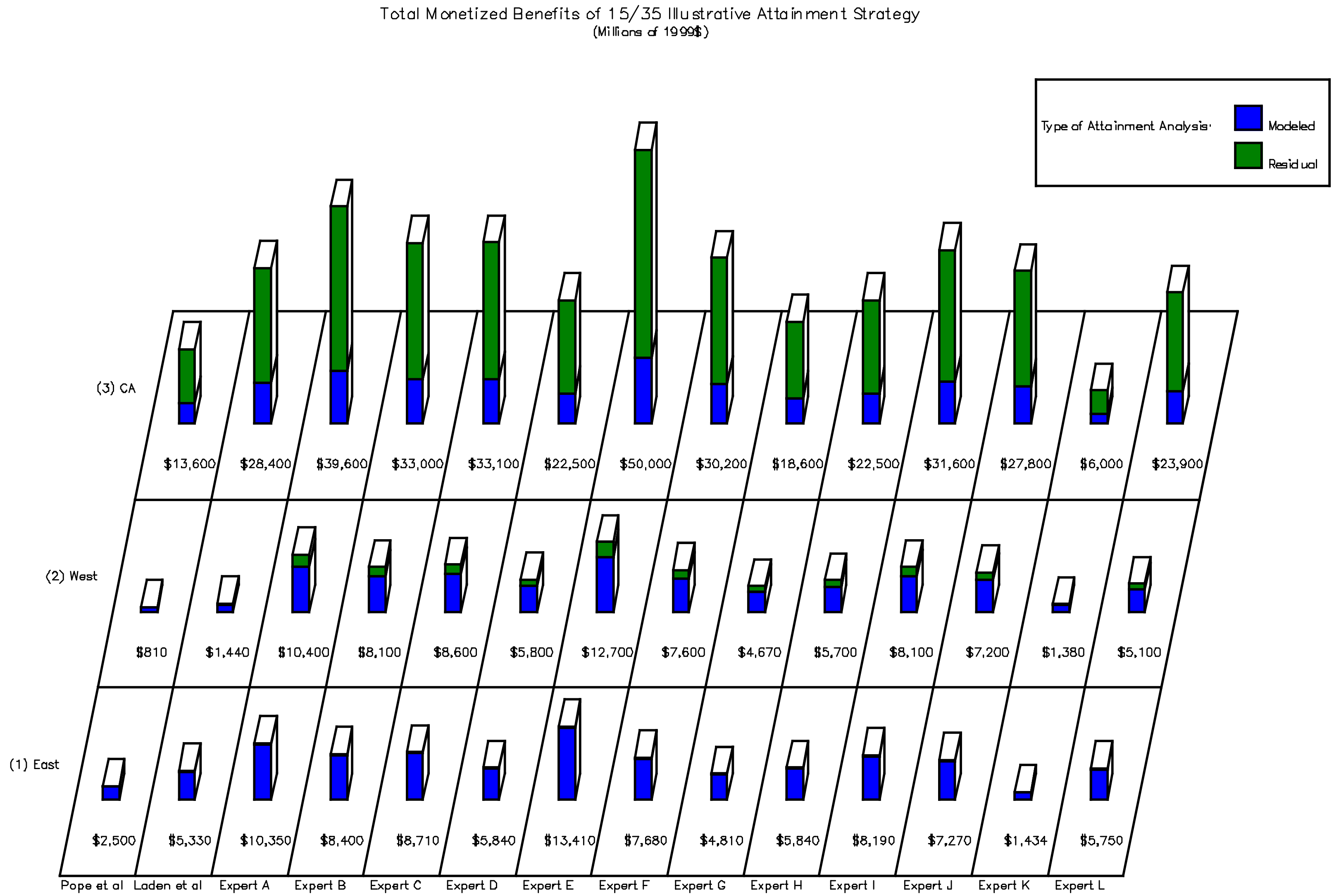


Figure 5-8. Comparison of Benefits of Illustrative Attainment Strategy for the Revised Standards (15/35) Across Regions and Sources of Mortality Effect Estimates

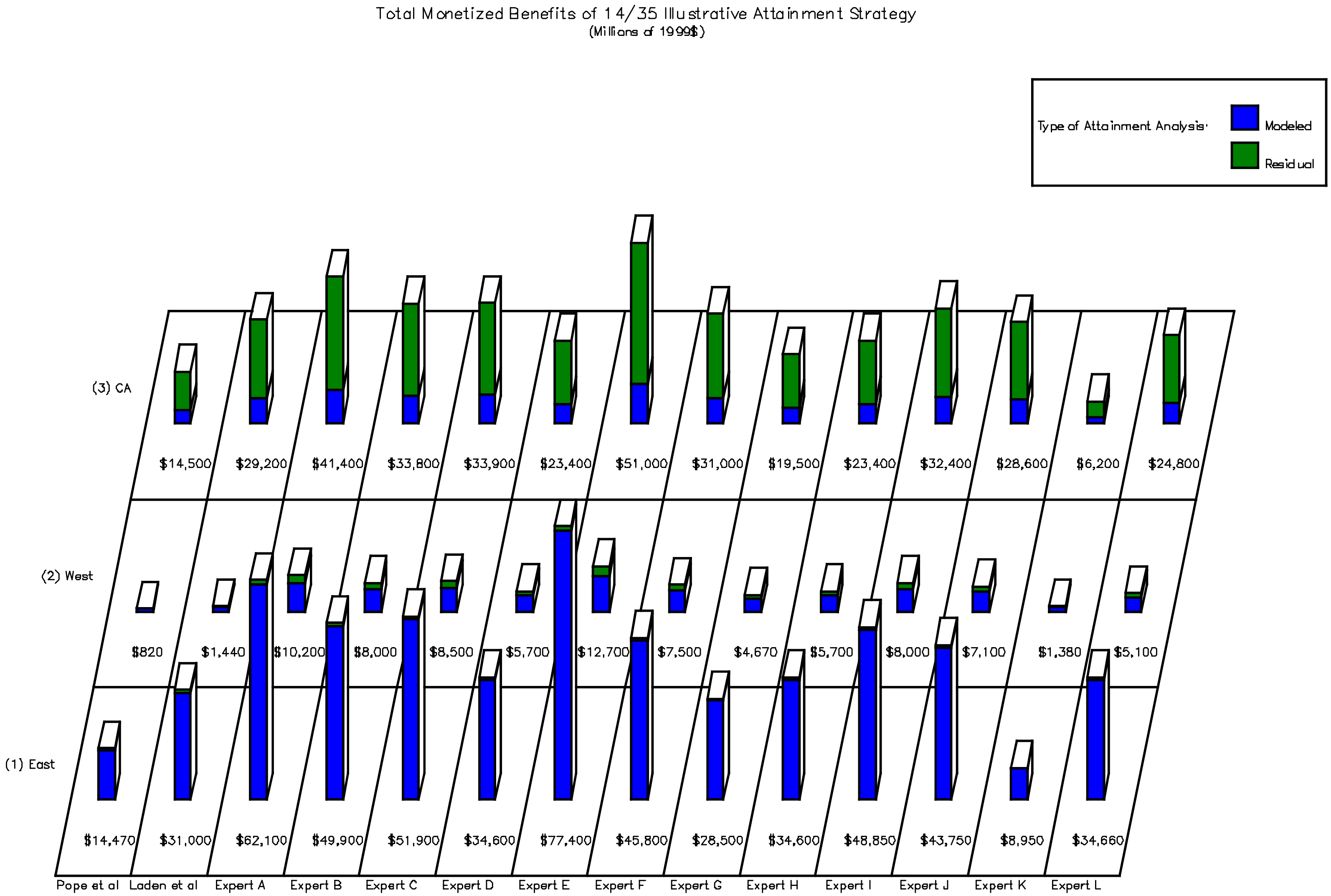


Figure 5-9. Comparison of Benefits of Illustrative Attainment Strategy for the More Stringent Alternative Standards (14/35) Across Regions and Sources of Mortality Effect Estimates

Table 5-28: Mortality Threshold Sensitivity Analysis for 15/35 Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug) 90th Percentile Confidence Intervals Provided in Parentheses [a]

		Estimated Reduction in Mortality Incidence								
		Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Level of Assumed Threshold	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*National Total Full Attainment*
Less Certainty That Benefits Are at Least as Large	No Threshold	620 (240 – 1,000)	15 (6 – 24)	510 (200 – 810)	140 (53 – 220)	2,000 (800 – 3,300)	570 (220 – 920)	1,900 (740 – 3,000)	1,700 (670 – 2,700)	3,700 (1,500 – 6,000)
	Threshold at 7.5 µg	610 (240 – 980)	15 (6 – 24)	320 (130 – 520)	110 (44 – 180)	2,000 (790 – 3,200)	560 (220 – 900)	1,900 (740 – 3,000)	1,500 (590 – 2,400)	3,500 (1,400 – 5,600)
	Threshold at 10 µg	360 (140 – 580)	17 (7 – 27)	80 (30 – 120)	15 (6 – 24)	1,600 (620 – 2,500)	520 (200 – 0,800)	1,600 (610 – 2,500)	960 (370 – 1,500)	2,500 (1,000 – 4,100)
	Threshold at 12 µg	38 (15 – 62)	2 (1 – 3)	12 (5 – 19)	0 (0 – 0)	1,200 (490 – 2,000)	430 (170 – 0,700)	1,200 (490 – 2,000)	480 (190 – 800)	1,700 (680 – 2,800)
More Certainty That Benefits are at Least as Large	Threshold at 14 µg	10 (4 – 16)	2 (1 – 3)	9 (3 – 14)	0 (0 – 0)	440 (170 – 700)	390 (150 – 0,600)	440 (170 – 700)	410 (160 – 700)	840 (330 – 1,400)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-29: Mortality Threshold Sensitivity Analysis for 14/35 Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug) 90th Percentile Confidence Intervals Provided in Parentheses [a]

		Estimated Reduction in Mortality Incidence								
		Eastern U.S.		*Western U.S. Excluding CA*		*California*		*National Total*		
	Level of Assumed Threshold	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Less Certainty That Benefits Are at Least as Large	No Threshold	3,700 (1,500 – 6,000)	70 (26 – 110)	500 (200 – 800)	130 (53 – 220)	560 (220 – 900)	2,000 (770 – 3,200)	4,800 (1,900 – 7,700)	2,200 (850 – 3,500)	7,000 (2,700 – 11,200)
	at 7.5 µg	3,500 (1,400 – 5,700)	70 (26 – 110)	320 (120 – 510)	110 (44 – 180)	550 (210 – 880)	2,000 (770 – 3,200)	4,400 (1,700 – 7,100)	2,100 (840 – 3,400)	6,500 (2,600 – 10,500)
	at 10 µg	2,100 (820 – 3,400)	70 (29 – 120)	80 (30 – 120)	15 (6 – 24)	500 (200 – 810)	1,600 (650 – 2,600)	2,700 (1,000 – 4,300)	1,700 (680 – 2,800)	4,400 (1,730 – 7,100)
Threshold	Threshold at 12 µg	220 (87 – 360)	60 (24 – 100)	12 (5 – 19)	0 (0 – 1)	420 (160 – 670)	1,300 (530 – 2,200)	650 (250 – 1,000)	1,400 (550 – 2,300)	2,100 (810 – 3,300)
More Certainty That Benefits are at Least as Large Threshold	Threshold at 14 µg	54 (21 – 87)	44 (17 – 70)	9 (3 – 14)	0 (0 – 0)	370 (140 – 600)	480 (190 – 800)	430 (170 – 700)	530 (210 – 800)	960 (370 – 1,500)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-30: Sensitivity of Monetized Benefits of Reductions in Mortality Risk to Assumed Thresholds for 15/35 Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug) 90th Percentile Confidence Intervals Provided in Parentheses [a]

			Millions of 1999$								
			Eastern U.S.		*Western U.S. Excluding CA*		*California*		*Total Nationwide Attainment*		
	Level of Assumed Threshold	*Discount Rate*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Less Certain that Benefits Are at Least as Large	No Threshold	3%	$3,600 ($800 – $7,500)	$88 ($20 – $180)	$2,900 ($650 – $6,100)	$780 ($170 – $1,600)	$3,300 ($740 – $6,900)	$11,000 ($2,400 – $23,000)	$9,900 ($2,200 – $21,000)	$12,000 ($2,600 – $24,000)	$22,000 ($4,800 – $45,000)
		7%	$3,000 ($680 – $6,300)	$74 ($16 – $150)	$2,500 ($550 – $5,100)	$660 ($150 – $1,400)	$2,800 ($620 – $5,800)	$9,200 ($2,000 – $19,000)	$8,300 ($1,800 – $17,000)	$9,900 ($2,200 – $21,000)	$18,000 ($4,100 – $38,000)
	Threshold at 7.5 ug	3%	$3,500 ($780 – $7,300)	$88 ($20 – $180)	$1,900 ($420 – $3,900)	$650 ($140 – $1,300)	$3,200 ($720 – $6,800)	$11,000 ($2,400 – $23,000)	$8,600 ($1,900 – $18,000)	$12,000 ($2,600 – $24,000)	$20,000 ($4,500 – $42,000)
		7%	$3,000 ($660 – $6,100)	$74 ($16 – $150)	$1,600 ($350 – $3,300)	$550 ($120 – $1,100)	$2,700 ($610 – $5,700)	$9,100 ($2,000 – $19,000)	$7,300 ($1,600 – $15,000)	$9,800 ($2,200 – $20,000)	$17,000 ($3,800 – $35,000)
	Threshold at 10 ug	3%	$2,100 ($470 – $4,400)	$97 ($22 – $200)	$440 ($99 – $920)	$87 ($19 – $180)	$3,000 ($670 – $6,200)	$9,000 ($2,000 – $19,000)	$5,500 ($1,200 – $12,000)	$9,200 ($2,000 – $19,000)	$15,000 ($3,300 – $31,000)
		7%	$1,800 ($390 – $3,700)	$82 ($18 – $170)	$370 ($83 – $770)	$73 ($16 – $150)	$2,500 ($560 – $5,200)	$7,600 ($1,700 – $16,000)	$4,700 ($1,000 – $9,700)	$7,700 ($1,700 – $16,000)	$12,000 ($2,800 – $26,000)
	Threshold at 12 ug	3%	$220 ($49 – $460)	$10 ($2 – $21)	$67 ($15 – $140)	$3 ($1 – $6)	$2,500 ($560 – $5,200)	$7,200 ($1,600 – $15,000)	$2,800 ($620 – $5,800)	$7,200 ($1,600 – $15,000)	$10,000 ($2,200 – $21,000)
		7%	$190 ($42 – $390)	$9 ($2 – $18)	$57 ($13 – $120)	$2 ($1 – $5)	$2,100 ($470 – $4,400)	$6,100 ($1,400 – $13,000)	$2,400 ($520 – $4,900)	$6,100 ($1,400 – $13,000)	$8,400 ($1,900 – $18,000)
	Threshold at 14 ug	3%	$59 ($13 – $120)	$12 ($3 – $24)	$50 ($11 – $100)	$0 ($0 – $0)	$2,200 ($500 – $4,700)	$2,500 ($560 – $5,200)	$2,400 ($520 – $4,900)	$2,500 ($560 – $5,300)	$4,900 ($1,100 – $10,000)
More Certain that Benefits Are at Least as Large		7%	$49 ($11 – $100)	$10 ($2 – $20)	$42 ($9 – $87)	$0 ($0 – $0)	$1,900 ($420 – $3,900)	$2,100 ($470 – $4,400)	$2,000 ($440 – $4,100)	$2,100 ($470 – $4,400)	$4,100 ($910 – $8,500)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

Table 5-31: Sensitivty of Monetized Beneifts of Reductions in Mortality Risk to Assumed Thresholds for 14/35 Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug) 90th Percentile Confidence Intervals Provided in Parentheses [a]

			Millions of 1999$								
			Eastern U.S.		*Western U.S. Excluding CA*		*California*		*Total Nationwide Attainment*		
	Level of Assumed Threshold	*Discount Rate*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*Modeled Partial Attainment*	*Residual Attainment*	*National Total Full Attainment*
Less Certain that Benefits Are at Least as Large	No Threshold	3%	$22,000 ($4,800 – $45,000)	$390 ($86 – $800)	$2,900 ($640 – $6,000)	$780 ($170 – $1,600)	$3,200 ($720 – $6,700)	$11,000 ($2,500 – $24,000)	$28,000 ($6,200 – $58,000)	$13,000 ($2,800 – $26,000)	$40,000 ($9,000 – $84,000)
		7%	$18,000 ($4,000 – $38,000)	$320 ($72 – $670)	$2,400 ($540 – $5,000)	$660 ($150 – $1,400)	$2,700 ($610 – $5,700)	$9,600 ($2,100 – $20,000)	$23,000 ($5,200 – $48,000)	$11,000 ($2,400 – $22,000)	$34,000 ($7,500 – $70,000)
	Threshold at 7.5 ug	3%	$20,000 ($4,500 – $42,000)	$390 ($86 – $800)	$1,800 ($410 – $3,800)	$650 ($140 – $1,300)	$3,200 ($710 – $6,600)	$11,000 ($2,500 – $24,000)	$25,000 ($5,700 – $53,000)	$12,000 ($2,800 – $26,000)	$38,000 ($8,400 – $79,000)
		7%	$17,000 ($3,800 – $36,000)	$320 ($72 – $670)	$1,600 ($350 – $3,200)	$550 ($120 – $1,100)	$2,700 ($590 – $5,500)	$9,600 ($2,100 – $20,000)	$21,000 ($4,800 – $44,000)	$10,000 ($2,300 – $22,000)	$32,000 ($7,100 – $66,000)
	Threshold at 10 ug	3%	$12,000 ($2,700 – $25,000)	$430 ($96 – $900)	$450 ($100 – $930)	$87 ($19 – $180)	$2,900 ($650 – $6,000)	$9,500 ($2,100 – $20,000)	$15,000 ($3,400 – $32,000)	$10,000 ($2,200 – $21,000)	$26,000 ($5,700 – $53,000)
		7%	$10,000 ($2,300 – $21,000)	$360 ($81 – $760)	$380 ($84 – $780)	$73 ($16 – $150)	$2,400 ($540 – $5,100)	$8,000 ($1,800 – $17,000)	$13,000 ($2,900 – $27,000)	$8,500 ($1,900 – $18,000)	$21,000 ($4,800 – $45,000)
	Threshold at 12 ug	3%	$1,300 ($290 – $2,700)	$350 ($79 – $740)	$68 ($15 – $140)	$3 ($1 – $6)	$2,400 ($540 – $5,000)	$7,800 ($1,700 – $16,000)	$3,800 ($840 – $7,800)	$8,200 ($1,800 – $17,000)	$12,000 ($2,700 – $25,000)
		7%	$1,100 ($240 – $2,200)	$300 ($66 – $620)	$57 ($13 – $120)	$2 ($1 – $5)	$2,000 ($450 – $4,200)	$6,600 ($1,500 – $14,000)	$3,200 ($700 – $6,600)	$6,900 ($1,500 – $14,000)	$10,000 ($2,200 – $21,000)
	Threshold at 14 ug	3%	$310 ($69 – $650)	$250 ($56 – $520)	$50 ($11 – $100)	$0 ($0 – $0)	$2,100 ($480 – $4,500)	$2,800 ($620 – $5,800)	$2,500 ($560 – $5,200)	$3,000 ($680 – $6,300)	$5,600 ($1,200 – $12,000)
More Certain that Benefits Are at Least as Large		7%	$260 ($58 – $550)	$210 ($47 – $440)	$42 ($9 – $87)	$0 ($0 – $0)	$1,800 ($400 – $3,700)	$2,400 ($520 – $4,900)	$2,100 ($470 – $4,400)	$2,600 ($570 – $5,300)	$4,700 ($1,000 – $9,700)

a All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

We provide likelihood distributions both for the total dollar benefits estimate and for the incidence of premature mortality to show the uncertainty described by each expert's judgment as well as the range of uncertainty associated with the standard errors in the Pope et al. (2002) amd Laden et al (2006) studies. The uncertainty about the total dollar benefit associated with any single endpoint combines the uncertainties from two sources—the C-R relationship and the valuation—and is estimated with a Monte Carlo method.[26] Our estimates of the likelihood distributions for total benefits should be viewed within the context of the wide range of sources of uncertainty that we have not incorporated, including uncertainty in emissions, air quality, and baseline health effect incidence rates.

We are unable at this time to characterize the uncertainty in the estimate of benefits of improvements in visibility at Class I areas. As such, we treat the visibility benefits as fixed and add them to all percentiles of the health benefits distribution.

Given this unequal treatment of endpoints, it is likely that these distributions do not capture the full range of benefits, and in fact are likely to understate the uncertainty, especially on the high end of the range due to omission of potentially significant benefit categories.

Following these tables, we also provide a more comprehensive graphical presentation of the distributions of benefits generated using the available information from empirical studies and expert elicitation. Not all known PM-related health and welfare effects could be quantified or monetized. The monetized value of these 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 and welfare benefits plus B, the sum of the nonmonetized health and welfare benefits.

Total monetized benefits are dominated by benefits of mortality risk reductions. Based on the full range of expert elicitation results, the range of mean estimates across the full set of mortality effect estimates projects that attainment of the final standards of 15/35 will result in 1,200 to 13,000 avoided premature deaths annually in 2020 incremental to the 15/65 attainment strategy, and that an attainment strategy for the more stringent 14 $\mu g/m^3$ annual standard would result in 2,200 to 24,000 avoided premature deaths incremental to the 15/65 attainment strategy with 1,000 to 11,000 avoided premature deaths incremental to attainment of the final 15/35 standards.

The threshold sensitivity analysis shows that mortality impacts are fairly sensitive to assumed thresholds, especially in the Western U.S. (excluding CA), where annual average concentrations are low relative to California and the Eastern U.S. For the 15/35 attainment scenario, in the West, the assumption of a 10 $\mu g/m^3$ threshold leads to a reduction in estimated incidence of mortality of almost 85 percent compared with the no threshold case. In the East, impacts of the 10 $\mu g/m^3$ threshold are smaller, but still significant, with a reduction of over 40 percent. In California, where annual mean levels are generally quite high, the impact of the 10 $\mu g/m^3$ threshold is small, with a reduction of only 10 percent. Nationwide, the average impact of the 10

[26] In each iteration of the Monte Carlo procedure, a value is randomly drawn from the incidence distribution, and a value is randomly drawn from the unit dollar value distribution. The total dollar benefit for that iteration is the product of the two. If this is repeated for many (e.g., thousands of) iterations, the distribution of total dollar benefits associated with the endpoint is generated.

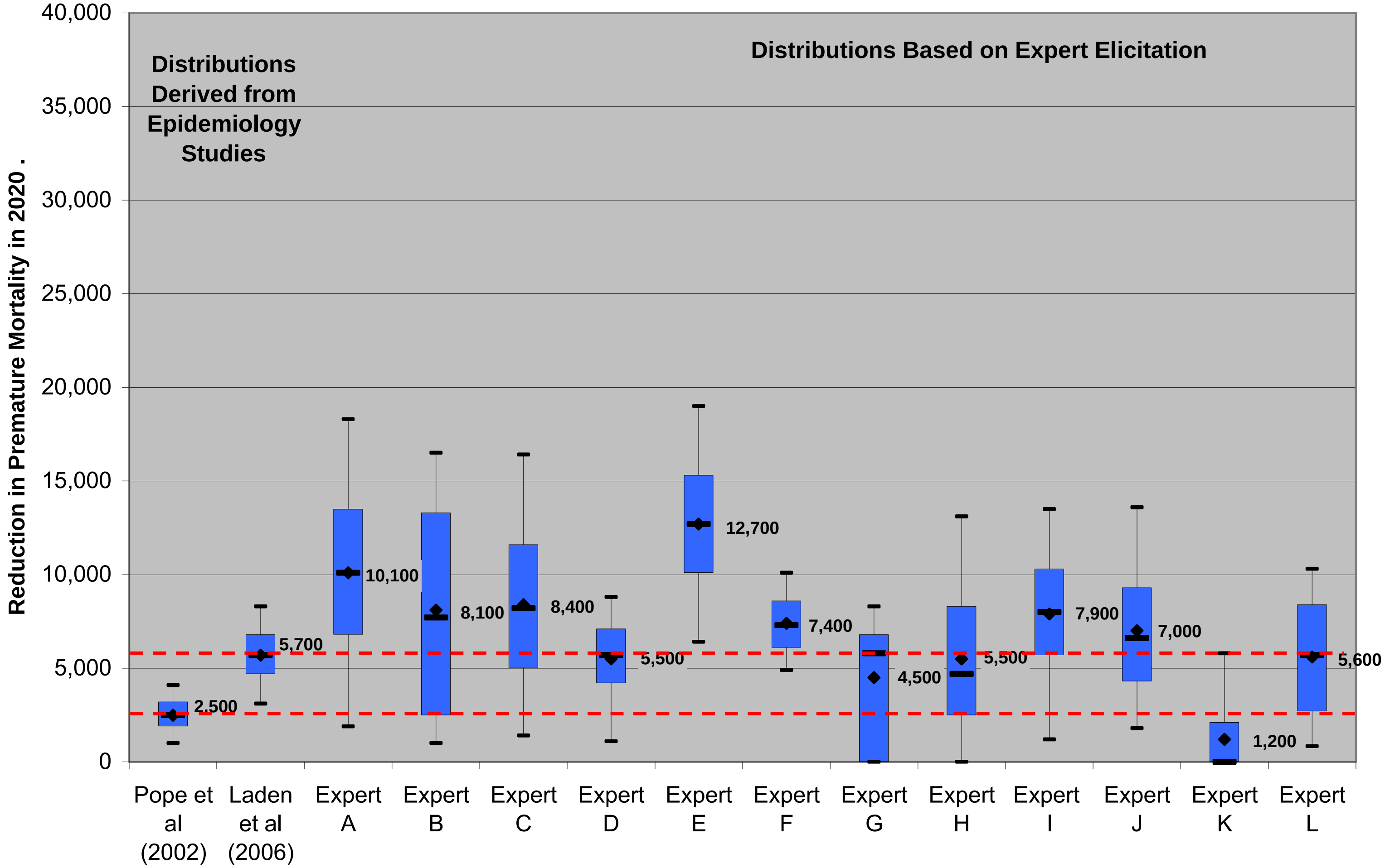
$\mu g/m^3$ threshold is a reduction in premature mortality incidence of approximately 32 percent. Threshold impacts are similar for the 14/35 attainment scenario.

Including the expert elicitation results, the estimated range of total incremental monetized benefits in 2020 for the final rule is $9 to $75 billion using a 3% discount rate and $8 to $64 billion using a 7% discount rate. Health benefits account for 97% of total benefits, in part because we are unable to quantify most of the nonhealth benefits. These unquantified benefits may be substantial, although the magnitude of these benefits is highly uncertain. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for $6.8 to 74 billion in 2020 is between 80 to 99 percent of total monetized health benefits, depending on the source of the mortality impact function. The next largest benefit is for reductions in chronic illness (CB and nonfatal heart attacks), although this value is in some cases more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, visibility, MRADs, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are almost 100 times more work loss days than premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of WTP. As such, the true value of these effects may be higher than that reported in Tables 5-20 through 5-27.

In addition to unquantified and unmonetized health benefit categories, Table 5-2 shows a number of welfare benefit categories that are omitted from the monetized benefit estimates for this rule. Only a subset of the expected visibility benefits-those for Class I areas in the southeastern and southwestern (including California) United States are included in the monetary benefits estimates we project for this rule. We believe the benefits associated with these non-health benefit categories are likely significant. For example, we are able to quantify significant visibility improvements in Class I areas in the Northeast and Midwest, but are unable at present to place a monetary value on these improvements. Similarly, we anticipate improvement in visibility in urban areas for which we are currently unable to monetize benefits. For the Class I areas in the southeastern and southwestern U.S., we estimate annual incremental benefits of $530 million for visibility improvements due to the 15/35 modeled attainment strategy, and $1,200 million for visibility improvements due to the 14/35 modeled attainment strategy. The value of visibility benefits in areas where we were unable to monetize benefits could also be substantial (see Appendix J).

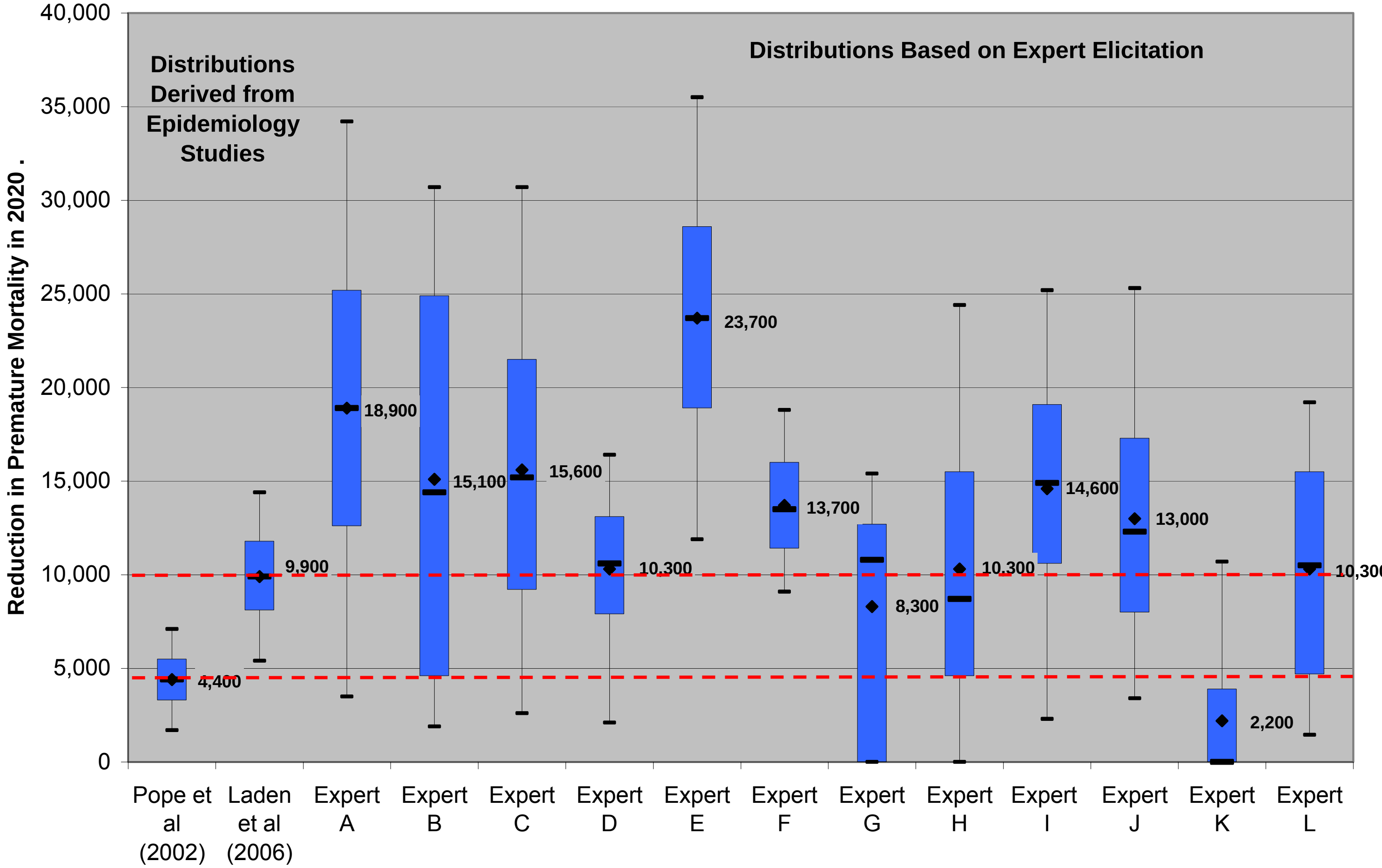
Figures 5-10 and 5-11 presents box plots of the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with Pope et al. (2002) and Laden et al. (2006).

The distributions are depicted as box plots with the diamond symbol (◆) showing the mean, the dash (–) showing the median (50th percentile), the box defining the interquartile range (bounded by the 25th and 75th percentiles), and the whiskers defining the 90% confidence interval (bounded by the 5th and 95th percentiles of the distribution).



Note: Distributions labeled Expert A - Expert L are based on individual expert responses. The distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

Figure 5-10. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with Illustrative Strategies to Attain 15/35, Incremental to Attainment of the 1997 Standards



Note: Distributions labeled Expert A - Expert L are based on individual expert responses. The distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

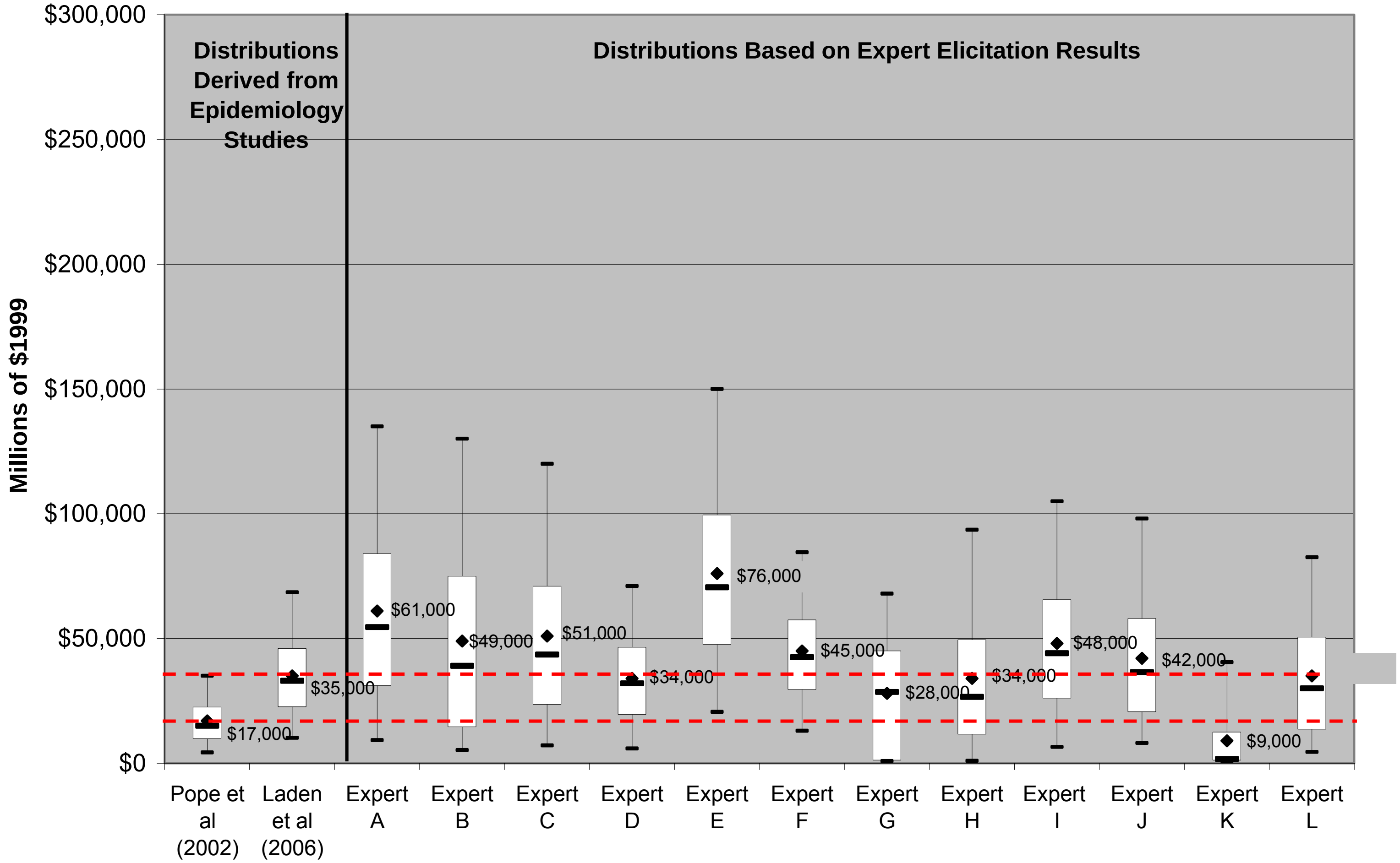
Figure 5-11. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with Illustrative Strategies to Attain 14/35, Incremental to Attainment of the 1997 Standards

For the 15/35 attainment strategy, the data-derived estimates based on Pope et al. (2002) and Laden et al. (2006) show that the mean predicted number of premature deaths avoided in 2020 ranges from 2,500 to 5,700. The lower end of this range is higher than one of the experts and the upper end of this range is lower than seven experts. The range falls within the uncertainty bounds of all but two experts.. The figure shows that the average annual number of premature deaths avoided in 2020 ranges from approximately 1,200 (based on the judgments of Expert K) to 12,700 (based on the judgments of Expert E). The medians span zero to 12,700, with the zero value due to the low probability of a causal relationship associated with one of the expert's distributions.

For the 14/35 attainment strategy, the data-derived estimates based on Pope et al. (2002) and Laden et al. (2006) show that the mean predicted number of premature deaths avoided in 2020 ranges from 4,400 to 9,900. The lower end of this range is higher than one of the experts and the upper end of this range is lower than seven experts. The range falls within the uncertainty bounds of all but two experts. The figure shows that the average annual number of premature deaths avoided in 2020 ranges from approximately 2,200 (based on the judgments of Expert K) to 23,700 (based on the judgments of Expert E). The medians span zero to 23,700, with the zero value due to the low probability of a causal relationship associated with one of the expert's distributions. The statistical uncertainty bounds of all of the estimates, including the data-derived distributions, overlap. Although the uncertainty bounds for some experts include zero, and some distributions have significant percentiles at zero, all of the distributions have a positive mean estimate.

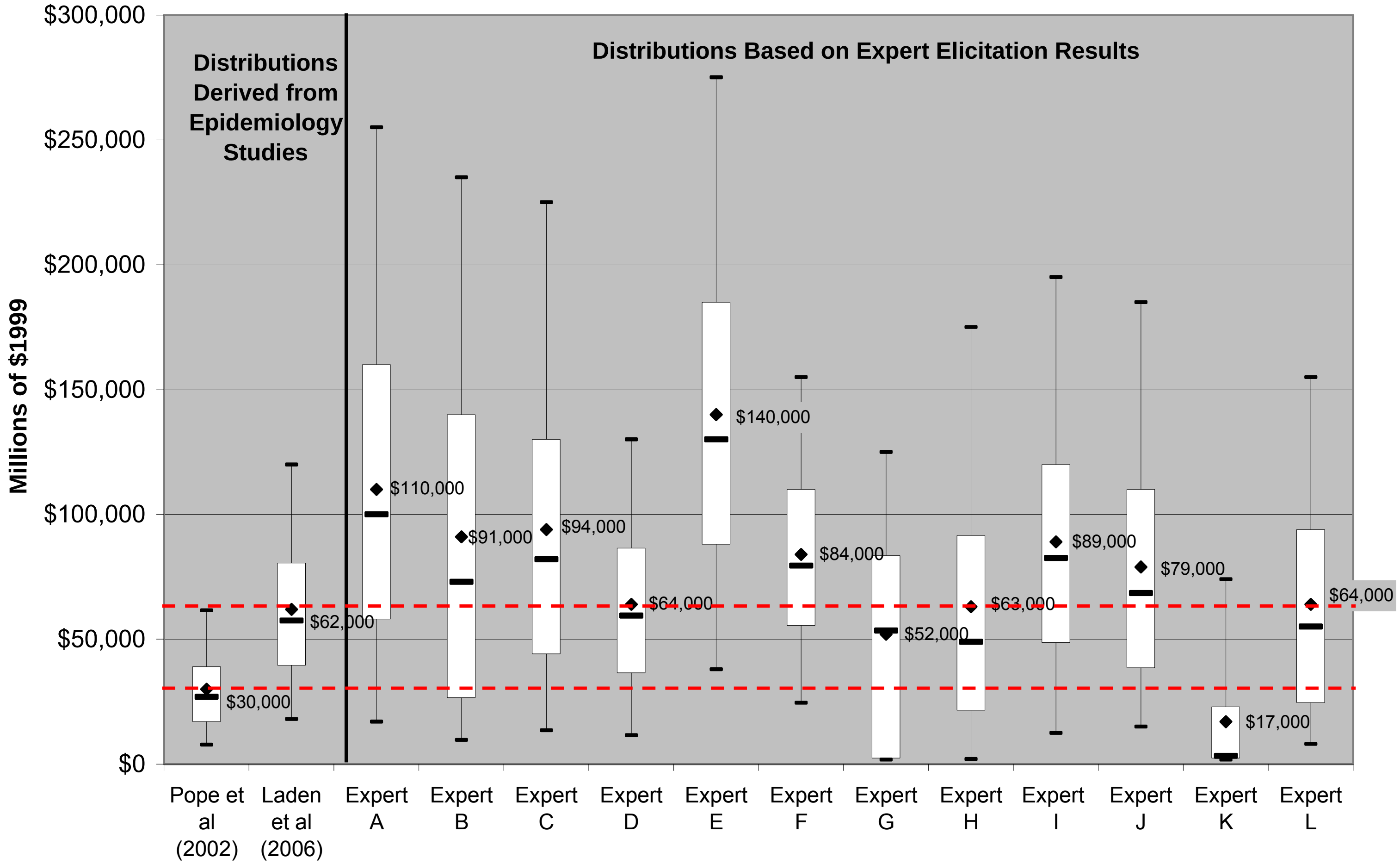
The statistical uncertainty bounds of all of the estimates, including the data-derived distributions, overlap. Although the uncertainty bounds for some experts include zero, and some distributions have significant percentiles at zero, all of the distributions have a positive mean estimate.

Figure 5-12 and 5-13 present box plots of the distributions of monetized benefits of reductions in premature mortality associated with use of the Pope et al. (2002), Laden et al. (2006), and expert-judgment based mortality incidence distributions. For the 15/35 attainment strategy (Figure 5-12), the data-derived estimates based on Pope et al. (2002) and Laden et al. (2006) show that the mean annual benefit ranges from $17 billion to $35 billion. Mean annual benefits for each expert range from approximately $9 billion (based on judgments of Expert K) to $75 billion (based on the judgments of Expert E). For the 14/34 attainment strategy (Figure 5-13), the data-derived estimates range from $30 billion to $62 billion. Mean annual benefits from the expert elicitation range from $17 billion (Expert K) to $140 billion (Expert E). As with the mortality incidence estimates, with the exception of Expert K, all of the expert based distributions have means greater than the Pope et al (2002) result, and 10 of the 12 expert based results are greater than or equal to the Laden et al (2006) results.



Note: All non-mortality distributions are based on classical statistical error derived from the standard errors reported in epidemiology studies and distributions of unit values based on empirical data. Visibility benefits are included as a constant. Mortality distributions labeled Expert A - Expert L are based on individual expert responses. The mortality distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. Dollar benefits have been adjusted upwards to account for growth in real income out to 2020.The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

Figure 5-12. Results of Probabilistic Uncertainty Analysis: Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 15/35 (Full attainment), Incremental to Attainment of the 1997 Standards



Note: All non-mortality distributions are based on classical statistical error derived from the standard errors reported in epidemiology studies and distributions of unit values based on empirical data. Visibility benefits are included as a constant. Mortality distributions labeled Expert A - Expert L are based on individual expert responses. The mortality distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. Dollar benefits have been adjusted upwards to account for growth in real income out to 2020.The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

Figure 5-13. Results of Probabilistic Uncertainty Analysis: Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 14/35 (Full attainment), Incremental to Attainment of the 1997 Standards

These distributions can also be displayed in terms of cumulative distribution functions. The cumulative distributions of monetized benefits are provided in Figures 5-14 and 5-15 for the 15/35 and 14/35 attainment scenarios, respectively.

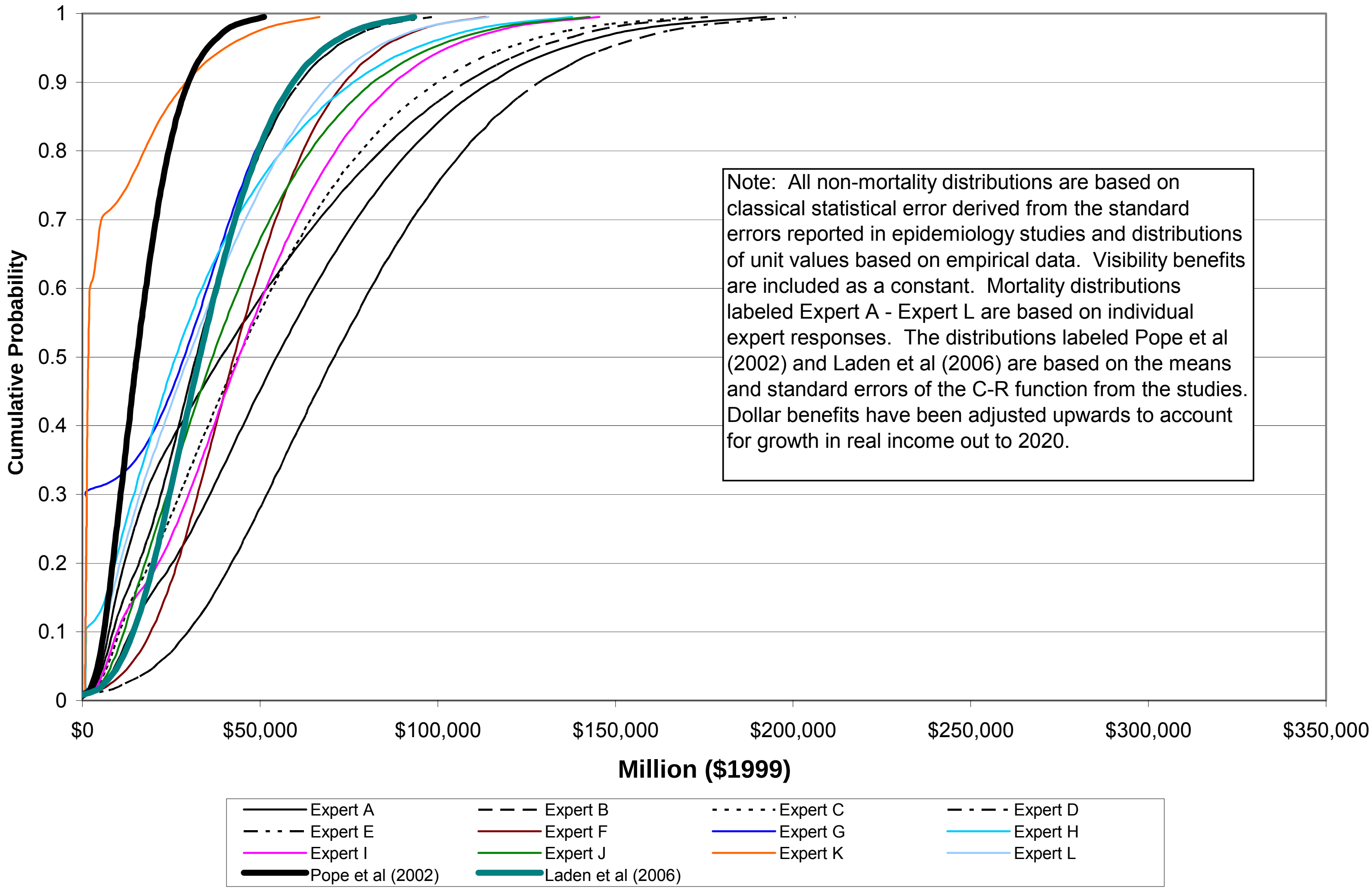


Figure 5-14. Results of Probabilistic Uncertainty Analysis: Cumulative Distributions of Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 15/35, Incremental to Attainment of the 1997 Standards

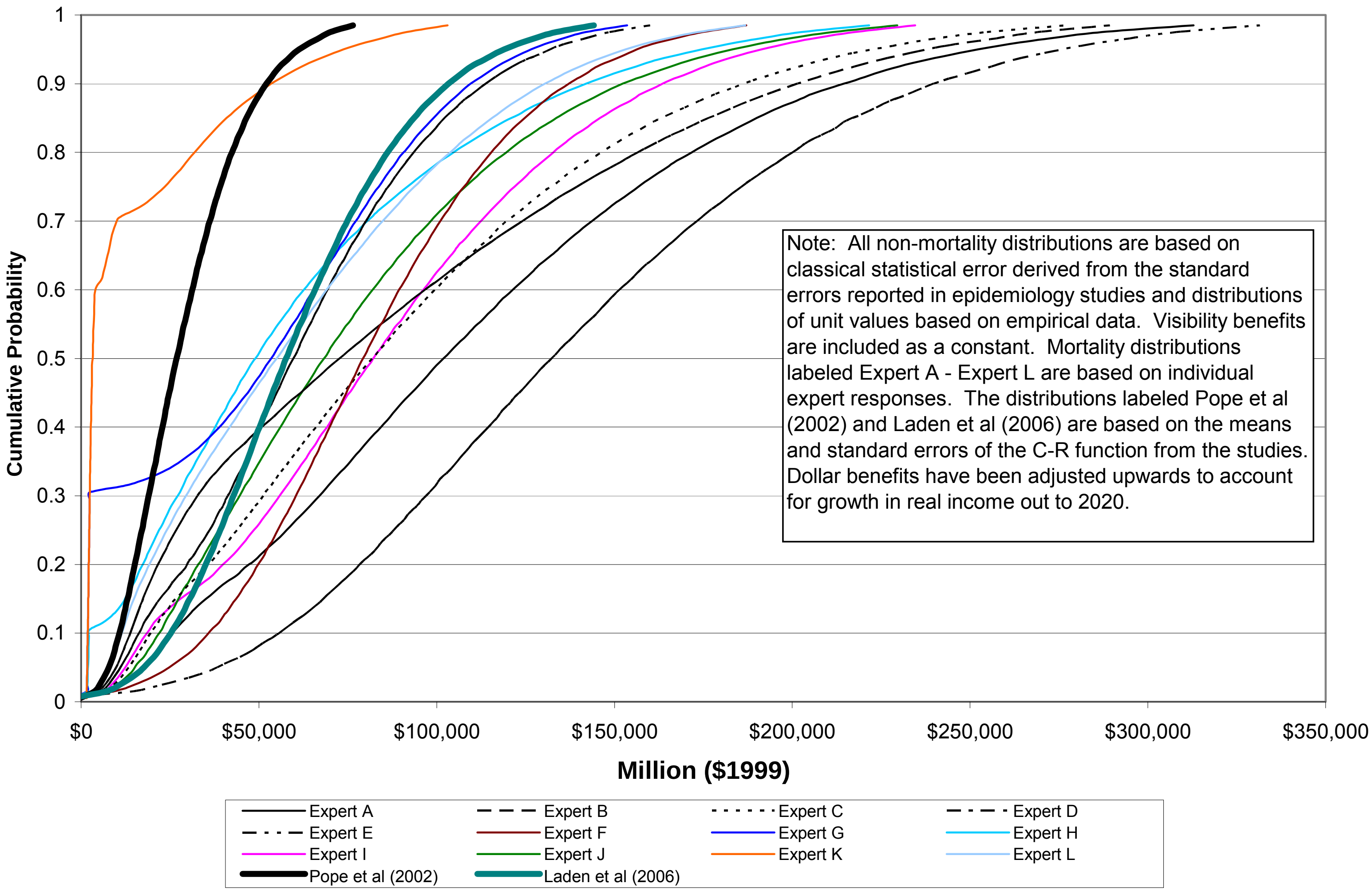


Figure 5-15. Results of Probabilistic Uncertainty Analysis: Cumulative Distributions of Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 14/35, Incremental to Attainment of the 1997 Standards

5.2.2 Benefits by Major PM Component

In order to better understand the sources of the benefits associated with PM attainment strategies, we provide a breakout of benefits by the major PM component species, including ammonium sulfate, ammonium nitrate, elemental carbon, organic carbon, and crustal material. This is accomplished by apportioning total benefits based on the proportion of the population weighted change in total $PM_{2.5}$ accounted for by each component species. This is not exact, but provides a reasonable approximation of the proportion of benefits associated with each species.

Figure 5-16 shows the proportion of total benefits associated with each species for the nation as a whole for the partial attainment scenarios for 15/35 and 14/35. It is not possible to accurately assess the composition of benefits for the full attainment scenario, due to the unknown composition of controls that might be used to reach full attainment in California and Salt Lake City. In the Eastern U.S., we have demonstrated that it is possible to reach full attainment using only direct PM controls, and as such, all of the full attainment benefits in that region can be assigned to the direct PM related species, including elemental carbon, organic carbon, and crustal materials.

Tables 5-32 and 5-33 provide the total benefits broken out by species for the nation for the 15/35 and 14/35 partial attainment scenarios.

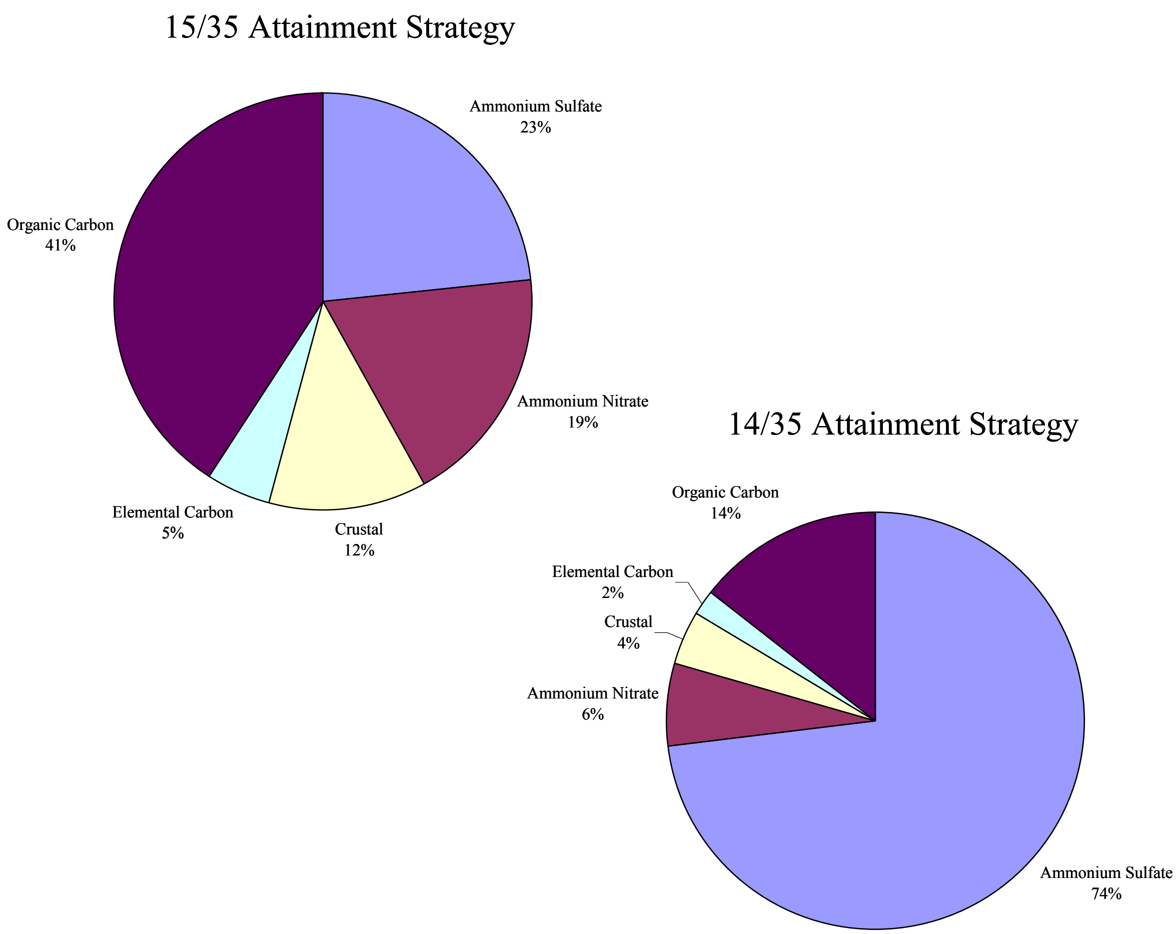


Figure 5-16. Proportion of Population-weighted Reduction in Ambient Annual PM2.5 Associated with PM2.5 Components for Modeled Attainment Strategies

Table 5-32: Apportionment of Monetized Health Benefits of Modeled Attainment Strategies to PM Component Species -- 3 Percent Discount Rate*

	15/35 Modeled Attainment Strategy					14/35 Modeled Attainment Strategy				
	Ammonium Sulfate	*Ammonium Nitrate*	*Crustal*	*Elemental Carbon*	*Organic Carbon*	*Ammonium Sulfate*	*Ammonium Nitrate*	*Crustal*	*Elemental Carbon*	*Organic Carbon*
Percent of Monetized Benefits	23.5%	18.5%	12.0%	5.2%	40.7%	73.2%	6.4%	4.1%	1.9%	14.5%
Apportioned Benefits: Source of Mortality Effect Estimate										
Data Derived										
ACS Study[a]	$1,500	$1,100	$700	$300	$2,500	$12,600	$1,100	$700	$300	$2,500
Harvard Six-City Study[b]	$3,100	$2,400	$1,600	$700	$5,400	$26,800	$2,300	$1,500	$700	$5,300
Expert Elicitation Derived										
Expert A	$6,400	$5,100	$3,300	$1,400	$11,200	$56,400	$4,900	$3,100	$1,500	$11,100
Expert B	$5,200	$4,100	$2,600	$1,200	$9,000	$45,200	$3,900	$2,500	$1,200	$8,900
Expert C	$5,400	$4,200	$2,700	$1,200	$9,300	$46,900	$4,100	$2,600	$1,200	$9,300
Expert D	$3,600	$2,800	$1,800	$800	$6,200	$31,200	$2,700	$1,700	$800	$6,200
Expert E	$8,100	$6,400	$4,100	$1,800	$14,000	$70,500	$6,100	$3,900	$1,900	$13,900
Expert F	$4,700	$3,700	$2,400	$1,100	$8,200	$41,300	$3,600	$2,300	$1,100	$8,200
Expert G	$2,900	$2,300	$1,500	$700	$5,100	$25,600	$2,200	$1,400	$700	$5,100
Expert H	$3,600	$2,800	$1,800	$800	$6,200	$31,200	$2,700	$1,700	$800	$6,200
Expert I	$5,000	$4,000	$2,600	$1,100	$8,700	$44,000	$3,800	$2,500	$1,200	$8,700
Expert J	$4,500	$3,500	$2,300	$1,000	$7,800	$39,100	$3,400	$2,200	$1,000	$7,700
Expert K	$900	$700	$500	$200	$1,500	$7,600	$700	$400	$200	$1,500
Expert L	$3,500	$2,800	$1,800	$800	$6,100	$30,900	$2,700	$1,700	$800	$6,100

- Does not include residual benefits of full attainment in areas that were not modeled to attain using illustrative control strategies.

[a] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[b] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

Table 5-33: Apportionment of Monetized Health Benefits of Modeled Attainment Strategies to PM Component Species -- 7 Percent Discount Rate*

	15/35 Modeled Attainment Strategy					14/35 Modeled Attainment Strategy				
	Ammonium Sulfate	*Ammonium Nitrate*	*Crustal*	*Elemental Carbon*	*Organic Carbon*	*Ammonium Sulfate*	*Ammonium Nitrate*	*Crustal*	*Elemental Carbon*	*Organic Carbon*
Percent of Monetized Benefits	23.5%	18.5%	12.0%	5.2%	40.7%	73.2%	6.4%	4.1%	1.9%	14.5%
Apportioned Benefits: Source of Mortality Effect Estimate										
Data Derived										
ACS Study[a]	$1,200	$1,000	$600	$300	$2,200	$10,800	$900	$600	$300	$2,100
Harvard Six-City Study[b]	$2,600	$2,100	$1,300	$600	$4,500	$22,800	$2,000	$1,300	$600	$4,500
Expert Elicitation Derived										
Expert A	$5,400	$4,300	$2,800	$1,200	$9,400	$47,600	$4,100	$2,700	$1,300	$9,400
Expert B	$4,400	$3,400	$2,200	$1,000	$7,600	$38,200	$3,300	$2,100	$1,000	$7,600
Expert C	$4,500	$3,600	$2,300	$1,000	$7,900	$39,600	$3,400	$2,200	$1,000	$7,800
Expert D	$3,000	$2,400	$1,600	$700	$5,300	$26,500	$2,300	$1,500	$700	$5,200
Expert E	$6,800	$5,400	$3,500	$1,500	$11,800	$59,500	$5,200	$3,300	$1,600	$11,800
Expert F	$4,000	$3,200	$2,100	$900	$6,900	$34,900	$3,000	$1,900	$900	$6,900
Expert G	$2,500	$2,000	$1,300	$600	$4,300	$21,700	$1,900	$1,200	$600	$4,300
Expert H	$3,000	$2,400	$1,600	$700	$5,200	$26,400	$2,300	$1,500	$700	$5,200
Expert I	$4,300	$3,400	$2,200	$1,000	$7,400	$37,200	$3,200	$2,100	$1,000	$7,400
Expert J	$3,800	$3,000	$1,900	$800	$6,600	$33,100	$2,900	$1,800	$900	$6,500
Expert K	$800	$600	$400	$200	$1,300	$6,600	$600	$400	$200	$1,300
Expert L	$3,000	$2,400	$1,500	$700	$5,200	$26,200	$2,300	$1,500	$700	$5,200

* Does not include residual benefits of full attainment in areas that were not modeled to attain using illustrative control strategies.

[a] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs

[b] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

As discussed in previous chapters, the 15/35 attainment strategy focused more on local controls of direct PM compared to the attainment strategy for 14/35. As such, the proportion of benefits accounted for by carbon and crustal components is much greater. Because the 14/35 strategy included a significant regional reduction in EGU and non-EGU SO2 in the Eastern U.S., the benefits for the 14/35 strategy are much more heavily comprised of sulfate reductions. In both cases, elemental carbon contributes only a small fraction of the benefits.

5.3 Discussion

This analysis has estimated the health and welfare benefits of reductions in ambient concentrations of particulate matter resulting from a set of illustrative control strategies to reduce emissions of $PM_{2.5}$ precursors. The result suggests there will be significant additional health and welfare benefits arising from reducing emissions from a variety of sources in and around projected nonattaining counties in 2020. While 2020 is the expected date that states would need to demonstrate attainment with the revised standards, it is expected that benefits (and costs) will begin occurring much earlier, as states begin implementing control measures to show reasonable progress towards attainment. Using the full range of benefits (including the results of the expert elicitation), our estimate that between 1,200 and 13,000 additional premature mortalities would be avoided annually when the emissions reductions from implementing the new standards are fully realized provides additional evidence of the important role that implementation of the standards plays in reducing the health risks associated with exceeding the standards.

There are several important factors to consider when evaluating the relative benefits of the attainment strategies for the revised 15/35 and more stringent 14/35 standards. First, California accounts for a large share of the total benefits for both of the evaluated standards. As noted in this and other chapters, California presented a unique challenge for modeling attainment with the standards because of the severe nature of the air quality problem and difficulties in modeling the impacts of emissions controls on air quality. Because we were only able to model a small fraction of the emissions controls that might be needed to reach attainment in California, the proportion of California benefits in the “residual attainment” category are large relative to other areas of the U.S. These benefits are likely to be more uncertain than the modeled benefits, and they are likely to understate the actual benefits of attainment strategies, because we applied an estimation approach that reduced concentrations only at the specific violating monitors and not surrounding monitors that did not violate the standards. The magnitude of this underestimate is unknown.

Another important factor to note is the geographic scope of the controls applied in the two illustrative attainment strategies. Comparing the benefits of the two attainment strategies, it is clear that the incremental impact of the attainment strategy for the tighter annual standard is to almost double the total benefits. This should not be construed to indicate that tightening the annual standard by one microgram is equivalent to tightening the daily standard by thirty micrograms. Much of the difference in benefits is due to the regional nature of the illustrative control strategy evaluated for the tighter annual standard. Because a regional SO2 program for EGU and nonEGU sources was evaluated, this resulted in much more widespread reductions in ambient $PM_{2.5}$ concentrations relative to the more localized emissions reductions programs evaluated for the 15/35 attainment strategy. Depending on the types and locations of controls selected by states to reach attainment, benefits of attaining either the revised or alternative standards can vary greatly from our projections.

As noted above, there continues to be scientific uncertainty about the specific toxicity of different components of overall PM2.5 mass. This issue is an active area of research for EPA. The Agency is exploring ways to estimate the importance of this assumption on the certainty of human health benefits and its implications for control strategy development and assessment. The agency has recently conducted an exploratory sensitivity analysis including this factor among a number of other potentially important input parameters. The preliminary findings of this analysis can be found in the draft report at located in the PM NAAQS RIA docket.

While EPA has not performed formal sensitivity analysis of the assumption of equal toxicity for this RIA, we can, nonetheless, suggest that in the face of uncertainties regarding differential toxicity, strategies that reduce a wide array of types of PM and precursor emissions will have more certain health benefits than strategies that are more narrowly focused. The illustrative attainment strategy for the revised standards results in a balanced mix of reductions in different PM2.5 components, suggesting it may be a more robust strategy than one that achieves reductions in only one component Until a more robust scientific basis exists for making reliable judgments about the relative toxicity of PM, it will not be possible to determine whether the strategy of reducing a wide array of PM types is the optimal approach.

Inherent in any analysis of future regulatory programs are uncertainties in projecting atmospheric conditions and source-level emissions, as well as population, health baselines, incomes, technology, and other factors. The assumptions used to capture these elements are reasonable based on the available evidence. However, data limitations prevent an overall quantitative estimate of the uncertainty associated with estimates of total economic benefits. If one is mindful of these limitations, the magnitude of the benefits estimates presented here can be useful information in expanding the understanding of the public health impacts of reducing $PM_{2.5}$ precursor emissions.

EPA will continue to evaluate new methods and models and select those most appropriate for estimating the health benefits of reductions in air pollution. It is important to continue improving benefits transfer methods in terms of transferring economic values and transferring estimated impact functions. The development of both better models of current health outcomes and new models for additional health effects such as asthma, high blood pressure, and adverse birth outcomes (such as low birth weight) will be essential to future improvements in the accuracy and reliability of benefits analyses (Guo et al., 1999; Ibald-Mulli et al., 2001). Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, and economists should result in a more tightly integrated analytical framework for measuring health benefits of air pollution policies.

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Chapter 6: Engineering Cost Estimates

Chapter Synopsis

This chapter summarizes the data sources we used, and the methodology we followed, to estimate the engineering cost of our illustrative control strategies. Section 6.1 summarizes the emission control databases and models we used to estimate engineering control cost for non-EGU, EGU and mobile emission sources. Section 6.2 presents cost by sector and state for the revised and alternative more stringent standards. Section 6.3 summarizes the costs of the supplemental carbonaceous particle controls described in Chapter 4. Section 6.4 describes the approach we used to estimate full attainment cost in California and Salt Lake City as well as some of the key uncertainties associated with the full attainment cost estimates derived using this methodology. Finally, Section 6.5 summarizes the modeled, supplemental and extrapolated control costs to present the incremental costs of attaining the revised and more stringent alternative $PM_{2.5}$ standards.

Note that this chapter presents both the costs of our modeled, supplemental and extrapolated emission controls. Modeled emission controls are those that we applied to industrial sources and subsequently simulated the resulting air quality changes in the air quality model. Supplemental emission controls were those carbonaceous particle controls that we applied outside of the air quality model. Finally, we developed extrapolated controls for those counties in California and Salt Lake City that remained in residual non-attainment after applying modeled and supplemental emission controls. The subsections below summarize the engineering cost of each of these three control types.

As is discussed throughout this report, the technologies and control strategies selected for analysis are illustrative of one way in which nonattainment areas can meet the revised standards. There are numerous ways to compile and evaluate potential control programs to comply with the standards, and EPA anticipates that State and Local governments will consider those programs that are best suited for local conditions. As such, the costs described in this chapter generally cover the costs of purchasing and installing the referenced technologies. Because we are not certain of the specific actions that State Agencies will take to design State Implementation Plans to meet the revised standards, we do not present estimated costs that government agencies may incur for managing the requirement and implementation of these control strategies or for offering incentives that may be necessary to encourage or motivate the implementation of the technologies, especially for technologies that are not necessarily market driven. Control measure costs referred to as "no cost" may require limited government agency resources for administration and oversight of the program, but those costs are outweighed by the saving to the industrial, commercial, or private sector. This analysis does not assume specific control measures that would be required in order to implement these technologies on a regional or local level.

6.1 Data Sources and Methodology

6.1.1 Non-EGU Point and Area Sources: AirControlNET

Once we determined the control technologies selected to meet the standard with the methodology discussed in Chapter 3, we used AirControlNET to estimate engineering control cost. AirControlNET calculates costs using three different methods: (1) by multiplying a dollar per ton estimate against the total tons of a pollutant reduced to derive a total cost estimate; (2) calculating cost by using an equation that incorporates information regarding key plant information; or, (3) both cost per ton and cost equations.[1] Most of the control cost information within AirControlNET has been developed as cost per ton inputs. This is likely due to the fact that estimating cost using an equation requires more data and the fact that parameters used in other non-cost per ton methods may not be readily available or broadly representative across sources within the inventory. The costing equations used in AirControlNET require either plant capacity or stack flow to determine annual, capital and/or Operating and Maintenance costs. Capital costs are converted to annual costs, in dollars per ton, using the capital recovery factor. The capital recovery factor incorporates the interest rate and equipment life (in years) of the control equipment. For more information on this cost methodology, please refer to Chapter 2 of Section 1 of the EPA Air Pollution Control Cost Manual. [2] Control measure costs identified as "both" use equations unless plant capacity or stack flow data is incomplete in the EPA emission inventories. In that case, a default dollar per ton of pollutant reduced value is applied (Pechan, 2006a).[3] Detailed documentation for all costing methods is provided in AirControlNET 4.1: Control Measures Documentation (Pechan, 2006b) along with descriptions of control measures and emission reductions.

6.1.2 EGU Sources: The Integrated Planning Model

The Integrated Planning Model (IPM) is a dynamic linear programming model that evaluates the costs and emissions impacts of proposed emissions reductions from the electric power sector. The model determines the least-cost means of meeting energy and peak demand requirements over a specified period, while complying with specified constraints, including air pollution regulations, transmission bottlenecks, fuel market restrictions, and plant-specific operational constraints. IPM is unique in its ability to provide an assessment that integrates power, environmental, and fuel markets. The model accounts for key operating or regulatory constraints (e.g. emission limits, transmission capabilities, renewable generation requirements, fuel market constraints) that are placed on the power, emissions, and fuel markets. IPM is particularly well-suited to consider complex treatment of emission regulations involving trading and banking of emission allowances, as well as traditional command-and-control emission policies.

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[1] AirControlNET does not provide cost per microgram ($/µg) estimates. Estimates of cost per µg require the use of AirControlNET <u>and</u> µg reduction estimates provided by the Response Surface Model (RSM) as explained in Chapter 3.

[2] The entire EPA Air Pollution Control Cost Manual can be found on the Internet at http://www.epa.gov/ttn/catc/products.html#cccinfo.

[3] Detailed information on default information used as part of cost estimates generated by AirControlNET can be found in a memorandum from Frank Divita, E.H. Pechan and Associates, Inc. to Larry Sorrels, U.S. Environmental Protection Agency, "AirControlNET – Cost Equations and Default Information," May 12, 2006.

IPM's goal is to minimize the total, discounted net present value, costs of meeting demand, power operation constraints, and environmental regulations over a specified period of time. Three pieces comprise the model: a linear "objective function," a series of "decision variables," and a set of linear "constraints" over which the objective function is minimized to yield an optimal solution.

Objective Function. The objective function is the sum of all the costs incurred by the electricity sector expressed as the net present value of all the component costs. These costs, which the linear programming formulation attempts to minimize, include the cost of new plant and pollution control construction, fixed and variable operating and maintenance costs, and fuel costs. Many of these cost components are captured in the objective function by multiplying the decision variables by a cost coefficient. Cost escalation factors are used in the objective function to reflect changes in cost over time. The applicable discount rates are applied to derive the net present value for the entire planning horizon from the costs obtained for all years in the planning horizon.

Decision Variables. Decision variables represent the values which the IPM model is "solving for," given the cost-minimizing objective function and electric system constraints. The decision variables are the model's "outputs" and represent the optimal least-cost solution to meeting the assumed constraints. The decision variables represented in IPM include:

- Generation Dispatch Decision Variables
- Capacity Decision Variables
- Transmission Decision Variables
- Emission Allowance Decision Variables
- Fuel Decision Variables

Constraints. Model constraints are implemented in IPM to accurately reflect the characteristics of and the conditions faced by the power sector. Constraints included in IPM include:

- Reserve Margin Constraints
- Demand Constraints
- Capacity Factor Constraints
- Turn Down/Area Protection Constraints
- Emissions Constraints
- Transmission Constraints
- Fuel Supply Constraints

In IPM, model plants that represent existing generating units have the option of maintaining their current system configuration, retrofitting with pollution controls, repowering, or retiring early. The decision to retrofit, repower, or retire is endogenous to IPM and based on the least cost approach to meeting the system and other operating constraints included in IPM. Detailed information on IPM can be found in in EPA's documentation report of the model (http://www.epa.gov/airmarkets/epa-ipm).

AirControlNET Estimates of Direct $PM_{2.5}$ Control Cost at EGU's

The costs of these upgrades vary by the capacity of the unit with the electrostatic precipitator (ESP). This variance enters into the equations to estimate capital and fixed operating and maintenance (O&M) costs. Variable O&M costs are constant for all unit capacities. The equations for estimating the costs of adding 2 collector plates are the following:

Capital Cost in $/kW = 17.5 x $(250/MW)^{0.3}$ (MW is unit capacity in megawatts)

Variable O&M cost in mills/kWh = 0.013 (same for all unit capacities)

Fixed O&M Cost in $/kW-yr = 0.31 x $(250/MW)^{0.3}$ (MW is unit capacity in megawatts)[4]

Two important assumptions that underlie these equations are a capacity factor of 85% (i.e., the unit is operating 85% of the time in a typical year), and a capital recovery factor of 0.12. The cost effectiveness of these ESP upgrades is a direct function of the capacity factor, i.e., an increase in the capacity factor improves the cost effectiveness of applying environmental controls. The 85% capacity factor is based on the coal-fired plant availability data reported by the North American Electric Reliability Council (NERC) in its Generating Availability Data System (GADS) reports. An average of the reported availability data for five years (2000-2004) was used to arrive at the capacity factor value. The data in GADS cover all major US coal-fired power generating units. The capital recovery factor reflects the expected economic life of the additional collector plates and the interest rate used to annualize the capital costs. In this case, the interest rate is the same as that employed in the current IPM.[5]

From these equations, one can see that capital and fixed O&M costs decrease on $/kW or a $/kW-yr basis as unit capacity increases. Thus, the total capital and O&M costs increase with unit capacity but at a decreasing rate. For example, at a unit capacity of 250 MW, the capital cost is $17.5/kW or $4,375,000, and the fixed O&M cost is $0.31/kW-yr or $678,900. At 500 MW, the capital cost is $14.2/kW or $7,100,000, and the fixed O&M cost is $0.25/kW-yr or $1,095,000. Hence, a doubling of unit capacity yields an increase of less than that for the costs of this ESP upgrade (62% higher for capital, 61% higher for fixed O&M). These cost equations provide values in December 2005 terms, and we deescalate these to 1999 dollars using the Chemical Engineering Plant Cost Index (CEPCI).

The cost equations for the upgrade of 1 additional collector plate yields somewhat lower cost estimates when compared to the addition of 2 collector plates. These equations can be found in the memorandum prepared by EPA and located in the docket.

Some caveats should be noted in the use of these costs. These costs are only for ESP modifications at EGUs. While there is no technical reason why these modifications cannot take place at industrial boilers or other non-EGU units, we do not apply this developmental control to non-EGU units because these equations and data are based on information taken from EGU

[4] Memorandum from Sikander Khan, U.S. EPA/OAP/CAMD to $PM_{2,5}$ NAAQS Docket, "Cost Estimation for Modification Options to Improve ESP Performance," August 21, 2006.
[5] Personal communication of Sikander Khan, U.S. EPA/OAP/CAMD with Larry Sorrels, U.S. EPA/OAQPS/HEID. March 16, 2006.

operations and hence may not be appropriate for application to non-EGU units. In addition, these costs are preliminary in nature and there is need for more detailed results to confirm their accuracy.

6.1.3 Mobile Sources

Cost information for mobile source controls was taken from studies conducted by EPA for previous rulemakings and studies conducted for development of voluntary and local measures that could be used by state or local programs to assist in improving air quality. These studies are mentioned further in section 6.2.3. Links to specific references are available at the website for EPA's Office of Transportation and Air Quality, www.epa.gov/otaq.

6.2 Cost by Sector

In this section, we provide engineering cost estimates of the control strategies identified in Chapter 3 that include control technologies on non-EGU stationary sources, area sources, electric generating units, and mobile sources. Engineering costs generally refer to the capital equipment expense, the site preparation costs for the application, and annual operating and maintenance costs. These costs serve as input to the economic impact analysis presented in Section 6, which produces an estimate of the quantifiable social cost of the regulatory option analyzed in this RIA. The total annualized cost of each control scenario is provided in Table 6-1 and reflects the engineering costs across sectors that are annualized at an interest rate of 7 percent; we also provide a summary estimate of engineering cost at a 3 percent discount rate. Total annualized cost of the revised standard, incremental to the current standard, is approximately $5 billion. Of this incremental cost of $5 billion, approximately $4.3 billion in costs are attributable to the extrapolated full attainment costs for California and Salt Lake City, which are speculative (see Section 6.4 below for a full discussion of the extrapolation methodology). To provide some context of this cost to society, this cost estimate is roughly equivalent to $35 per household per year in the U.S. The total annualized cost of the more stringent alternative for the annual standard, incremental to the current standard is approximately $7 billion (or $1.9 billion in additional costs over and above the revised standard of 15/35), which equates to approximately $50 per household in the U.S. Of this incremental cost of $7 billion, about $4.3 billion are attributable to the extrapolated full attainment costs for California and Salt Lake City, which are speculative. The economic impact analysis also provides a more in-depth evaluation of how the engineering costs will impact society through a distributional analysis of changes in price and production levels in affected industries, and who will bear the burden of the regulatory costs (consumers or suppliers).

Note that the cost estimates provided in table 6-1 are comprised of modeled, supplemental and extrapolated costs. Cost estimates for EGU's, mobile sources and other industrial sources are modeled engineering cost. The incremental cost of residual non-attainment is comprised of both supplemental and extrapolated control costs. In the subsections that follow we describe how we derived each of these control cost categories.

Tables 6-2 and 6-3 display total annualized cost of “modeled” controls by State (at a 7% interest rate) for non-EGU stationary and area sources, respectively. Details of the costs for each sector of control are provided in Sections 6.2.1 through 6.2.3.

Table 6-1: Comparison of Total Annualized Engineering Costs Across PM NAAQS Scenarios (millions of 1999 dollars) [a]

	Scenario	
Source Category	*Revised Stds: 15/35*	*Alternative Revised Stds:: 14/35*
I. Modeled Partial Attainment		
A. Electric Generating Units (EGU) Sector		
Local Controls on direct PM	$340	$350
Local Controls for NO_X	$59	$55
Regional EGU program (equivalent to a Phase III of CAIR)	n/a	$680
Total	**$400**	**$1,100**
B. Mobile Source Sector		
Local Measures - direct PM	$30	$30
Local Measures – Nox	$31	$31
Total	**$60**	**$60**
C. Non-EGU Sector		
Point Sources (Ex: Pulp & Paper, Iron & Steel, Cement, Chemical Manu.)		
SO_2 Regional Program for Industrial Sources	n/a	$1,000
Local Known Controls	$300	$240
Area Sources (Ex: Res. Woodstoves, Agriculture)	$44	$46
Developmental Controls (Point & Areas Sources)	$32	$36
Total	**$380**	**$1,300**
II. Incremental Cost of Residual Nonattainment[b,c]		
East	$3	$180
West	$300	$300
California	$4,000	$4,000
Total	**$4,300**	**$4,500**
III. Full Attainment (Partial, plus Residual Nonattainment)		
Total Annualized Costs (using a 7% interest rate)	**$5,100**	**$7,000**
Total Annualized Costs (using a 3% interest rate)	**$5,050**	**$6,800**

a All estimates provided reflect a baseline of 2020 which include implementation of several national programs (e.g. CAIR, CAMR, CAVR), and compliance with the current standard of 15/65.

b Upon review of emissions and air quality results of the control strategies applied in this RIA, some areas were indicated with residual nonattainment (requiring additional reductions to meet the standard) as a result of our initial selection of controls. The incremental costs of residual nonattainment reflect supplemental controls and extrapolated costs of additional control measures that would be necessary to bring areas with residual nonattainment into compliance. Chapter 4 provides details of the assessment. Numbers may not sum due to rounding.

c The incremental cost of residual non-attainment for the West and California are extrapolated. The methodology used to derive these estimates is described in Chapter 6. These estimates are derived using a 7 percent discount rate.

6.2.1 *Non-EGU Stationary and Area Sources*

In Table 6-2 and 6-3 below, we present the total annualized cost to each State for the proposed standard and the more stringent alternative. The costs reflected in this table represent annualized costs of the modeled attainment strategies (including local known controls on point and area sources as well as developmental controls) selected for analysis of the two regulatory options. We also provide some observations about the cost estimates that provide some insight into the control strategies selected. Readers interested in reviewing each of the emission controls we applied can consult the Emission Controls Technical Support Document, located in the docket.

Table 6-2: Total Annualized Costs of Modeled Attainment Strategies Applied to Non-EGU (Point) Stationary Sources: Costs by State and Pollutant Category* (millions of 1999$)

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*	*Observations*
Alabama	SO_2 ***Total***	$0 ***$0***	$36 ***$36***	Costs reflect controls of the SO_2 regional program considered for the 14/35 scenario. Alabama is not projected to be in nonattainment for the revised daily standard once the area complies with the current standard of 15/65
California	NO_x $PM_{2.5}$ ***Total***	$0 $3 ***$3***	$1 $3 ***$4***	Incremental control for the annual 14 std. and the daily 35 std reflect additional counties that attained 15/65 but do not attain the new daily standard and the more stringent alternative std. analyzed
Georgia	SO_2 ***Total***	$0 ***$0***	$140 ***$140***	Costs reflect controls of the SO_2 regional program considered for the 14/35 scenario
Idaho	NO_x $PM_{2.5}$ ***Total***	$2 $3 ***$5***	$2 $3 ***$5***	Costs reflect controls selected to meet the daily standard only
Illinois	SO_2 ***Total***	$0 ***$0***	$140 ***$140***	Illinois complies with the daily standard at 35 µg when it complies with the 15/65 current standard. Costs reflect controls selected to meet the current standard and the SO_2 regional program considered for 14/35.
Indiana	SO_2 ***Total***	$0 ***$0***	$170 ***$170***	Indiana complies with the daily standard at 35 µg when it complies with the 15/65 current standard. Costs reflect controls selected for the SO_2 regional program considered for 14/35.
Kentucky	SO_2 ***Total***	$0 ***$0***	$48 ***$48***	Kentucky complies with the daily standard at 35 µg when it complies with the 15/65 current standard. Costs reflect controls selected to meet the current standard and the SO_2 regional program considered for 14/35.

* Costs presented in this table are rounded to the nearest million and are incremental to costs of meeting the current standard of 15/65.

Table 6-2: Total Annualized Costs of Modeled Attainment Strategies Applied to Non-EGU Stationary (Point) Sources: Costs by State and Pollutant Category (continued)* (millions of 1999$)

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*	*Observations*
Michigan	NO_x	$0	$44	Michigan meets the daily standard. Costs reflect controls selected for the SO_2 regional program considered for 14/35 and other point source controls.
	$PM_{2.5}$	$0	<$1	
	SO_2	$0	$160	
	Total	***$0***	***$200***	
Missouri	SO_2	$0	$110	Costs reflect the SO_2 regional program only
	Total	***$0***	***$110***	
Montana	NO_x	$3	$3	Costs reflect controls to meet the daily standard only.
	$PM_{2.5}$	$13	$13	
	Total	***$16***	***$16***	
Ohio	$PM_{2.5}$	$2	<$1	Costs reflect controls to meet the current standard, the new daily standard at 35 µg, the regional SO_2 program considered for the 14/35 scenario that reduced the number of controls needed from direct $PM_{2.5}$ sources.
	SO_2	$0	$160	
	Total	***$2***	***$160***	
Oregon	NO_x	$10	$10	Cost reflect controls to meet the daily standard only.
	$PM_{2.5}$	$11	$11	
	Total	***$21***	***$21***	
Pennsylvania	$PM_{2.5}$	$28	$28	Control strategies required non-EGU stationary controls in all three regulatory scenarios analyzed for both the daily and annual standards
	SO_2	$72	$49	
	Total	***$100***	***$76***	
Utah	$PM_{2.5}$	<$1	<$1	Cost reflect controls to meet the daily standard only.
	Total	***<$1***	***<$1***	
Washington	NO_x	$84	$77	Cost reflect controls to meet the daily standard only.
	$PM_{2.5}$	$25	$25	
	Total	***$109***	***$100***	
West Virginia	$PM_{2.5}$	$15	$15	Although West Virginia attains the scenarios analyzed, controls strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	SO2	$38	$0	
	Total	***$54***	***$15***	

*** Costs presented in this table are rounded to the nearest million and are incremental to costs of meeting the current standard of 15/65.**

Table 6-2: Total Annualized Costs of Modeled Attainment Strategies Applied to Non-EGU Stationary (Point) Sources: Costs by State and Pollutant Category (continued)* (millions of 1999$)

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*	*Observations*
Total Annualized Costs for the Non-EGU point source sector (7% Discount Rate)		***$310***	***$1,200***	
Total Annualized Costs for the Non-EGU point source sector (3% Discount Rate)		***$290***	***$1,200***	

* Costs presented in this table are rounded to the nearest million and are incremental to costs of meeting the current standard of 15/65.

Table 6-3: Total Annualized Costs of Modeled Attainment Strategies **Applied to Non-EGU Area Sources: Costs by State and Pollutant Category* (millions of 1999$)**

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*	*Observations*
California	NH_3	<$1	<$1	Incremental control for the annual 14 std. and the daily 35 std reflect additional counties that attained 15/65 but not the new annual and daily standards analyzed
	NO_x	$0	<$1	
	$PM_{2.5}$	$10	$10	
	SO_2	$0	$0	
	Total	***$10***	***$11***	
Idaho	NO_x	<$1	***<$1***	Costs reflect controls selected to meet the daily standard only
	$PM_{2.5}$	<$1	***<$1***	
	Total	***<$1***	***<$1***	
Michigan	NH_3	$0	***<$1***	Controls for direct $PM_{2.5}$ emissions are most effective to meet the current standard. Additional controls are needed for the 14/35 scenario and included costs of the SO_2 regional industrial source program.
	NO_x	$0	$2	
	$PM_{2.5}$	$0	$3	
	SO_2	$0	***<$1***	
	Total	***$0***	***$6***	
Montana	NO_x	***<$1***	***<$1***	Costs reflect controls selected to meet the daily standard only
	$PM_{2.5}$	$1	$1	
	Total	***$1***	***$1***	
Ohio	$PM_{2.5}$	$2	***<$1***	Cost reflect controls selected to meet both the annual and daily standards. Incremental area source costs are lower for 14/35 due to the regional EGU and non-EGU programs implemented
	Total	***$2***	***<$1***	

* Costs presented in this table are rounded to the nearest million and are incremental to costs of meeting the current standard of 15/65.

Table 6-3: Total Annualized Costs of Modeled Attainment Strategies Applied to Non-EGU Area Sources: Costs by State and Pollutant Category (continued)* (millions of 1999$)

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*	*Observations*
Oregon	NH_3	***<$1***	***<$1***	Costs reflect controls selected to meet the daily standard only
	NO_x	***<$1***	***<$1***	
	$PM_{2.5}$	$22	$22	
	SO_2	***<$1***	***<$1***	
	Total	***$24***	***$24***	
Pennsylvania	NH_3	***<$1***	***<$1***	Costs reflect controls selected to meet the daily standard only. The more stringent annual standard of 14 µg is met through EGU and non-EGU point source controls.
	$PM_{2.5}$	$17	$17	
	SO_2	$4	$4	
	Total	***$22***	***$22***	
Utah	$PM_{2.5}$	$3	$3	Costs reflect controls selected to meet the daily standard only
	Total	***$3***	***$3***	
Washington	NO_x	$1	$2	Costs reflect controls selected to meet the daily standard only
	$PM_{2.5}$	$6	$6	
	SO_2	$1	$1	
	Total	***$9***	***$9***	
West Virginia	$PM_{2.5}$	***<$1***	***<$1***	Although West Virginia attains the scenarios analyzed, controls strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	SO_2	***<$1***	***<$1***	
	Total	***<$1***	***<$1***	
Total Annualized Cost for the Area Source Sector (7% Discount Rate)		***$72***	***$77***	
Total Annualized Cost for the Area Source Sector (3% Discount Rate)		***$71***	***$75***	

* Costs presented in this table are rounded to the nearest million and are incremental to costs of meeting the current standard of 15/65.

6.2.2 EGU Sources

Costs of Controls Outside the CAIR Region and Costs of Direct PM Controls Nationwide

In addition to the discussion of controls on EGU's in Section 6.2.1, we also applied EGU controls to sources from the AirControlNET model. Controls selected are focused on those controls that are not considered part of the CAIR rule, such as direct $PM_{2.5}$ control technologies, and in the Western U.S. controls for NO_x emissions from these sources. The direct PM and NO_x controls for EGU's were selected only when this sector was identified as a cost-effective category for control strategies. In Table 6-4, incremental EGU controls for the selected standard are chosen only in a limited number of States, including: Ohio, Pennsylvania, Utah, and Washington, and are selected to help these areas attain a more stringent daily standard.

Table 6-4: Total Annualized Costs Applied to EGU Sources using AirControlNET*: Costs by State and Pollutant Category (millions of 1999$)

State	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*
Michigan	$PM_{2.5}$	$0	$36
Ohio	$PM_{2.5}$	$140	$110
Pennsylvania	$PM_{2.5}$	$190	$190
Utah	NO_x	$55	$55
	$PM_{2.5}$	$13	$13
	Total	*$68*	*$68*
Washington	$PM_{2.5}$	$2.9	$2.9
West Virginia	$PM_{2.5}$	$0	$0
Wisconsin	$PM_{2.5}$	$0	$0
Total Annualized Cost for EGU sources from ACNet (7% Discount Rate)		***$400***	***$410***
Total Annualized Cost for EGU sources from ACNet (3% Discount Rate)		***$360***	***$370***

* Costs presented in this table are incremental to costs of meeting the current standard of 15/65.

Power Sector Impacts of Illustrative CAIR Extended Analysis

As previously discussed, the power sector will achieve significant emission reductions under the Clean Air Interstate Rule (CAIR) over the next 10 to 15 years. When fully implemented, CAIR will reduce SO2 emissions in these States by over 70 percent and NOx emissions by over 60 percent from 2003 levels. These reductions will greatly improve air quality and will lessen the challenges that some areas face when solving nonattainment issues significantly.

The analysis and projections in this section attempt to show the potential impacts of the Illustrative CAIR Extended approach to facilitate attainment of the more stringent alternative annual standard of 14 μ/m^3 and daily standard of 35 μ/m^3. Generally, the incremental impacts of the Illustrative CAIR Extended approach on the power sector are relatively modest.

Projected Costs. EPA projects that the annual incremental costs of the Illustrative CAIR Extended approach are $0.51 billion in 2015 and $0.68 billion in 2020. The cost of electricity generation represents roughly one-third to one-half of total electricity costs, with transmission and distribution costs representing the remaining portion. The additional annual costs reflect additional retrofits (scrubbers), generation shifts, and the increased cost of allowances. Although the Illustrative CAIR Extended approach comes into effect in 2020 (with a third phase to CAIR), economic modeling indicates that the least-cost approach to complying involves changing banking patterns by reducing emissions prior to 2020. The additional reductions (and pollution controls) prior to 2020 result in additional costs to the power sector in 2015 as it complies in the most cost-effective manner.

Figure 6-1. Incremental Annual Cost of CAIR and CAIR Extended for EGUs (billions $1999)

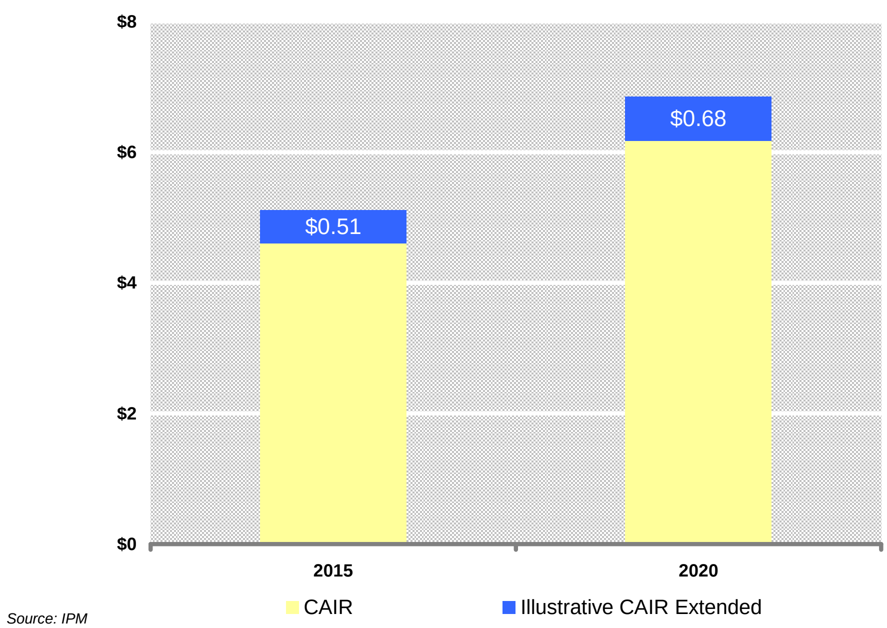
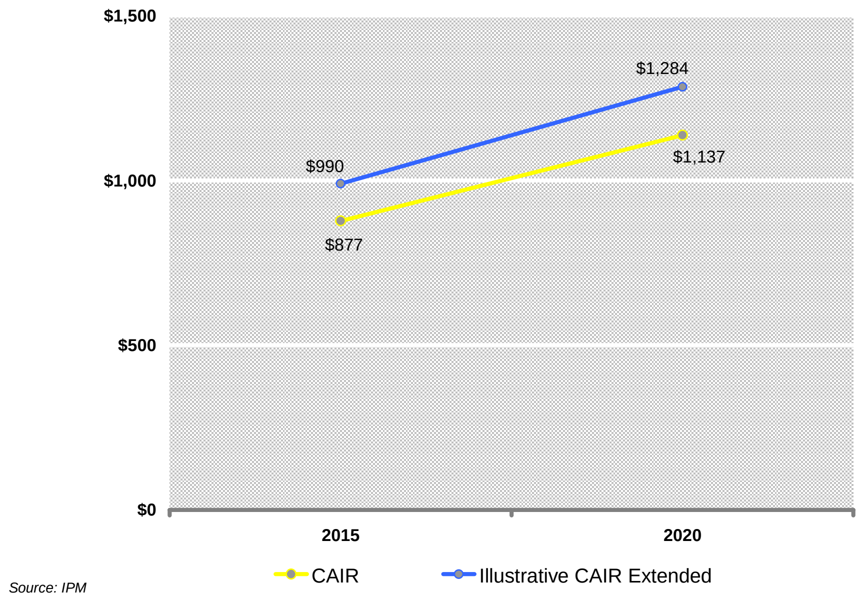
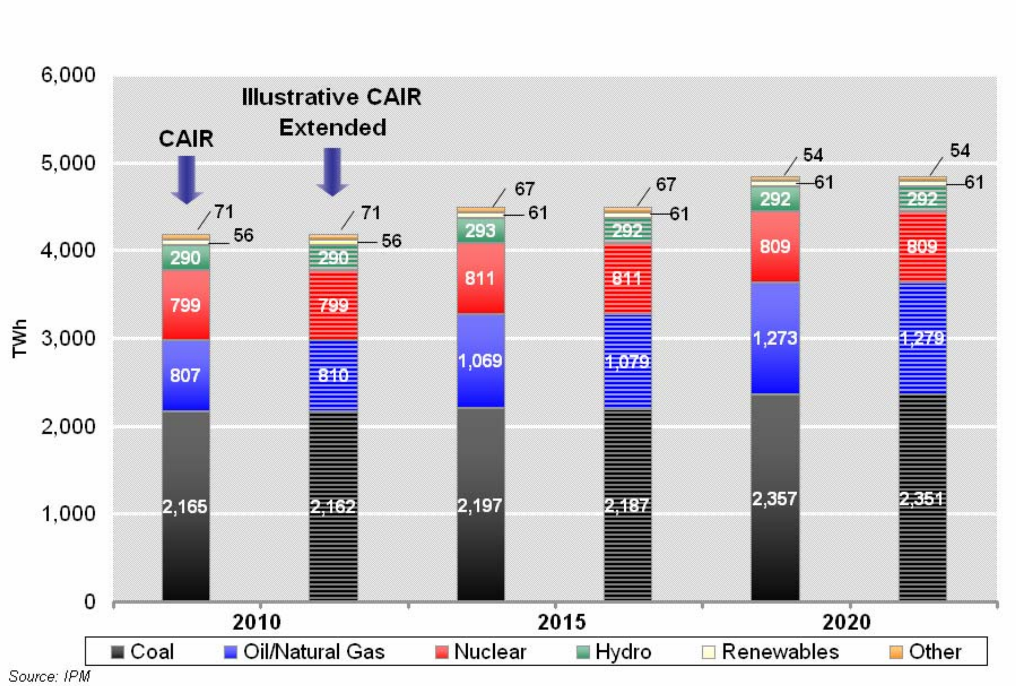


Figure 6-2. Marginal Cost of SO2 Allowances with CAIR and CAIR Extended for EGUs ($1999)



Projected Generation Mix. Coal-fired generation and natural gas-fired generation are projected to remain relatively unchanged because of the phased-in nature of CAIR, which allows industry the appropriate amount of time to install the necessary pollution controls. The Illustrative CAIR Extended approach does not change the way the power sector produces electricity in any significant way, and changes in the electricity generation mix of the CAIR Extended approach, relative to CAIR, are negligible.

Figure 6-3. Projected Generation Mix in 2010, 2015, and 2020 with CAIR and CAIR Extended (TWh)



Projected Nationwide Retail Electricity Prices. Retail electricity prices are not projected to increase noticeably under the Illustrative CAIR Extended approach, relative to CAIR. The extension of the cap-and-trade approach allows industry to meet the requirements of CAIR and the CAIR Extended approach in the most cost-effective manner, thereby minimizing the costs passed on to consumers. Retail electricity prices are projected to increase less than a third of a percent in 2020 under the Illustrative CAIR extended approach, relative to CAIR. Electricity price projections are from IPM and do not include possible price increases in certain areas outside of the CAIR region that may result from applying additional local controls on EGUs (See Chapter 3 for additional discussion of local controls on EGUs outside of the CAIR region).
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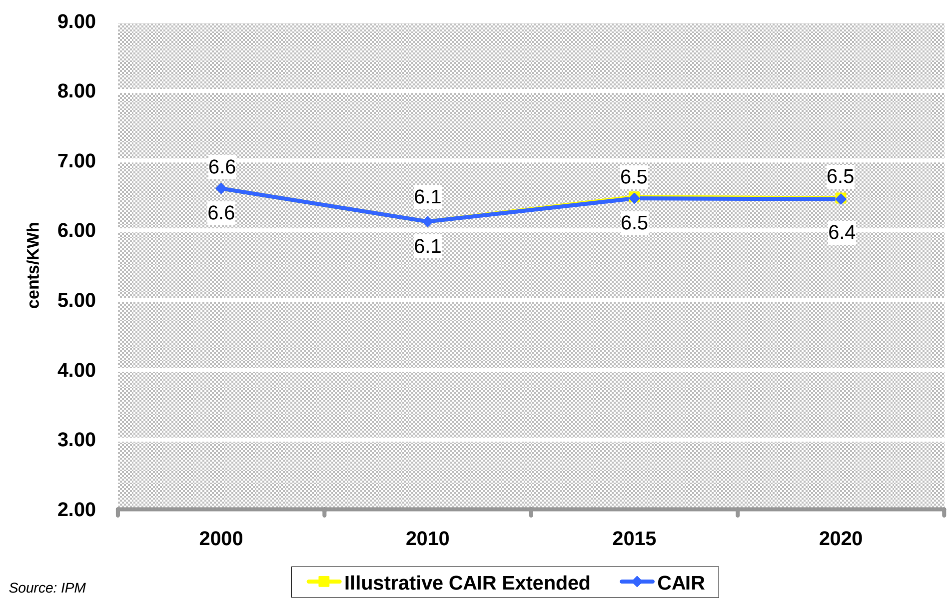
Figure 6-4. Projected Nationwide Retail Electricity Prices ($1999) with CAIR and CAIR Extended



6.2.3 Mobile Sources

This sub-section presents cost information for each mobile source control technology included in the analysis. As is discussed in Appendix A, EPA considered several national mobile source rules in the analysis of meeting the current standard of 15/65. In this sub-section, we discuss the costs of local measures for mobile sources that can be applied incremental to the national rules in order to comply with the revised and alternative standards. Costs for the individual technologies are in terms of $/ton of emissions reduced. These values were applied to the tons of emissions reduced in each geographic area and were then summed to determine total costs for each scenario. Note that control technologies or measures that affect emissions from mobile sources frequently have impacts on multiple pollutants. Where this is the case, we attempt to provide information on our cost calculation methodology with respect to the pollutants of concern.

Note Regarding Mobile Source Air Toxics Rule

The recent proposal to reduce mobile source air toxics (71 FR 15804, March 29, 2006) discusses data showing that direct $PM_{2.5}$ emissions from gasoline vehicles are elevated at cold temperatures. The proposed vehicle hydrocarbon standards contained in the March 29, 2006 action would also reduce these elevated PM emissions. This RIA does not include the effects of this proposed rule because we do not currently have the data to model the impacts of elevated cold-temperature PM emissions across the entire in-use fleet. As a result, these cold-temperature emissions are not included in our baseline emission inventories, which may understate the baseline—and consequently projected—inventory of mobile source $PM_{2.5}$ emissions. The final mobile source air toxics rule would thus reduce $PM_{2.5}$ emissions, and improve air quality, by an amount not reflected in our analysis of these standards and may make compliance easier by reducing the need for some control strategies. EPA is currently analyzing these data from a large collaborative test program with industry, and our next emissions model (MOVES) will include cold temperature effects for PM.

Geographical Scope of Mobile Source Controls

It is important to clarify the sequence by which mobile source control measures were applied within the broader context of all control measures. In applying the cost information for the 15/35 and 14/35 scenarios, we first applied cost-effective local stationary source (point and area) controls. Next, due to time and analytical constraints, we applied local mobile source control measures only in areas where all available control measures were needed (southern California) and areas where a small additional amount of reductions would be needed to reach attainment (Chicago, Detroit, and the remaining areas in the West indicated by our air quality modeling as exceeding the standard). However, this does not imply that State and local authorities will sequence application of control measures in a similar fashion. State and local governments may have numerous reasons for employing mobile source control strategies *before* a set of measures that control point or area sources (for example, further point source controls would be less cost-effective than mobile measures, and/or an area's stationary sources are already well-controlled).

The following table lists the geographic areas to which mobile source control measures were applied.

Table 6-5: Geographic Areas to which Mobile Source Controls were Applied for 15/35 and 14/35

Geographic Area	15/35 & 14/35 Scenarios
National Rules	All counties in the U.S.
	Southern California
	Chicago MSA
	Detroit MSA
	Missoula, MT MSA
Local Measures	Lincoln County, MT
	Shoshone County, ID
	Eugene-Springfield, OR MSA
	Klamath Falls, OR MSA
	Medford, OR MSA
	Logan, UT-ID MSA
	Salt Lake City, UT MSA
	Seattle-Bellevue-Everett, WA MSA
	Tacoma, WA MSA

More information on each of the rules and control measures can be found in Chapter 3, as well. In the table below, incremental mobile source controls for the selected standard are presented for the eastern U.S. (east of the Mississippi), western U.S. (except California), and California.

Table 6-6: Total Incremental Annualized Costs Applied to Mobile Sources (millions of 1999$)[a]

Geographic Area	*Pollutant*	*Total Incremental Annualized Cost of 15/35*	*Total Incremental Annualized Cost of 14/35*
Eastern U.S.			
- Local Measures	$PM_{2.5}$	$7.4	$7.4
	NO_x	$9.2	$9.2
	Total	*$17*	*$17*
Western U.S. (except CA)			
- Local Measures	PM2.5	$7.6	$7.6
	NOx	$8.8	$8.8
	Total	*$16*	*$16*
California			
- Local Measures	$PM_{2.5}$	$15	$15
	NO_x	$13	$13
	Total	*$28*	*$28*
Total Incremental Annualized Cost for Mobile Sources		***$60***	***$60***

[a] Estimates rounded to two significant figures for clarity of presentation

Emerging Mobile Source Technologies

The control strategies employed in our mobile source analysis consist of, for the most part, regulations, tools, and programs that are based on well-understood pollution control technologies and techniques. Technologies to retrofit diesel engines, to take one example, are fairly well-established and are in use in communities around the country today, though further technological advances may result in increased efficiencies and lower costs. Our analysis did not incorporate what might be termed emerging or developmental mobile source control measures, although the history of control measures leads us to anticipate the emergence of new techniques and technologies that will lower emissions of $PM_{2.5}$ and its precursors from mobile sources.

For example, research is currently underway to develop even more efficient engine designs and emission control systems both for onroad vehicles and nonroad vehicles, engines, and equipment. Research topics include improving current technologies (e.g., particulate traps, highly efficient combustion techniques); possibly using on-road emission control technologies in nonroad vehicles, engines, and equipment; and various forms of other "clean" automotive technologies.[6] This latter category includes a broad set of vehicle and fuel trends that are likely to have a substantial impact on the transportation sector, but for which data on costs and abatement efficiencies is either too scarce or simply unavailable, and therefore not suitable for inclusion in this analysis. Examples of technologies and other trends that were not analyzed as potential control measures include the following:

- Increased penetration of ethanol into the fuels market (either E10 or E85). Research relating to the net impacts on air emissions of ethanol use is ongoing.
- Research into other alternative, and possibly "cleaner," fuels.
- Advances in various forms of hybrid engine technologies.
- Development of hydrogen fuel cell vehicles (H2FCVs) (and the concomitant hydrogen supply infrastructure).
- Congestion pricing systems (e.g., peak-period fees).

Estimated Costs of Local Measures

Diesel Retrofits and Vehicle Replacement - For purposes of modeling, we divided the retrofit measure into two categories: the 1st 50% of retrofit potential (low end) and the 2nd 50% of retrofit potential (high end) to provide modeling and analytical flexibility with how such measures are applied. For example, such a division would help when applying retrofit measures to a nonattainment area in which only 50% of retrofit potential is adequate to achieve attainment. We categorize the low end as the most cost-effective retrofits since, ideally, states and local governments would first retrofit the most cost-effective fleets in terms of expected emissions reduction (based on vehicle miles traveled or VMT, expected life, model year, engine type, etc.) and cost of retrofit (based on technology and installation costs).

[6]More information can be found on EPA's website, http://www.epa.gov/otaq/technology/index.htm#rel-links.

The cost-effectiveness ($/ton of PM) estimates for retrofits are based on EPA's recent study of DOC and catalyzed DPF (CDPF) retrofits for school buses as well as class 6, 7, and 8b trucks; and just DOC retrofits for 250 hp bulldozers (the "C-E study"). The C-E study is available at http://www.epa.gov/cleandiesel/documents/420s06002.pdf. For purposes of the RIA, we believe this study is the best source of information since it is based on the most current data available. However, the C-E study was intentionally narrow in scope, and in using its data for an analysis as comprehensive as the RIA, raises a number of limitations that affect the data's applicability. For example:

- The C-E study does not address several categories of engines analyzed in the retrofit measure for the RIA (e.g. Class 5 trucks, most nonroad engines).
- The C-E study does not estimate cost-effectiveness for repower or replacement, which are both included in the retrofit measure for the RIA.
- The C-E study is based on 2007 costs for technologies and emissions data for fleets. VMT, technology costs, and other variables will be different in 2015 and 2020.
- For highway engines, the C-E study is based on emission factors from recent testing which are higher than emissions factors found in MOBILE 6.2. EPA used the MOBILE 6.2 model to develop the inventory for the RIA and to analyze emissions reduction potential from retrofits. EPA will integrate the recent highway vehicle testing data into the next highway emissions model, MOVES. In the meantime, states and local governments will continue to use MOBILE 6.2 to estimate highway vehicle emissions for SIP and transportation conformity purposes.

For estimating the more cost-effective highway vehicle retrofits, we averaged the low end of the cost-effectiveness range of both measures (DOC and CDPF) for all three groups of highway vehicles in the C-E study (school buses, class 6 & 7 trucks, and class 8b trucks). For estimating the less cost-effective highway retrofits, we used the average of the range of cost-effectiveness of both measures and all three groups of vehicles. We used the average, rather than the high end of the cost-effectiveness range, because we believe that technology and installation costs are likely to decrease by 2015 and 2020.

For the estimate of the cost-effectiveness of the low end potential of nonroad engine retrofits, we used the low end of the cost-effectiveness range for DOC retrofits of 250 hp bulldozers. For the estimate of the cost-effectiveness of the high end potential of nonroad engine retrofits, we used the average of the range of cost-effectiveness for DOC retrofits of 250 hp bulldozers. Again, we used the average, rather than the high end of the cost-effectiveness range, because we believe that technology and installation costs are likely to decrease by 2015 and 2020. The results are presented in Table 6-7 below:

Table 6-7. Cost Effectiveness for Diesel Retrofit Scenarios

Summary of Cost-Effectiveness for Various Diesel PM Retrofit Scenarios (April 2006 EPA Study) $/ton PM				
	Measure	**Min**	**Max**	**Average**
School Bus	DOC	$12,000	$49,100	$30,550
	CDPF	$12,400	$50,500	$31,450
Class 6&7 Truck	DOC	$27,600	$67,900	$47,750
	CDPF	$28,400	$69,900	$49,150
Class 8b Truck	DOC	$11,100	$40,600	$25,850
	CDPF	$12,100	$44,100	$28,100
250 hp Bulldozer	DOC	$18,100	$49,700	$33,900
Application to PM NAAQS RIA Package of Retrofit Measures (DOC, DPF, Repower, Replace) $/ton PM				
Highway (low end)	**$17,267**			
Highway (high end)	**$35,475**			
Nonroad (low end)	**$18,100**			
Nonroad (high end)	**$33,900**			

Note that these $/ton PM estimates are applied across the board for all types of retrofit measures (DOCs, CDPFs, repower, replacement) and highway vehicle and nonroad engine types.

The overall cost-effectiveness of this measure is estimated to be:

- Highway 1st 50% - $17,267/ton PM
- Highway 2nd 50% - $35,475/ton PM
- Nonroad 1st 50% - $18,100/ton PM
- Nonroad 2nd 50% - $33,900/ton PM

Eliminating Long Duration Truck Idling - For purposes of this RIA, we identified this measure as a no cost strategy: that is to say, at $0/ton PM. Both truck stop and terminal electrifications and mobile idle reduction technologies have upfront capital costs, but for the most part these costs can be fully recovered by fuel savings. The examples below illustrate the potential rate of return on investments in idle reduction strategies.

Truck Stop and Terminal Electrifications (TSEs)
The average price of TSE technology is $11,500 per parking space. The average service life of this technology is 15 years. Truck engines at idle consume approximately 1 gallon per hour of idle. Current TSE projects are operating in environments where trucks are idling, on average, for 8 hours per day per space for 365 days per year (or about 2,920 hours per year). Since TSE technology can completely eliminate long duration idling at truck spaces (i.e. a 100% fuel savings), this translates into 2,920 gallons of fuel saved per year per space. At current diesel prices ($2.90/gallon), this fuel savings translates into $8,468. Therefore, an $11,500 capital investment should be recovered within about 17 months. In this scenario, TSE investments offer over a 70% annual rate of return over the life of the technology.

While it is technically feasible to electrify all parking spaces that support long duration idling trucks, we should note that TSE technology is generally deployed at a minimum of 25-50 parking spaces per location to maximize economies of scale. The financial attractiveness of installing TSE technology will depend on the demonstrated truck idling behavior – the greater the rates of idling, the greater the potential emissions reductions and associated fuel and cost savings.

Mobile Idle Reduction Technologies (MIRTs)
The price of MIRT technologies ranges from $1,000-$10,000. The most popular of these technologies is the auxiliary power unit (APU) because it provides air conditioning, heat, and electrical power to operate appliances. The average price of an APU is $7,000. The average service life of an APU is 10 years. An APU consumes two-tenths of a gallon per hour, so the net fuel savings is 0.80 gallons per hour. EPA estimates that trucks idle for 7 hours per rest period, on average, and about 300 days per year (or 2,100 hours per year). Since idling trucks consume 1 gallon of fuel per hour of idle, APUs can reduce fuel consumption for truck drivers/owners by approximately 1,680 gallons per year. At current diesel prices ($2.90/gallon), truck drivers/owners would save $4,872 on fuel if they used an APU. Therefore, a $7,000 capital investment should be recovered within about 18 months. In this scenario, APU investments offer almost a 70% annual rate of return over the life of the technology.

Intermodal Transport - We believe that a 1% shift is viable and could occur at a low or no cost, since rail is likely to be less expensive than truck transport due primarily to lower fuel costs. For purposes of economic analysis, we identified this measure as a no cost strategy ($0/ton PM). A certain level of intermodal shifting may require new investments in rail infrastructure, but these costs should be fully recovered over time by the fuel and other transport cost savings. We did not have adequate data to conduct a more detailed cost analysis. Our understanding of costs is based on anecdotal evidence and confidential business information from partners in EPA's SmartWay Transport Partnership program. There will be a great deal of variability in the financial attractiveness of transitioning to intermodal transport versus truck-only transport based on the capacity of current rail infrastructure; willingness of rail and truck companies to cooperate; the rail industry's ability to make capital investments; and local government support for accommodating additional rail lines, rail facilities, and rail operation flexibility.

Best Workplaces for Commuters (BWC) - We used the Transportation Research Board's (TRB) cost-effectiveness analysis of Congestion Mitigation and Air Quality Improvement Program (CMAQ) projects to estimate the cost-effectiveness of this measure.[7] TRB conducted an extensive literature review and then synthesized the data to develop comparable estimates of cost-effectiveness of a wide range of CMAQ-funded measures. We took the average of the median cost-effectiveness of a sampling of CMAQ-funded measures and then applied this number to the overarching BWC measure. The CMAQ-funded measures we selected were:

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[7] Transportation Research Board, National Research Council, 2002. *The Congestion Mitigation and Air Quality Improvement Program: assessing 10 years of experience*, Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program.

- regional rideshares
- vanpool programs
- park-and-ride lots
- regional transportation demand management
- employer trip reduction programs

We felt that these measures were a representative sampling of BWC incentive programs. There is a great deal of variability, however, in the type of programs and the level of incentives that BWC employers offer, which can impact both the amount of emissions reductions and the cost of BWC incentive programs.

We chose to apply the resulting average cost-effectiveness estimate to one pollutant – NO_x – in order to be able to compare BWC to other NO_x reduction strategies. TRB reported the cost-effectiveness of each measure, however, as a $/ton reduction of both VOC and NOx by applying the total cost of the program to a 1:4 weighted sum of VOC and NOx [total emissions reduction = (VOC * 1) + (NO_x * 4)]. There was not enough information in the TRB study to isolate the $/ton cost-effectiveness for just NO_x reductions, so we used the combined NO_x and VOC estimate.

We chose to report the cost-effectiveness of controlling NO_x over $PM_{2.5}$ for two reasons. First, BWC has a greater impact on NO_x emissions than $PM_{2.5}$ since it targets light-duty gasoline vehicles which have very low levels of $PM_{2.5}$ emissions. Second, the TRB study did not report cost-effectiveness information for $PM_{2.5}$ due to the lack of available data. The results are presented in Table 6-8 below:

Table 6-8. Cost-Effectiveness for Best Workplaces for Commuters Programs

	Low	*High*	*Median*
Regional Rideshare	$1,200	$16,000	$7,400
Vanpool Programs	$5,200	$89,000	$10,500
Park-and-ride lots	$8,600	$70,700	$43,000
Regional TDM	$2,300	$33,200	$12,500
Employer trip reduction programs	$5,800	$175,500	$22,700
Average of All Measures	$4,620	$76,900	**$19,200**

The overall cost-effectiveness of this measure is estimated as $19,200 per ton of NOx reduced.

6.3 Estimating the Cost of the Supplemental Emission Controls

As described earlier in this Chapter, for some urban areas it became necessary to apply additional cost-effective emission controls on sources of carbonaceous particles in areas for which our illustrative control scenario did not model attainment. Using the cost per microgram estimation method described in Chapter 3, we determined the total number of tons of carbonaceous particles that would be necessary to reduce to simulate attainment with the revised or more stringent alternative standards. If additional cost-effective carbonaceous particle controls were available, we applied these controls to achieve a reduction in the estimated tonnage. Table 6-9 below summarizes the projected non-attainment areas to which we applied these controls as well as the total tons abated and the total cost.[8]

Table 6-9. Supplemental Emission Controls Applied on Sources of Carbonaceous Particles

PM2.5 Standard and Urban Area	*Tons Abated*	*Total Cost (Million 1999$)*
15/35		
Cleveland	933	$3
14/35		
Birmingham	3,600	$40
Chicago	3,490	$120

6.4 Estimating the Attainment Cost for California and Salt Lake City

As described in Chapter 3, California and Salt Lake City posed especially challenging attainment problems due to a confluence of data limitations and the magnitude of their non-attainment problem. Because we were unable to simulate full attainment using existing or supplemental emission controls, estimating the cost of attaining the residual non-attainment air quality increment required an alternative approach. Below we outline our cost estimation methodology and cost estimates for California and Salt Lake City.

Estimating the Attainment Cost for California

The magnitude of the projected non-attainment problem in California described in Chapter 3 necessitated using a cost-estimation methodology that differs from that used to derive cost for other areas of the country. Many sectors are already well controlled in California, and the additional "add-on" controls that we applied in this analysis did not result in significant emissions reductions. California is likely to rely much more on technological change and innovative control strategies (development and penetration of hydrogen fuel cell vehicles, for example). At the same time, because it is so much harder to predict the effectiveness and cost of new technologies or strategies, our final cost estimates showing California attainment are much more uncertain. As such, our analysis of California, and in particular our presentation of costs for the state, require a separate treatment in this RIA.

[8] Note that supplemental control costs found in table 6-12 sum to $152M. This estimate is approximately $30M less than the engineering cost estimate we used when deriving economic costs (see Chapter 7). This discrepancy is due to the fact that we began the economic impact analysis prior to having finalized the supplemental control costs.

We estimate the cost of full attainment in California by constructing a cost curve that reflects the rising marginal costs of pollution abatement as firms apply the most cost effective controls first, before installing controls that may be less cost-effective. To account for these increasing marginal costs, we estimate the cost of the residual non-attainment increment in California by extrapolating the cost of the aggregate state-wide air quality increment that we attained with known stationary source carbonaceous particle and NOx controls. We chose carbonaceous particle and NOx controls because according to our analysis, these tend to be most cost-effective on a per-microgram basis in California. Having derived this extrapolated marginal cost per microgram curve, we then used it to estimate the incremental cost of achieving the residual non-attainment increment. This extrapolation entailed the following steps:

1. Estimate the air quality impact per ton of directly-emitted carbonaceous particles and NOx abated in our control case

2. Estimate the incremental cost per microgram abated for each carbonaceous particle and NOx emission control applied by calculating the cost per ton of each control applied and dividing this number by the impact per ton[9]

3. Plot the incremental cost per microgram reduction in ambient $PM_{2.5}$ attributable to the carbonaceous and NOx controls (see figures 6-5 and 6-6 below)

4. Calculate the slope of the observed marginal cost curve for carbonaceous particles and NOx as the basis of the extrapolated cost per microgram line that extends out to the targeted air quality increment.

5. Estimate the cost of the residual non-attainment increment by calculating the area under the extrapolated cost curves to derive a total cost estimate.

This method extrapolates future costs by fitting a linear cost curve to all of the observed cost and air quality data. While the curves below do not illustrate the shape this extrapolated curve, it would track the horizontal portion of the observed data and intersect the steeply sloping portion of the curve. As we describe further below, the extrapolated portion of the curve is highly uncertain. In an effort to develop a reasonable multi-pollutant $PM_{2.5}$ control strategy that will achieve the residual non-attainment increment, we assumed that California would reduce both carbonaceous particles and NOx. However, to generate a reasonable upper-bound to our full attainment cost estimate, we assumed that California would apply only NOx or PM controls. Figures 6-5 and 6-6 below illustrate the shape of the NOx and carbonaceous particle observed cost per microgram curves.

Note that this extrapolation approach assumes no technological change that would shift the marginal cost curve downward. However, it is highly probable that as California works to develop control strategies to implement the revised $PM_{2.5}$ NAAQS that new technologies will be developed will result in lower cost estimates.

[9] To estimate the air quality impact of abating a given ton of carbonaceous particles, we divided the CMAQ-predicted change in carbon (elemental, organic and crustal) between our base and control cases in California by the total tonnage of carbon reduction in our California control case. We followed this same procedure to derive a NOx impact per ton estimate, dividing the total model-predicted change in nitrate by the total tons of NOx abated.

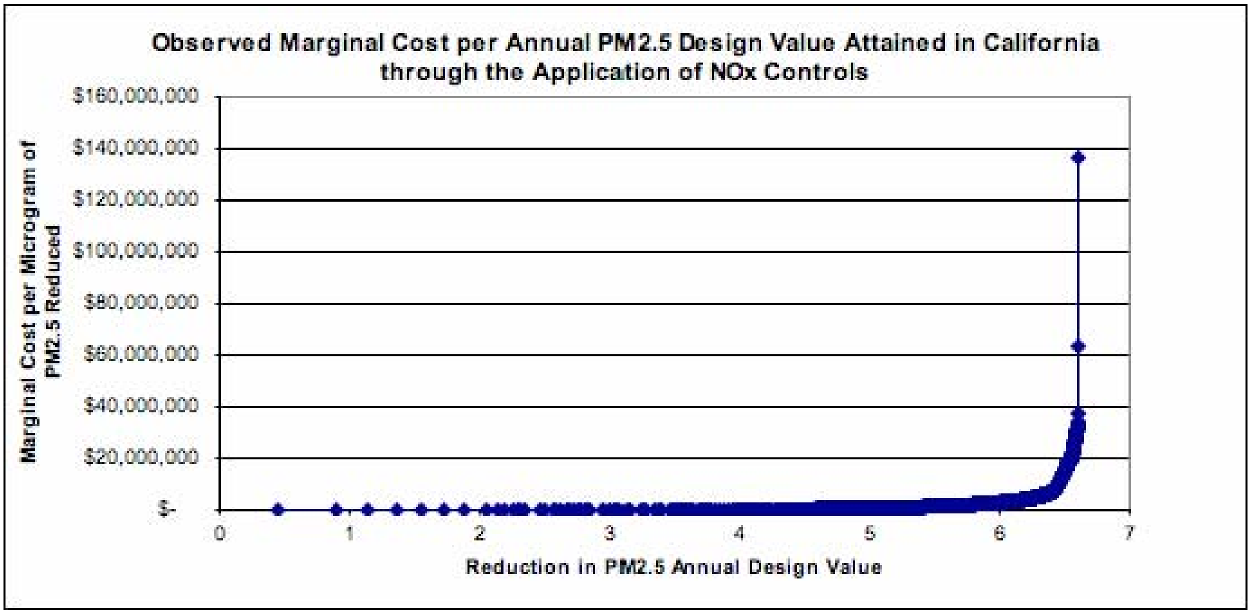

Figure 6-5. Marginal cost per microgram of reducing PM2.5 through the application of NOx controls

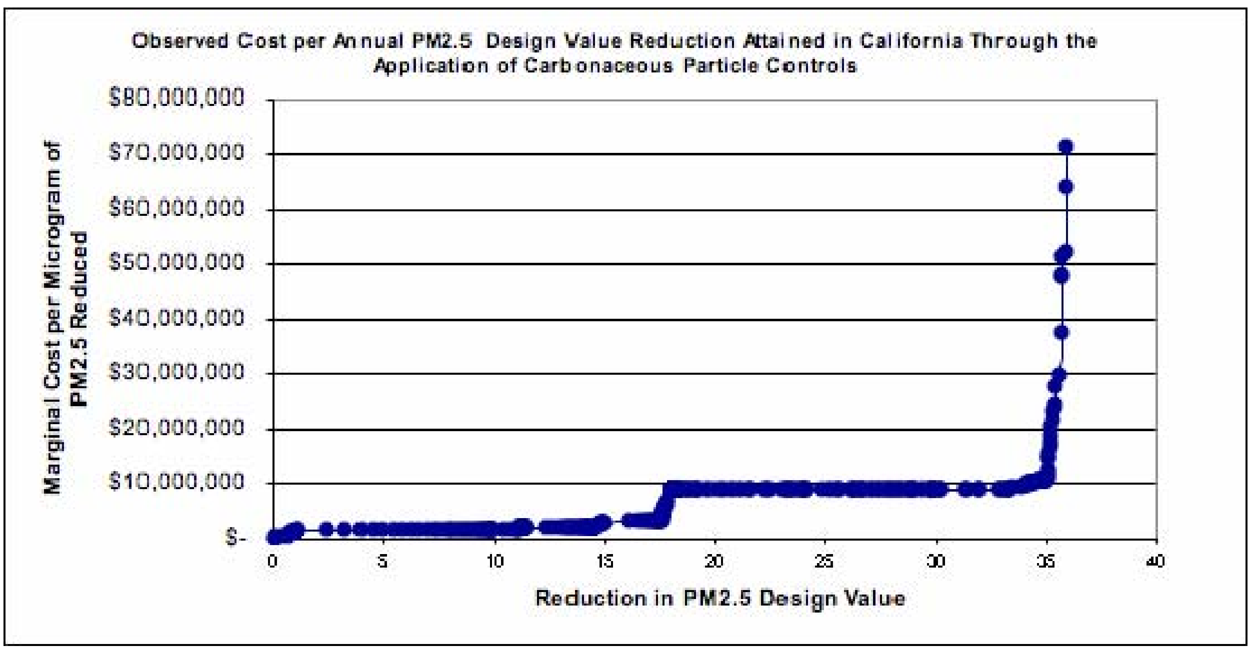

Figure 6-6. Marginal cost per microgram of reducing PM2.5 through the application of carbonaceous particle controls

Both of these figures feature a steeply-sloping marginal cost curve, suggesting that the last remaining emission controls applied were relatively expensive and produced a small improvement in the annual design value. In these figures, each diamond or circle represents the incremental reduction in design value and marginal cost of each NOx and carbonaceous particle emission controls. In figure 6-5, of the approximately 1,500 controls applied, only 200 have an estimated cost per microgram of more than $20M; about 30 have a cost per microgram of more than $30M. In figure 6-6, of the approximately 1,700 emission controls applied, only about 50 have a cost per microgram of more than $10M. The relatively small number of controls that comprise the steeply-sloping portion of the curve argue against extrapolating off of only this portion of the curve.

Table 6-10 summarizes the estimated full attainment cost of attaining the revised and alternative more stringent standards using three strategies: $PM_{2.5}$ and NOx combined, NOx only and PM2.5 only. Generally, the combined NOx and PM control strategy yields the lowest extrapolated control cost. However, the extrapolated control cost for simulated attainment with 15/35 is higher using the combined NOx-PM strategy than it is for NOx or PM alone. This result may be due to the fact that NOx controls are more cost-effective on a per-microgram basis when applied to meet the daily standard. Note that the "modeled" attainment cost for the revised and more stringent alternative standards is relatively small due to the fact that we had already exhausted most of our database of emission controls when simulating attainment with the 1997 standards.

Table 6-10: Incremental Attainment Cost Estimate for California to the Revised and More Stringent Alternative Standards in 2020 (millions of 1999$)*

Standard	*NOx Controls Only*	*PM Controls Only*	*NOx and PM Controls*
Revised Daily Standard of 35 in 2020			
Modeled	$41	$41	$41
Full	$3,500	$5,700	$4,000
Total	$3,500	$5,700	$4,000
More Stringent Alternative Annual Standard of 14 in 2020			
Modeled	$42	$42	$42
Full	$4,100	$5,200	$4,000
Total	$4,100	$5,200	$4,000

* Costs presented in this table are incremental to costs of meeting the current standard of 15/65.

There are several important uncertainties and limitations to this method of estimating residual non-attainment cost. First, the limitations and uncertainties that apply to the engineering costs used to simulate partial attainment in California are incorporated into this methodology as well. Thus, uncertainties regarding the under- or over-estimate of cost, control efficiency or applicability of emission controls apply here as well. For example, this methodology does not attempt to capture the impacts learning-by-doing or technological innovation; both of these phenomena have historically resulted in downward/outward shifts of marginal cost curves or flattening of its slope. The result of our inability to capture such effects may be a conservative (high) cost estimate.

Second, estimated control cost is sensitive to assumptions regarding the appropriate portion of the observed cost curve off of which to estimate the slope. As described above, both the PM and NOx marginal cost curve bend steeply, suggesting that a relatively small number of high cost per-microgram controls are affecting the shape of the curve. This factor argues for using the slope of the full curve as the basis for extrapolation, rather than using only costs above or below the knee.

Third, there are uncertainties regarding the estimated air quality impact of a given ton of directly-emitted carbonaceous particles. To the extent that we have under- or over-estimated the average air quality impact across all violating California monitors of a given reduction in directly-emitted carbonaceous particles, these marginal cost estimates may be over- or under-estimated. Moreover, we assume that each marginal decrease in directly-emitted carbonaceous particles is close enough to influence the violating $PM_{2.5}$ monitor.

<u>Estimating the Attainment Cost in Salt Lake City</u>

Data limitations prevented us from following the methodology that we employed to estimate California full attainment cost. Where we applied several hundred NOx and over one thousand carbonaceous particle emission controls across the state of California, we applied only a small handful of NOx emission controls and a few hundred carbonaceous particle controls in the Salt Lake urban area. Thus, we lacked the data points to derive a credible marginal cost per microgram curve.

As an alternative, we estimated full attainment cost by multiplying the aggregate residual daily non-attainment increment by the average cost per microgram. Table 6-11 below summarizes these calculations.

Table 6-11. Estimated Cumulative Full-Attainment Cost for Salt Lake City to Attain Revised Daily Standard of 35 µg/m^3 (millions 1999$)

Total partial-attainment cost:	$74
Aggregate µg/m3 change at highest county monitor for 15/35 control scenario:	12.25
Average cost per µg/m3 change in daily design value:	$6
Daily attainment increment needed at highest county monitors:	x 25
Intermediate cost estimate	$152
Uncertainty factor	x 2
Final cost of achieving the non-attainment increment:	$304

The principal limitation of this cost estimation method is that it assumyes that the cost of achieving the remaining air quality increment will be equal to the average cost of the air quality increment achieved with known controls. Thus, it does not account for the fact that, in the short run, the marginal cost curve of emission controls is upward sloping, rather than flat. To account for this source of uncertainty, and ensure that we do not underestimate future residual attainment costs, we have doubled the average cost per microgram. Doubling the average cost per microgram also doubles the resulting incremental cost of achieving the non-attainment increment from $152M to $304M.

Limitations and Uncertainties to Engineering Cost Estimates

EPA bases its estimates of emission control costs on the best available information from available engineering studies of air pollution controls and developed a reliable modeling framework for analyzing the cost, emission changes, and other impacts of regulatory controls. However, our cost analysis is subject to uncertainties and limitations, which we document on a qualitative basis below.

The annualized cost estimates of the private compliance costs that are provided in this analysis are meant to show the increase in production (engineering) costs to the various affected sectors in our control strategy analyses. To estimate these annualized costs, EPA uses a conventional and widely-accepted approach that is commonplace for estimating engineering costs in annual terms. For estimating annualized costs, EPA has applied a capital recovery factor (CRF) multiplier to capital investments and added that to the annual incremental operating expenses. The CRF is derived from estimates of the cost of capital (private discount rate), and the equipment life of that capital (i.e., the total capital investment required for purchase of a control device). As explained earlier in this RIA, we apply a 7 percent and three percent discount rate for annualizing the costs for non-EGU point and area sources over the equipment life where available for the control device. Information on the equipment life for different control devices can be found in the control measures documentation report for AirControlNET (EPA, 2006). The private compliance costs presented earlier are EPA's best estimate of the direct private compliance costs for these illustrative control strategies.

The direct private compliance cost includes, but is not limited to, capital investments in pollution controls as an up front and an annualized costs, and operating and maintenance (or O&M) expenses. The methodology employed by EPA to estimate the costs of control can be found in the EPA Air Pollution Control Cost Manual (EPA, 2002). EPA believes that the cost assumptions used for non-EGU point and area sources and direct $PM_{2.5}$ controls for EGUs reflect, as closely as possible, the best information available to the Agency today. The cost associated with monitoring emissions, reporting, and record keeping for affected sources is not included in these annualized cost estimates, but EPA believes these costs should be minor in comparison to the control costs based on the estimates prepared for the $PM_{2.5}$ Implementation Rule Information Collection Request (ICR).

Furthermore, there are some unquantified costs that EPA wants identifies as limitations to its illustrative analyses. These costs include the costs of federal and State administration of the program, which we believe are less than the alternative of States developing approvable SIPs, securing EPA approval of those SIPs, and Federal/State enforcement. The Agency also did not consider transactional costs and/or effects on labor supply in these illustrative analyses.

From another vantage point, the illustrative analysis for non-EGU point and area source controls and direct $PM_{2.5}$ controls for EGUs does not take into account the potential for advancements in the capabilities of pollution control technologies as well as reductions in their costs over time. In recognition of this factor, EPA's mobile source program uses adjusted engineering cost estimates of pollution control equipment and installation costs to account for this fact and these are included in the mobile source costs presented in this RIA.[10] We do not have sufficient information to adjust engineering cost estimates for non-EGU point and area source controls and direct $PM_{2.5}$ controls for EGUs nor for other EGU controls at this time.

Also, as noted in Chapter 3, the costs estimated for non-EGU point and area source controls and mobile source controls are engineering costs only; they do not take into account the response of consumers to increases in product prices resulting from applications of these controls. Consumer responses related to application of these controls and all of the EGU controls, however, are estimated as part of the economic impact analyses generated by EMPAX and presented in Chapter 7 of this RIA. The direct engineering costs estimated in this RIA do not reflect the actual impact of these illustrative controls on consumers. Given some price elasticity of demand for products whose consumption is affected by the implementation of these illustrative controls, the actual impact to consumers will be less than that implied by the direct engineering controls.

[10] See recent regulatory impact analysis for the Tier 2 Regulations for passenger vehicles (1999) and Heavy-Duty Diesel Vehicle Rules (2000). There is also evidence that scrubber costs will decrease in the future because of the learning_by_doing phenomenon, as more scrubbers are installed (see Manson, Nelson, and Neumann, 2002. "Assessing the Impact of Progress and Learning Curves on Clean Air Act Compliance Costs," Industrial Economics Incorporated).

The greater the price elasticity of demand for a given affected product, the higher the impact on demand for that product by a consumer. See Chapter 7 of this RIA for more details.

Recent research suggests that the total social costs of a new regulation may be affected by interactions between the new regulation and pre-existing distortions in the economy, such as taxes. In particular, if cost increases due to a regulation are reflected in a general increase in the price level, the real wage received by workers may be reduced, leading to a small fall in the total amount of labor supplied. This "tax interaction effect" may result in an increase in deadweight loss in the labor market and an increase in total social costs. Although there is a good case for the existence of the tax interaction effect, recent research also argues for caution in making prior assumptions about its magnitude. Chapter 8 of EPA's draft "Guidelines for Preparing Economic Analysis" discusses in detail the tax interaction effect in the context of environmental regulation. These economic analysis guidelines are still under review within EPA.

On balance, after consideration of various unquantified costs (and savings that are possible), EPA believes that the annual private compliance costs that we have estimated are more likely to overstate the future annual compliance costs that industry will incur, rather than understate those costs.

Technological Innovation, Learning-by-Doing, and Cost Estimates

We note that historically, compliance costs over long time periods have consistently been overestimated in regulatory analyses. Cost estimates frequently do not capture the effects of learning-by-doing or technological innovation and diffusion. The historical role of the CAA as a "technology-forcing" law, as well as a review of currently developing technologies, provides a sound basis for anticipating that technological progress will continue in response to new standards. It is difficult to predict technological improvements and their associated effects on cost because we have insufficient knowledge of which new technologies will be successful enough to have a meaningful impact on costs over the next ten to fifteen years—though history tells us such innovations will occur. This dynamic must be examined alongside observations regarding increasing marginal abatement costs.

6.5 Summary of Incremental Costs

Table 6-12 below summarizes the annualized costs of modeled control strategies that achieve partial attainment with the regulatory scenarios, as well as the supplemental and extrapolated engineering control costs (see Chapter 4 for a complete discussion of supplemental and extrapolated costs).

Table 6-12. Summary of Modeled Engineering, Supplemental and Extrapolated Engineering Attainment Costs (millions of 1999$)

	Revised Standards: 15/35		Alternative More Stringent Standards: 14/35	
Cost estimate	*3 Percent Discount Rate*	*7 Percent Discount Rate*	*3 Percent Discount Rate*	*7 Percent Discount Rate*
Modeled Partial Attainment	$770	$840	$2,300	$2,500
Supplemental[a]	$3	$3	$170	$180
Extrapolated[b]	$4,300	$4,300	$4,300	$4,300
Total Annualized Cost of Full Attainment	***$5,050***	***$5,100***	***$6,800***	***$7,000***

a Upon review of emissions and air quality results of the control strategies applied in this RIA, some areas were indicated with residual nonattainment (requiring additional reductions to meet the standard) as a result of our initial selection of controls. The incremental costs of residual nonattainment reflect supplemental controls and extrapolated costs of additional control measures that would be necessary to bring areas with residual nonattainment into compliance. Chapter 4 provides details of the assessment. Numbers may not sum due to rounding.

b The incremental cost of residual non-attainment for the West and California are extrapolated. The methodology used to derive these estimates is described in Chapter 6. These estimates are derived using a 7 percent discount rate.

6.6 References

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U.S. Environmental Protection Agency (EPA). July 2002. EPA Air Pollution Control Cost Manual. Sixth Edition. EPA-452/B-02-001. Found on the Internet at http://www.epa.gov/ttn/catc/products.html#cccinfo.

Chapter 7: Economic Cost Estimates

7.1 Synopsis

This chapter presents the economic impact results of the illustrative control strategies developed by EPA for the purpose of providing an approach of actions that could be taken to meet attainment of two $PM_{2.5}$ NAAQS alternatives: a revised 15 µg/m^3 annual/ 35 µg/m^3 daily standard (15/35) and a more stringent alternative14 µg/m^3 annual/ 35 µg/m^3 daily (14/35). Each of these alternative approaches is incremental to meeting the current 15 µg/m^3 annual/ 65 µg/m^3 daily (15/65) standard and have a proposed implementation date of 2020. Given the possible impacts of this guidance on manufacturing industries, the transportation sector, electricity generators, consumers, and U.S. Gross Domestic Product (GDP) as a whole, we believe it is important to gauge the extent to which other parts of the economy might also be affected by the implementation of these $PM_{2.5}$ NAAQS alternatives. Therefore, an analysis of the economy-wide effects of implementing the two $PM_{2.5}$ NAAQS scenarios is conducted by applying estimated direct costs to EPA's computable general equilibrium model (EMPAX-CGE). As the chapter will show, the social costs for each standard are only slightly greater than the engineering costs applied to the CGE model.

Before the chapter begins with a background and description of EMPAX-CGE followed by a presentation of the results, three stipulations are highlighted below that will assist the reader in interpreting the economic impacts and relating these impacts to the attainment costs presented in Chapter 6.

(a) The selection criteria for the 15/35 and 14/35 control strategies, and their related compliance costs, are designed to select the least cost controls, from an engineering cost standpoint, that generate the highest $PM_{2.5}$ reductions and benefit per ton estimates, but not necessarily the lowest economic impact. Therefore, although the control strategies are selected to reduce $PM_{2.5}$ at the lowest engineering cost, they do not represent the lowest impact strategies from a social cost standpoint. Thus, while this economic impact analysis presents results for the control strategy approach detailed in Chapter 3 of the RIA, it should not be viewed as the only economic impact estimate of the $PM_{2.5}$ NAAQS or even as the approach with the lowest social cost. Instead, the results should be viewed as guidance or useful information for states preparing their implementation plans. It is likely that states will design implementation plans that present an alternative control strategy and in some cases design plans that take into account secondary impacts to industries and consumers within their borders. In such a case, the end result would be a set of SIPs that are more economically optimal and may have lower industry impacts than those described below.

(b) The costs analyzed in this economic impact chapter include only the modeled engineering costs detailed in Chapter 6, section 6.2 as well as an additional $180 million in supplemental costs for the 14/35 scenario (Chapter 6, section 6.3). Not included in estimating economic impacts, are the extrapolated cost estimates detailed in Chapter 6, section 6.4. Therefore, the direct costs for the two scenarios range from $850 million (1999 dollars) in 2020 for the 15/35 alternative to $2.6 billion (1999 dollars) for alternative 14/35 during the same year. Since a large portion of the attainment costs are not included, social cost estimates may underestimate the impact these standards will have on the economy.

(c) In the interest of learning how possible changes in manufactured-goods prices might affect businesses and households, along with how changes in electricity/energy prices might affect industry groups that are large energy users, EPA employed the "EMPAX-CGE" computable general equilibrium (CGE) model, which has been peer reviewed and used in recent analyses of the Clean Air Interstate Rule (CAIR) and the Clean Air Visibility Rule (CAVR). As with similar models, EMPAX-CGE focuses on the cost-side of spillover effects on the economy. This implies its estimated industry-sector impacts may be overstated because EMPAX-CGE is not configured to capture the beneficial economic consequences of the increased labor availability and productivity expected to result from air quality improvements. If these labor productivity improvements were included, the small production output decreases projected by the model might be partially or entirely offset. EPA continues to investigate the feasibility of incorporating labor productivity gains and other beneficial effects of air quality improvements in CGE models.

7.1.1 Results Summary

Results of the macroeconomic analysis generally show small nation-wide impacts of the $PM_{2.5}$ NAAQS on manufacturing and energy industries, as well as small regional impacts. The 15/35 alternative generates a 0.01 percent decrease in GDP in 2020 while 14/35 results in a 0.02 percent GDP decrease for the same year. On average, industries show less than one-half of one percent decrease in output with the exception of cement manufacturing, which has output reductions of just over one-half of one percent for 14/35. However, as stated above, a large portion of the attainment costs are not inputted into EMPAX-CGE. Furthermore, the model does not incorporate productivity benefits resulting from air quality improvements. Therefore, as a result of these two potentially offsetting conditions, it is difficult for EPA to determine if the results presented here overstate or understate the impacts on industry output and U.S. GDP.

7.2 Background

To complement the analysis of effects on specific manufacturing sectors from AirControlNET, implications for mobile sources from MOBILE6.2 and NONROAD, and changes in electricity generation from IPM (only for the 14/35 standard), the macroeconomic implications of the $PM_{2.5}$ NAAQS standards have been estimated using EPA's EMPAX-CGE model. The focus of this component of the $PM_{2.5}$ NAAQS analysis is on examining the sectoral and regional distribution of economic effects across the U.S. economy. This section briefly discusses the EMPAX model and the approach used to incorporate findings from other models in EMPAX-CGE.

7.2.1 Background and Summary of EMPAX-CGE Model

EMPAX was first developed in 2000 to support economic analysis of EPA's maximum achievable control technology (MACT) rules for combustion sources (reciprocating internal combustion engines, boilers, and turbines). The initial framework consisted of a national multimarket partial-equilibrium model with linkages only between manufacturing industries and the energy sector. Modified versions of EMPAX were subsequently used to analyze economic impacts of strategies for improving air quality in the Southern Appalachian mountain region as part of efforts associated with the Southern Appalachian Mountain Initiative (SAMI).

Recent work on EMPAX has extended its scope to cover all aspects of the U.S. economy at a regional level in either static or dynamic modes. Although major regulations directly affect a large number of industries, substantial indirect impacts can also result from changes in production, input use, income, and household consumption patterns. Consequently, EMPAX now includes economic linkages among all industrial and energy sectors as well as households that supply factors of production such as labor and purchase goods (i.e., a CGE framework). This gives the version of EMPAX called EMPAX-CGE the ability to trace economic impacts as they are transmitted throughout the economy and allows it to provide critical insights to policy makers evaluating the magnitude and distribution of costs associated with environmental policies. The dynamic version of EMPAX-CGE employed in this analysis, and its data sources, are described in Section 7.3.

7.2.2 Modeling Methodology for the $PM_{2.5}$ NAAQS Standards

EMPAX-CGE can be used to analyze a wide array of policy issues and is capable of estimating how a change in a single part (or multiple parts) of the economy will influence producers and consumers across the United States. However, some types of policies, including the $PM_{2.5}$ NAAQS standard, are difficult to capture adequately within a CGE structure because of the boiler- and firm-specific nature of emission reduction costs. Consequently, an interface has been developed that allows linkages between EMPAX-CGE and the detailed technology models discussed in Chapter 6 (AirControlNET, MOBILE6.2, NONROAD, and IPM). These linkages give the combined modeling system the advantages of technology detail and broad macroeconomic coverage, thereby permitting EMPAX-CGE to investigate economy-wide policy implications.

As discussed in Chapter 6, the three technology models estimate cost changes by industry and region of the United States for the sectors of the economy affected by the $PM_{2.5}$ NAAQS standard. In order for EMPAX-CGE to effectively incorporate these additional costs, they have to be expressed in terms of the productive inputs used in CGE models (i.e., capital, labor, and material inputs produced by other industries). Rather than assume the costs represent a proportional scaling up of all inputs, Nestor and Pasurka (1995) data on purchases made by industries for environmental-protection reasons are used to allocate these additional expenditures across inputs within EMPAX-CGE. Once these expenditures are specified, the incremental costs from the technology models can be used to adjust the production technologies in the CGE model. For the 14/35 scenario, additional linkages are made between EMPAX-CGE and IPM to handle specific IPM findings related to resource costs and fuel consumption in electricity generation.[1]

[1] See Appendix E in the RIA for the Final CAIR rule for additional discussion of these IPM-EMPAX linkages (http://www.epa.gov/interstateairquality/technical.html).

7.3 EMPAX-CGE Model Description: General Model Structure

This section provides additional details on the EMPAX-CGE model structure, data sources, and assumptions. The version of EMPAX-CGE used in this analysis is a dynamic, intertemporally optimizing model that solves in 5 year intervals from 2005 to 2050. It uses the classical Arrow-Debreu general equilibrium framework wherein households maximize utility subject to budget constraints, and firms maximize profits subject to technology constraints. The model structure, in which agents are assumed to have perfect foresight and maximize utility across all time periods, allows agents to modify behavior in anticipation of future policy changes, unlike dynamic recursive models that assume agents do not react until a policy has been implemented.

Nested CES functions are used to portray substitution possibilities available to producers and consumers. Figure 7-1 illustrates this general framework and gives a broad characterization of the model.[2] Along with the underlying data, these nesting structures and associated substitution elasticities determine the effects that will be estimated for policies. These nesting structures and elasticities used in EMPAX-CGE are generally based on the Emissions Prediction and Policy Analysis (EPPA) Model developed at the Massachusetts Institute of Technology (Babiker et al., 2001). Although the two models are quite different (EPPA is a recursive dynamic, international model focused on national level climate change policies), both are intended to simulate how agents will respond to environmental policies.

[2] Although it is not illustrated in Figure 7-1, some differences across industries exist in their handling of energy inputs. In addition, the agriculture and fossil-fuel sectors in EMPAX-CGE contain equations that account for the presence of fixed inputs to production (land and fossil-fuel resources, respectively).

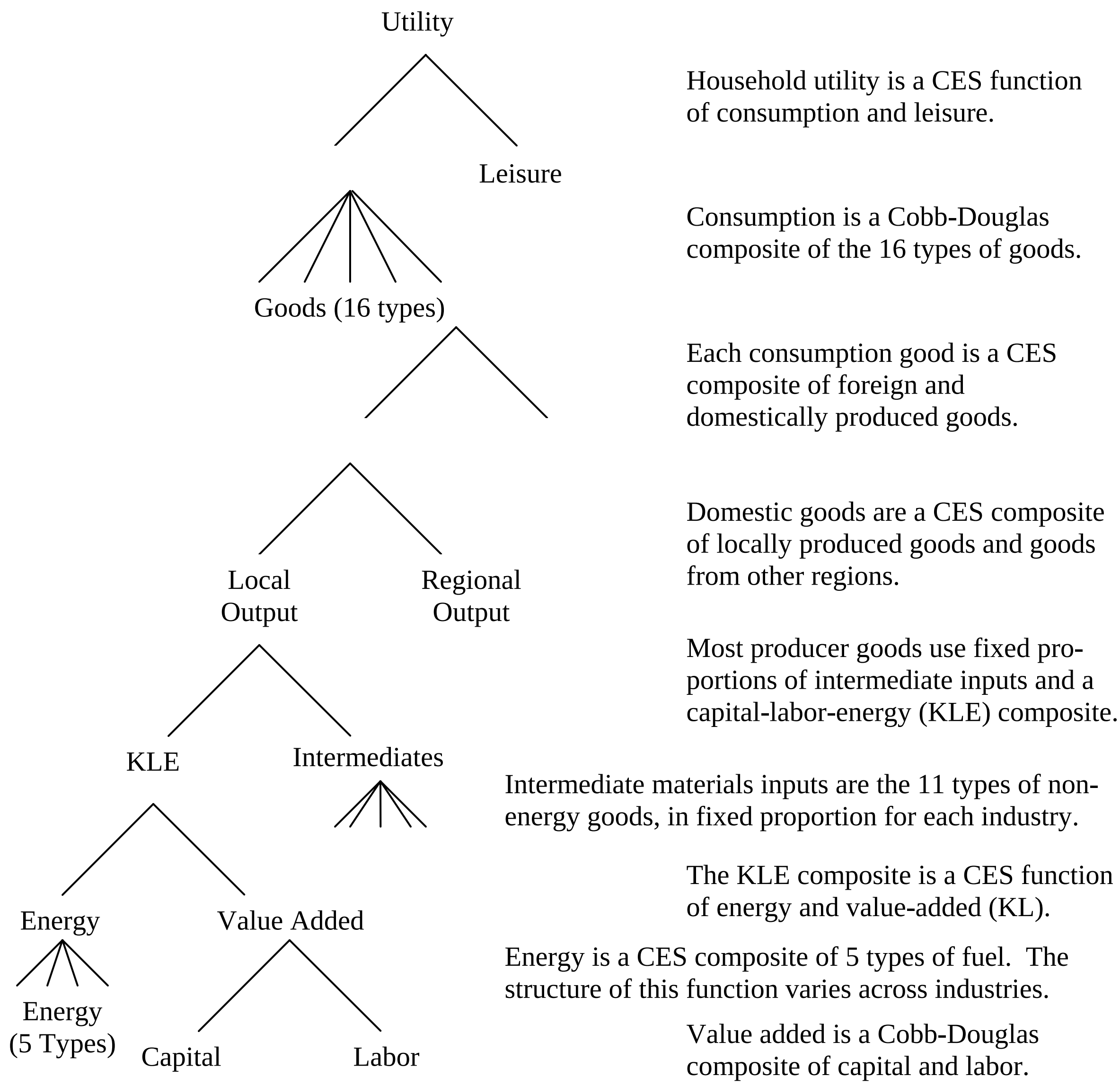

Figure 7-1. General Production and Consumption Nesting Structure in EMPAX-CGE

Given this basic similarity, EMPAX-CGE has adopted a comparable structure. EMPAX-CGE is programmed in the GAMS[3] language (Generalized Algebraic Modeling System) and solved as a mixed complementarity problem (MCP) [4] using MPSGE software (Mathematical Programming Subsystem for General Equilibrium).[5] The PATH solver from GAMS is used to solve the MCP equations generated by MPSGE.

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[3] See Brooke, Kendrick, and Meeraus (1996) for a description of GAMS (http://www.gams.com/).
4 Solving EMPAX-CGE as a MCP problem implies that complementary slackness is a feature of the equilibrium solution. In other words, any firm in operation will earn zero economic profits and any unprofitable firms will cease operations. Similarly, for any commodity with a positive price, supply will equal demand, or conversely any good in excess supply will have a zero price.
5 See Rutherford (1999) for MPSGE documentation (http://debreu.colorado.edu).

7.3.1 Data Sources

The economic data come from state level information provided by the Minnesota IMPLAN Group[6] and energy data come from EIA.[7] Although IMPLAN data contain information on the value of energy production and consumption in dollars, these data are replaced with EIA data for several reasons. First, the policies being investigated typically focus on energy markets, making it essential to include the best possible characterization of these markets in the model. Although the IMPLAN data are developed from a variety of government data sources at the U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics, these data do not always agree with energy information collected by EIA directly from manufacturers and electric utilities. Second, it is necessary to have physical quantities for energy consumption in the model to portray effects of environmental policies. EIA reports physical quantities, while IMPLAN does not. Finally, although the IMPLAN data reflect the year 2000, the initial baseline year for the model is 2005. Thus, AEO energy production and consumption, output, and economic growth forecasts for 2005 are used to adjust the year 2000 IMPLAN data.

EMPAX-CGE combines these economic and energy data to create a balanced social accounting matrix (SAM) that provides a baseline characterization of the economy. The SAM contains data on the value of output in each sector, payments for factors of production and intermediate inputs by each sector, household income and consumption, government purchases, investment, and trade flows. A balanced SAM for the year 2005 consistent with the desired sectoral and regional aggregation is produced using procedures developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000). The methodology relies on standard optimization techniques to maintain the calculated energy statistics while minimizing the changes needed in the economic data to create a new balanced SAM that matches AEO forecasts for the baseline model year of 2005.

These data are used to define 10 regions within the United States, each containing 40 industries. Regions have been selected to capture important differences across the country in electricity generation technologies, while industry aggregations are controlled by available energy consumption data. Prior to solving EMPAX-CGE, these regions and industries are aggregated up to the categories to be included in the analysis.

Table 7-1 presents the industry categories included in EMPAX-CGE for policy analysis. Their focus is on maintaining as much detail in the energy intensive sectors[8] as is allowed by available energy consumption data and computational limits of dynamic CGE models. In addition, the electricity industry is separated into fossil fuel generation and nonfossil generation, which is necessary because many electricity policies affect only fossil fired electricity.

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[6] See http://www.implan.com/index.html for a description of the Minnesota IMPLAN Group and its data.
[7] These EIA sources include *AEO 2003*, the *Manufacturing Energy Consumption Survey*, *State Energy Data Report*, *State Energy Price and Expenditure Report*, and various annual industry profiles.
[8] EIS industry categories are based on EIA definitions of energy-intensive manufacturers in the *Assumptions for the Annual Energy Outlook 2003*.

Table 7-1. EMPAX-CGE Industries

EMPAX Industry	NAICS Classifications
Coal	2121
Crude Oil[a]	211111
Electricity (fossil and nonfossil)	2211
Natural Gas	211112, 2212, 4862
Petroleum Refining	324
Agriculture	11
Energy-Intensive Sector: Food	311
Energy-Intensive Sector: Paper and Allied	322
Energy-Intensive Sector: Chemicals	325
Energy-Intensive Sector: Glass	3272
Energy-Intensive Sector: Cement	3273
Energy-Intensive Sector: Iron and Steel	3311
Energy-Intensive Sector: Aluminum	3313
Other Manufacturing	312-316, 321, 323, 326-327, 331-339
Services	All Others
Transportation[b]	481-488

[a] Although NAICS 211111 covers crude oil and gas extraction, the gas component of this sector is moved to the natural gas industry.

[b] Transportation does not include NAICS 4862 (natural gas distribution), which is part of the natural gas industry.

Figure 7-2 shows the five regions run in EMPAX-CGE in this analysis, which have been defined based on the expected regional distribution of policy impacts, availability of economic and energy data, and computational limits on model size. These regions have been constructed from the underlying 10 region database designed to follow, as closely as possible, the electricity market regions defined by the North American Electric Reliability Council (NERC).[9] Note that, for purposes of presenting results, the four regions; *Northeast*, *Southeast*, *Midwest* and *Plains*, have been aggregated into an "East" region to approximate the region of interest in this analysis.

[9] Economic data and information on nonelectricity energy markets are generally available only at the state level, which necessitates an approximation of the NERC regions that follows state boundaries. For the IAQR analysis, these approximations include Northeast = NPCC + MAAC, Southeast = SERC + FERC, Midwest = ECAR + MAIN, Plains = MAPP + SPP + ERCOT, and West = WSCC. See http://www.nerc.com/ for further discussion of these regions.

Figure 7-2. Regions defined in EMPAX-CGE

7.3.2 Production Functions

All productive markets are assumed to be perfectly competitive and have production technologies that exhibit constant returns to scale, except for the agriculture and natural resource extracting sectors, which have decreasing returns to scale because they use factors in fixed supply (land and fossil fuels, respectively). The electricity industry is separated into two distinct sectors: fossil fuel generation and nonfossil generation. This allows tracking of variables such as heat rates for fossil fired utilities (Btus of energy input per kilowatt hour of electricity output).

All markets must clear (i.e., supply must equal demand in every sector) in every period, and the income of each agent in the model must equal their factor endowments plus any net transfers. Along with the underlying data, the nesting structures shown in Figure 7-1 and associated substitution elasticities define current production technologies and possible alternatives.

7.3.3 Utility Functions

Each region in the dynamic version of EMPAX-CGE contains four representative households, classified by income, that maximize intertemporal utility over all time periods in the model subject to budget constraints, where the income groups are:

- $0 to $14,999,
- $15,000 to $29,999,
- $30,000 to $49,999, and
- $50,000 and above.

These representative households are endowed with factors of production including labor, capital, natural resources, and land inputs to agricultural production. Factor prices are equal to the marginal revenue received by firms from employing an additional unit of labor or capital. The value of factors owned by each representative household depends on factor use implied by production within each region. Income from sales of these productive factors is allocated to purchases of consumption goods to maximize welfare.

Within each time period, intratemporal utility received by a household is formed from consumption of goods and leisure. All consumption goods are combined using a Cobb Douglas structure to form an aggregate consumption good. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure depends on empirical estimates of labor supply elasticities and indicates how willing households are to trade off leisure time for consumption. Over time, households consider the discounted present value of utility received from all periods' consumption of goods and leisure.

Following standard conventions of CGE models, factors of production are assumed to be intersectorally mobile within regions, but migration of productive factors is not allowed across regions. This assumption is necessary to calculate welfare changes for the representative household located in each region in EMPAX-CGE. EMPAX-CGE also assumes that ownership of natural resources and capital embodied in nonfossil electricity generation is spread across the United States through capital markets.

7.3.4 Trade

In EMPAX-CGE, all goods and services are assumed to be composite, differentiated "Armington" goods made up of locally manufactured commodities and imported goods. Output of local industries is initially separated into output destined for local consumption by producers or households and output destined for export. This local output is then combined with goods from other regions in the United States using Armington trade elasticities that indicate agents make relatively little distinction between output from firms located within their region and output from firms in other regions within the United States. Finally, the domestic composite goods are aggregated with imports from foreign sources using lower trade elasticities to capture the fact that foreign imports are more differentiated from domestic output than are imports from other regional suppliers in the United States.

7.3.5 Tax Rates and Distortions

Taxes and associated distortions in economic behavior have been included in EMPAX-CGE because theoretical and empirical literature found that taxes can substantially alter estimated policy costs. The IMPLAN economic database used by EMPAX-CGE includes information on taxes such as indirect business taxes (all sales and excise taxes) and social security taxes. However, IMPLAN reports factor payments for labor and capital at their gross of tax values, which necessitates use of additional data sources to determine personal income and capital tax rates. Information from the TAXSIM model at the National Bureau of Economic Research (Feenberg and Coutts, 1993), along with user cost of capital calculations from Fullerton and Rogers (1993), are used to establish tax rates.

Along with these rates, distortions associated with taxes are a function of labor supply decisions of households. As with other CGE models focused on interactions between tax and environmental policies (e.g., Bovenberg and Goulder [1996]; Goulder and Williams [2003]), an important feature of EMPAX-CGE is its inclusion of a labor leisure choice—how people decide between working and leisure time. Labor supply elasticities related to this choice determine, to a large extent, how distortionary taxes are in a CGE model. Elasticities based on the relevant literature have been included in EMPAX-CGE (i.e., 0.4 for the compensated labor supply elasticity and 0.15 for the uncompensated labor supply elasticity). These elasticity values give an overall marginal excess burden associated with the existing tax structure of approximately 0.3.

7.3.6 Intertemporal Dynamics and Economic Growth

There are four sources of economic growth in EMPAX-CGE: technological change from improvements in energy efficiency, growth in the available labor supply (from both population growth and changes in labor productivity), increases in stocks of natural resources, and capital accumulation. Energy consumption per unit of output tends to decline over time because of improvements in production technologies and energy conservation. These changes in energy use per unit of output are modeled as AEEIs, which are used to replicate energy consumption forecasts by industry and fuel from EIA. [10] The AEEI values provide the means for matching expected trends in energy consumption that have been taken from the AEO forecasts. They alter the amount of energy needed to produce a given quantity of output by incorporating improvements in energy efficiency and conservation. Labor force and regional economic growth, electricity generation, changes in available natural resources, and resource prices are also based on the AEO forecasts.

Savings provide the basis for capital formation and are motivated through people's expectations about future needs for capital. Savings and investment decisions made by households determine aggregate capital stocks in EMPAX-CGE. The IMPLAN dataset provides details on the types of goods and services used to produce the investment goods underlying each region's capital stocks. Adjustment dynamics associated with formation of capital are controlled by using quadratic

[10] See Babiker et al. (2001) for a discussion of how this methodology was used in the EPPA model (EPPA assumes that AEEI parameters are the same across all industries in a country, while AEEI values in EMPAX-CGE are industry specific).

adjustment costs experienced when installing new capital, which imply that real costs are experienced to build and install new capital equipment.

Prior to investigating policy scenarios, it is necessary to establish a baseline path for the economy that incorporates economic growth and technology changes that are expected to occur in the absence of the policy actions. Beginning from the initial balanced SAM dataset, the model is calibrated to replicate forecasts from AEO. Upon incorporating these forecasts, EMPAX-CGE is solved to generate a baseline consistent with them through 2025. Once this baseline is established, it is possible to run the "counterfactual" policy experiments discussed below.

7.4 Results for $PM_{2.5}$ NAAQS 15/35 and 14/35

This section compares attainment of the revised $PM_{2.5}$ NAAQS standard (alternative 15/35) and a more stringent alternative (14/35) to a baseline for the economy that includes the Clean Air Interstate Rule (CAIR), the Clean Air Mercury Rule (CAMR), the Clean Air Visibility Rule (CAVR), and the current $PM_{2.5}$ NAAQS standard 15 $\mu g/m^3$ annual/ 65 $\mu g/m^3$ daily (15/65). Impacts are measured in the 2020 implementation year and are the result of engineering costs described in Section 7.1 (b). Thus, the following graphs compare the 15/35 and 14/35 standards to an economic growth path that incorporates impacts from CAIR, CAMR, CAVR, and $PM_{2.5}$ NAAQS 15/65 through the year 2020.

7.4.1 Projected Impacts on U.S. Industries of Incremental Costs of Reaching Tighter Standards (15/35 and 14/35)

Impacts of the alternative $PM_{2.5}$ NAAQS standards on manufacturing costs can affect output and prices of all industries in the EMPAX-CGE model. These effects may increase or decrease output and/or revenue, depending on their implications for production costs and technologies and shifts in household demands. In general, the impacts on industries will be dependent on the control strategies and follow a pattern similar to the stringency of the $PM_{2.5}$ NAAQS standards.

As shown in Figure 7-3a, impacts on industrial output quantities are generally small across all industries for 15/35, while there are slightly larger effects in a limited number of industries for 14/35. Outside of the energy-intensive sectors (EIS), estimated changes in output of manufactured goods are less than five one-hundredths of one percent (0.05%). Effects on energy producers are also of a similar magnitude, aside from electricity generation and coal under 14/35, which limits any spillover effects to other businesses and households.

As described in Chapter 6, selected control options for the 14/35 standard involve additional actions by electric utilities, influencing U.S. coal consumption. Other energy industries also engage in additional measures, which can affect energy users such as the EIS sectors. Cement, aluminum and paper production are influenced by direct control costs on their respective industries and any changes in energy markets. Note, however, that even across the energy-intensive industries, output quantities decline on average by less than a quarter of a percent.

Figure 7-3b shows how these changes in output quantities (or units) compares to changes in gross output revenues, where revenue changes include the effects of changes in both quantity and output prices (which reflect changes in production costs). While additional gross revenues may not imply that net revenues have increased for a given industry, Figure 7-3b is useful in illustrating the overall changes occurring in the economy in dollar terms. The first set of results to note across the two figures are the differences between the slight decline in electricity output and a small increase in output revenues for the electricity industry, which are the result of changes in production costs that lead to slightly higher electricity prices. Also, across the economy as a whole, although there is almost no change in the quantity of services produced, in revenue terms the changes in energy-related industries are much smaller than in services due to the overall size of the service industry in the U.S. economy.

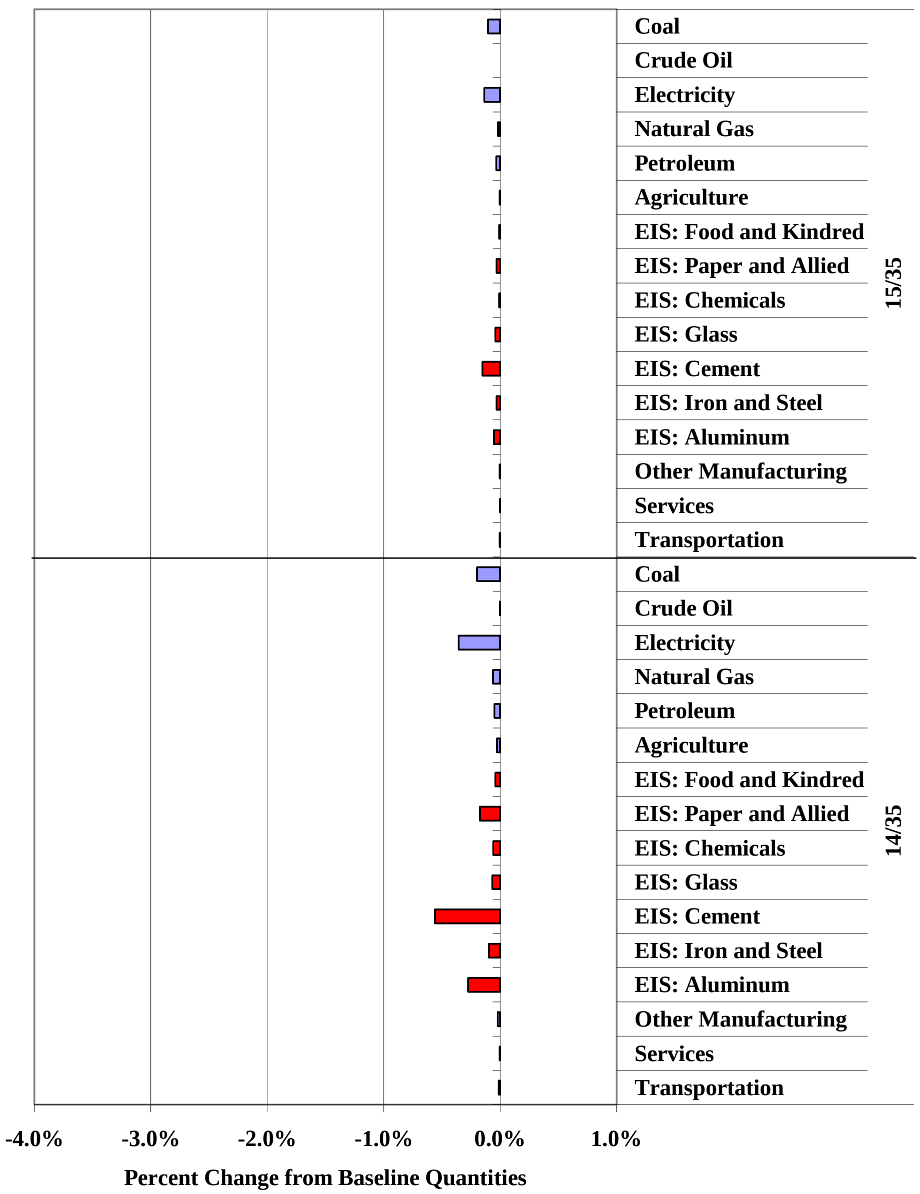

Figure 7-3a. $PM_{2.5}$ NAAQS 15/35 and 14/35 Impacts on U.S. Domestic Output Quantity, 2020

Source: EMPAX-CGE

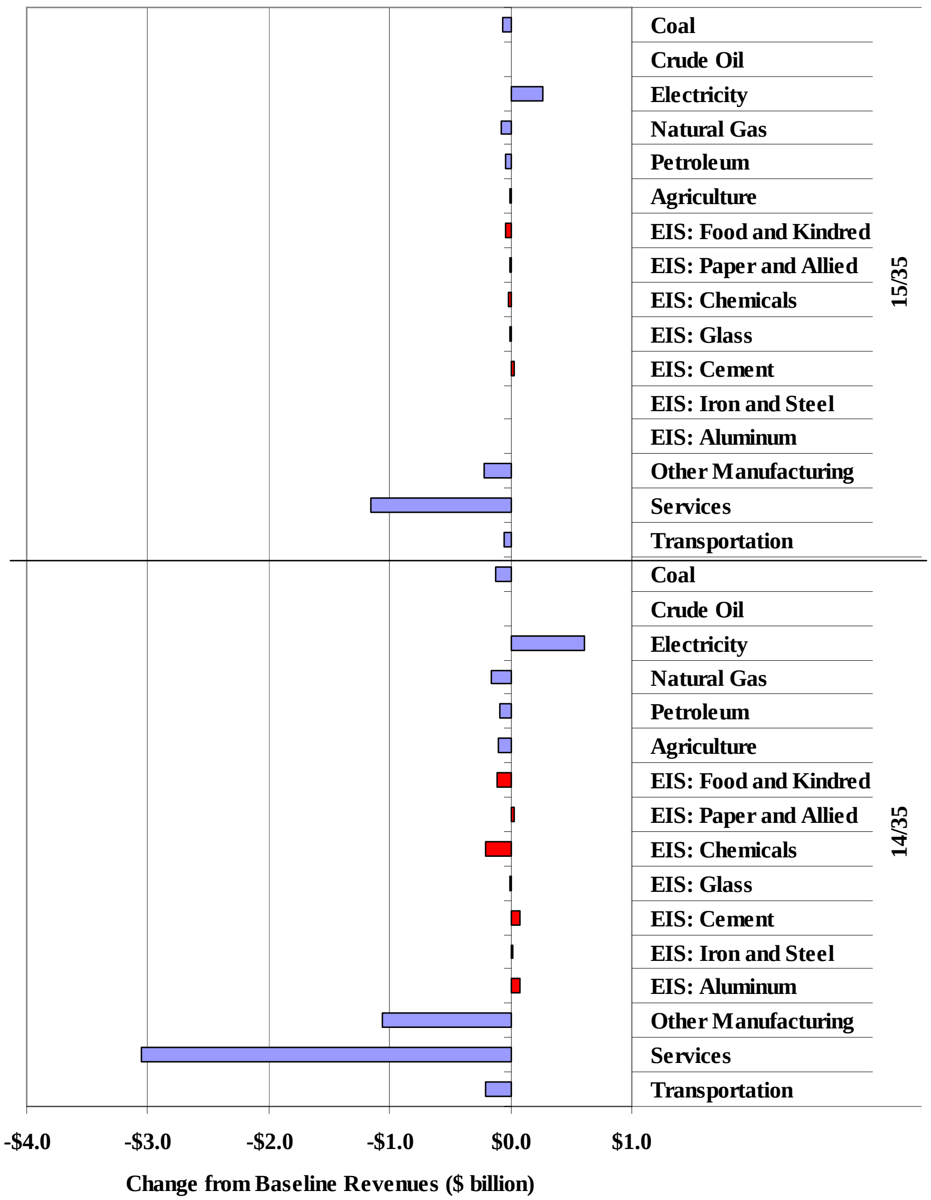

Figure 7-3b. $PM_{2.5}$ NAAQS 15/35 and 14/35 Impacts on U.S. Domestic Output Revenues, 2020

Source: EMPAX-CGE

7.4.2 Projected Impacts on Regional Energy-Intensive Industries

Regional effects will tend to show variation that does not appear at the national level. To examine how such variations might occur in response to the two alternative $PM_{2.5}$ NAAQS standards, this analysis presents findings for an East-West split of the United States (see Section

7.3.1 for a definition)[11]. Since changes in output for most industries are essentially unaffected, Figures 7-4 and 7-5 focus on regional results for the energy-intensive industries in EMPAX-CGE.

As with the U.S. average results from Figure 7-3a, even though the energy-intensive sectors show more regional variation, based on differences in production methods and changes in manufacturing costs, the majority of the impacts are less than one tenth of one percent. However, for each scenario, there are one to two industries that demonstrate measurable, but still relatively small, impacts. Under 15/35, energy-intensive output tends to be redistributed slightly from West to East as decreases in cement and aluminum manufacturing output in the West are offset by increases in the East.[12] For the 14/35 results shown in Figure 7-5a, this finding is reversed for cement in the East, which is projected to be offset by an increase in output quantities in the West, giving an end result of a one-half of one percent decrease in cement output for the U.S. In revenue terms, the changes in Figure 7-4b are generally similar to the quantity changes in Figure 7-4a. For some industries such as cement and aluminum, gross revenues are somewhat higher while output quantities have declined slightly as the result of changes in production costs. A similar story holds true for the 14/35 standard in Figure 7-5b.

When examining such findings, however, it is important to note that these impacts and redistributions are directly related to the specific control options assumed in this illustrative analysis. As previously stated, these results represent the impact of an approach presented by EPA that could meet attainment under the alternative standards. While EPA is providing this analysis as guidance for States, it is expected that States will evaluate the best strategies for achieving compliance and may choose options that could significantly alter these regional effects. Therefore, SIPs will most likely be different than the strategies developed in this RIA and could be designed to alleviate any disproportionate impacts on sensitive industries. For example, given the impact on aluminum and cement production, as well as paper manufacturing, assumed with the two scenarios, affected States may well design SIP strategies that mitigate the impact on these particular industries, perhaps distributing costs more uniformly among all sectors.

[11] For more detailed regional impact figures, in accordance to the EMPAX-CGE regions shown on Figure 7-2, please see Appendix F.

[12] Redistribution of production will also tend to occur among states in each region, with some states' increasing output to offset any declines in neighboring states.

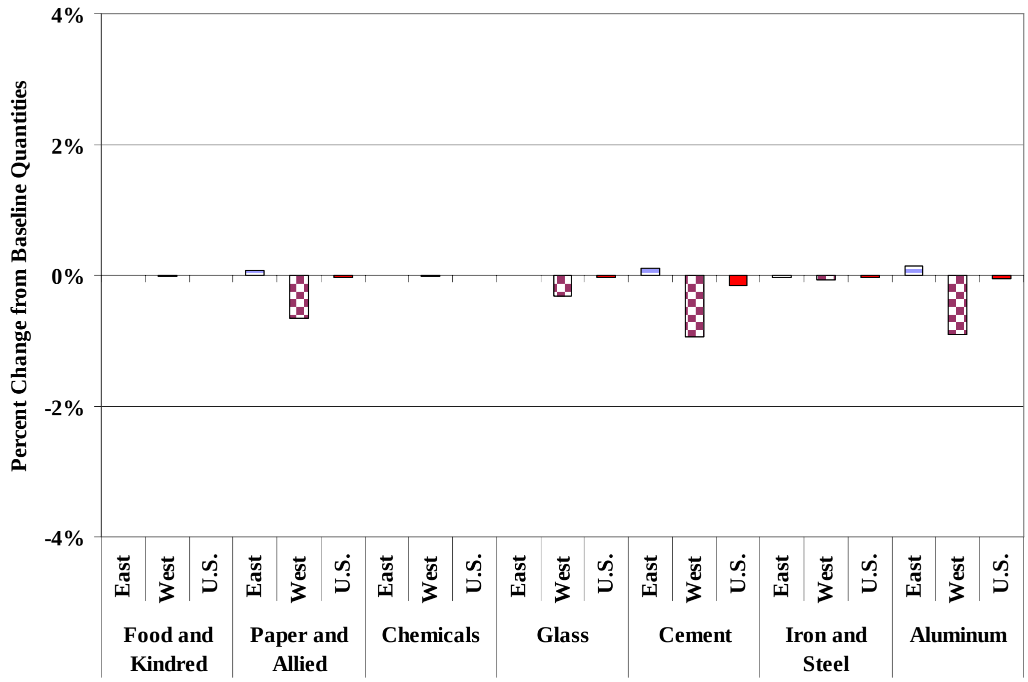

Figure 7-4a. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy-Intensive Output Quantities, 2020

Source: EMPAX-CGE

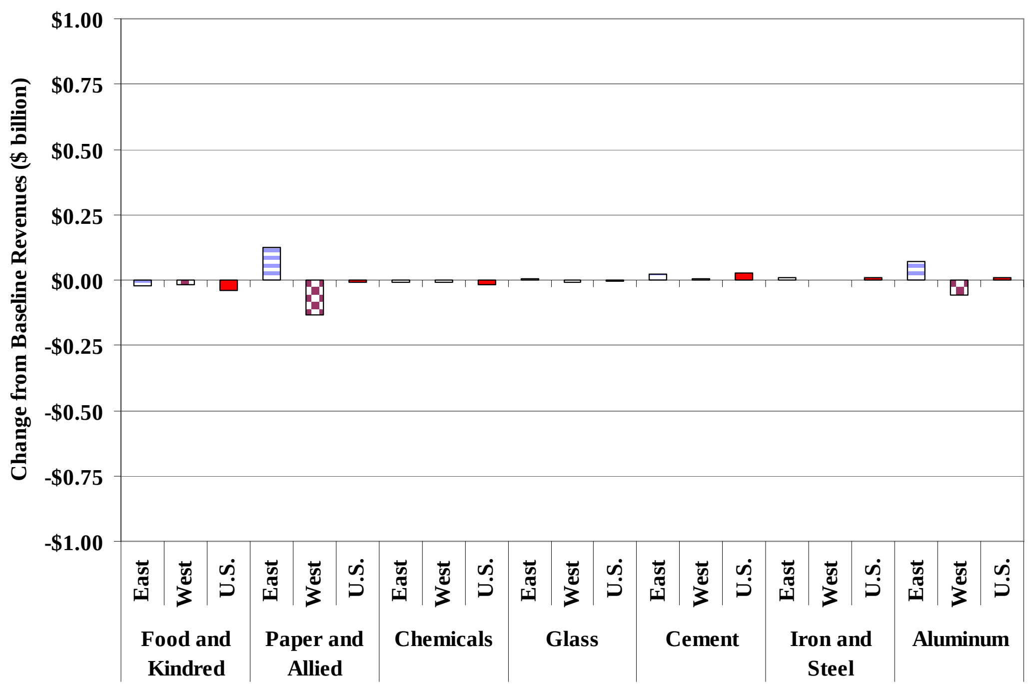

Figure 7-4b. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy-Intensive Output Revenues, 2020

Source: EMPAX-CGE

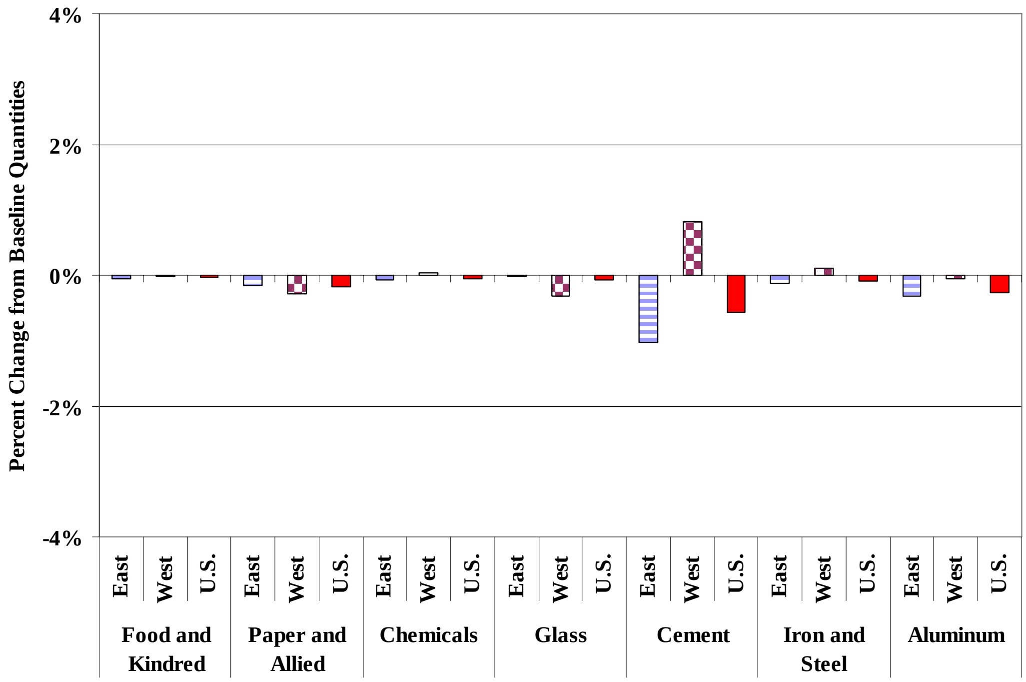

Figure 7-5a. $PM_{2.5}$ NAAQS 14/35 Impacts on Regional Energy-Intensive Output Quantities, 2020

Source: EMPAX-CGE

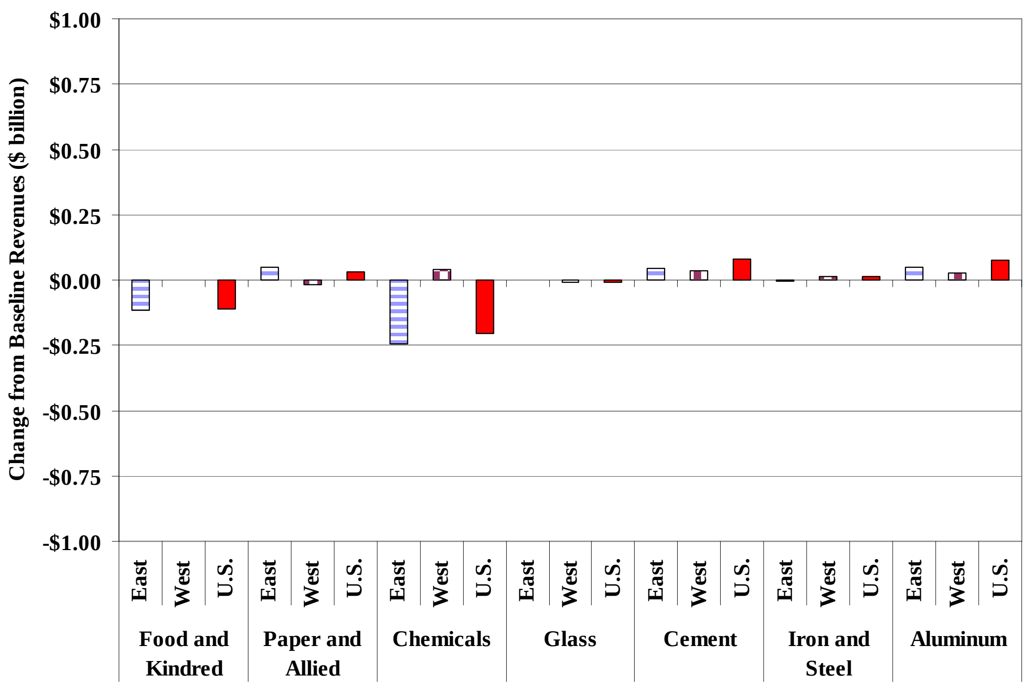

Figure 7-5b. $PM_{2.5}$ NAAQS 14/35 Impacts on Regional Energy-Intensive Output Revenues, 2020

Source: EMPAX-CGE

7.4.3 Projected Impacts on GDP

The combination of economic interactions affecting business and household behavior will be reflected in the changes in GDP estimated by a CGE model. Given that this cost-based approach to analyzing the $PM_{2.5}$ NAAQS standard does not reflect its benefits to the environment, public health, and labor productivity, CGE models (including EMPAX-CGE) will tend to over estimate declines in total production in the United States. Potentially offsetting these benefits are attainments costs that have not been included in this analysis mainly due to their lack of direct industry cost information (See Section 7.1 (b)). Consequently, these results can be considered incomplete because they do not reflect potential productivity benefits of the $PM_{2.5}$ NAAQS or the full cost of attainment. The impacts on GDP should be viewed as an approximation of the costs of the $PM_{2.5}$ NAAQS and are provided here for illustration.

Figure 7-6 illustrates GDP in the EMPAX-CGE model's baseline forecast and the two $PM_{2.5}$ NAAQS policy cases. As shown, the estimated GDP impact is negligible and, in fact, it is not possible to adjust the scale of the graph to the point where the two lines do not overlap. Projected decreases in GDP for the $PM_{2.5}$ NAAQS 15/35 and 14/35 standards of roughly 0.01 and 0.02 percent, respectively, for the year 2020. This is equivalent to a \$1.15 billion decrease in GDP for 15/35 and a \$3.54 billion decrease for 14/35 during the implementation year. In absolute terms, these estimated implications for U.S. GDP are extremely small relative to the total size of the economy. Even these small costs could be negated if the CGE analyses were extended to include benefits associated with the $PM_{2.5}$ NAAQS standard such as improvements in labor productivity from environmental improvements.

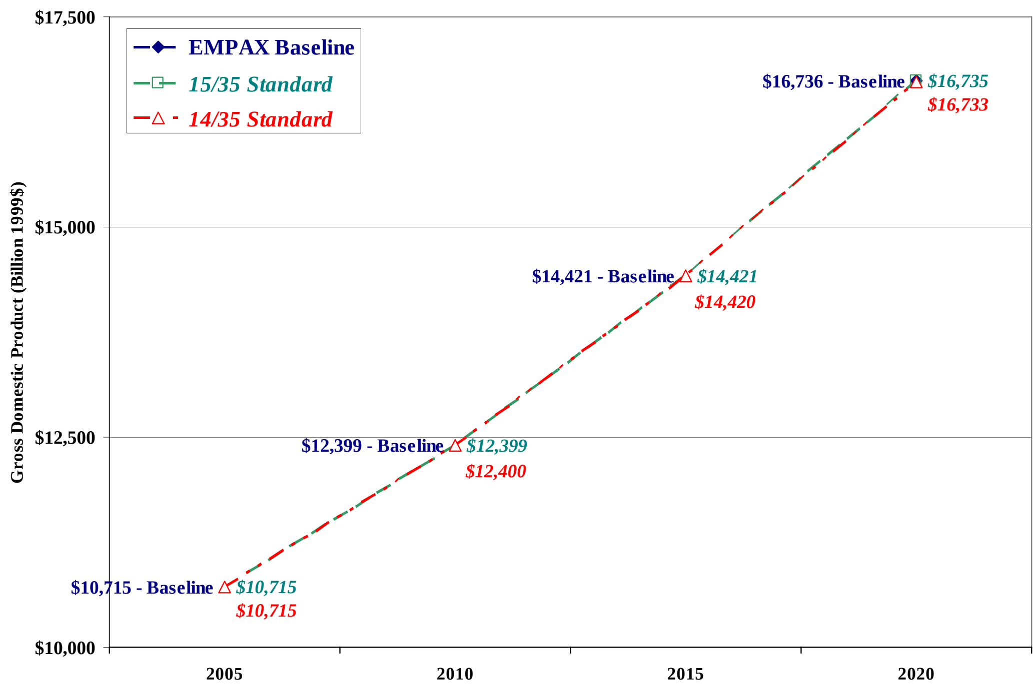

Figure 7-6. Change in U.S. GDP Compared to EMPAX-CGE Baseline

Source: Department of Energy, Energy Information Administrations; EMPAX-CGE

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Chapter 8: Statutory and Executive Order Impact Analyses

Synopsis

This chapter summarizes the Statutory and Executive Order (EO) impact analyses relevant for the PM NAAQS Regulatory Impact Analysis. In general, because this RIA analyzes a series of illustrative attainment strategies to meet the revised NAAQS, and because States will ultimately implement the new NAAQS, the Statutory and Executive Orders below did not require additional analysis. For each EO and Statutory requirement we describe both the requirements and the way in which our analysis addresses these requirements.

8.1 Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order (EO) 12866 (58 FR 51735, October 4, 1993), the PM NAAQS action is an "economically significant regulatory action" because it is likely to have an annual effect on the economy of $100 million or more. Accordingly, EPA prepared this regulatory impact analysis (RIA) of the potential costs and benefits associated with this action, entitled "Regulatory Impact Analysis for Particulate Matter National Ambient Air Quality Standards" (September 2006). The RIA estimates the costs and monetized human health and welfare benefits of attaining two alternative combinations of revised $PM_{2.5}$ NAAQS nationwide. Specifically, the RIA examines the alternatives of 15 $\mu g/m^3$ annual, 35 $\mu g/m^3$ daily and 14 $\mu g/m^3$ annual, 35 $\mu g/m^3$ daily. The RIA contains illustrative analyses that consider a limited number of emissions control scenarios that States and Regional Planning Organizations might implement to achieve the 1997 $PM_{2.5}$ NAAQS and these alternative $PM_{2.5}$ NAAQS. It calculates the incremental costs that might be incurred between the base year of 2015, which is the year by which States must all be in attainment with the 1997 $PM_{2.5}$ standards (15 $\mu g/m^3$ annual, 65 $\mu g/m^3$ daily), and 2020, which is the final date by which States would implement controls to attain the revised $PM_{2.5}$ standards.

As discussed above in section I.A, the Clean Air Act and judicial decisions make clear that the economic and technical feasibility of attaining ambient standards are not to be considered in setting or revising NAAQS, although such factors may be considered in the development of State plans to implement the standards. Accordingly, although an RIA has been prepared, the results of the RIA have not been considered in issuing this final rule.

8.2 Paperwork Reduction Act

This RIA does not impose an information collection burden under the provisions of the Paperwork Reduction Act, 44 U.S.C. 3501 et seq. There are no information collection requirements directly associated with revisions to a NAAQS under section 109 of the CAA.

Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

An agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

8.3 Regulatory Flexibility Act

The EPA has determined that it is not necessary to prepare a regulatory flexibility analysis in connection with this RIA. For purposes of assessing the impacts of today's rule on small entities, small entity is defined as: (1) a small business that is a small industrial entity as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

After considering the economic impacts of today's final rule on small entities, EPA has concluded that this action will not have a significant economic impact on a substantial number of small entities. This rule will not impose any requirements on small entities. Rather, this rule establishes national standards for allowable concentrations of particulate matter in ambient air as required by section 109 of the CAA. See also *ATA I* at 1044-45 (NAAQS do not have significant impacts upon small entities because NAAQS themselves impose no regulations upon small entities).

8.4 Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), Public Law 104-4, establishes requirements for Federal agencies to assess the effects of their regulatory actions on State, local, and Tribal governments and the private sector. Under section 202 of the UMRA, EPA generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with "Federal mandates" that may result in expenditures to State, local, and Tribal governments, in the aggregate, or to the private sector, of $100 million or more in any 1 year. Before promulgating an EPA rule for which a written statement is needed, section 205 of the UMRA generally requires EPA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows EPA to adopt an alternative other than the least costly, most cost-effective or least burdensome alternative if the Administrator publishes with the final rule an explanation why that alternative was not adopted. Before EPA establishes any regulatory requirements that may significantly or uniquely affect small governments, including Tribal governments, it must have developed under section 203 of the UMRA a small government agency plan. The plan must provide for notifying potentially affected small governments, enabling officials of affected small governments to have meaningful and timely input in the development of EPA regulatory proposals with significant Federal intergovernmental mandates, and informing, educating, and advising small governments on compliance with the regulatory requirements.

Today's final rule contains no Federal mandates (under the regulatory provisions of Title II of the UMRA) for State, local, or Tribal governments or the private sector. The rule imposes no new expenditure or enforceable duty on any State, local or Tribal governments or the private sector, and EPA has determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments. Furthermore, as indicated previously, in setting a NAAQS EPA cannot consider the economic or technological feasibility of attaining ambient air quality standards, although such factors may be considered to a degree in the development of State plans to implement the standards. See also *ATA I* at 1043 (noting that because EPA is precluded from considering costs of implementation in establishing NAAQS, preparation of a Regulatory Impact Analysis pursuant to the Unfunded Mandates Reform Act would not furnish any information which the court could consider in reviewing the NAAQS). Accordingly, EPA has determined that the provisions of sections 202, 203, and 205 of the UMRA do not apply to this final decision. The EPA acknowledges, however, that any corresponding revisions to associated SIP requirements and air quality surveillance requirements, 40 CFR part 51 and 40 CFR part 58, respectively, might result in such effects. Accordingly, EPA has addressed unfunded mandates in the notice that announces the revisions to 40 CFR part 58, and will, as appropriate, address unfunded mandates when it proposes any revisions to 40 CFR part 51.

8.6 Executive Order 13132: Federalism

Executive Order 13132, entitled "Federalism" (64 FR 43255, August 10, 1999), requires EPA to develop an accountable process to ensure "meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications." "Policies that have federalism implications" is defined in the Executive Order to include regulations that have "substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government."

At the time of proposal, EPA concluded that the proposed rule would not have federalism implications. The EPA stated that the proposed rule would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. However, EPA recognized that States would have a substantial interest in this rule and any corresponding revisions to associated SIP requirements and air quality surveillance requirements, 40 CFR part 51 and 40 CFR part 58, respectively. Therefore, in the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and State and local governments, EPA specifically solicited comment on the rule from State and local officials at the time of proposal. No comments were submitted related to the PM2.5 standard and E.O.13132.

Therefore, EPA concludes that this final rule does not have federalism implications. It will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. The rule does not alter the relationship between the Federal government and the States regarding the establishment and implementation of air quality improvement programs as codified in the CAA. Under section 109 of the CAA, EPA is mandated to establish NAAQS; however, CAA section 116 preserves the rights of States to establish more stringent requirements if deemed necessary by a State. Furthermore, this rule does not impact CAA section 107 which establishes that the States have primary responsibility for implementation of the NAAQS. Finally, as noted above in section E on UMRA, this rule does not impose significant costs on State, local, or Tribal governments or the private sector. Thus, Executive Order 13132 does not apply to this rule.

8.7 Executive Order 13175: Consultation and Coordination with Indian Tribal Governments

Executive Order 13175, entitled "Consultation and Coordination with Indian Tribal Governments" (65 FR 67249, November 9, 2000), requires EPA to develop an accountable process to ensure "meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications." This rule concerns the establishment of PM NAAQS. The Tribal Authority Rule gives Tribes the opportunity to develop and implement CAA programs such as the PM NAAQS, but it leaves to the discretion of the Tribe whether to develop these programs and which programs, or appropriate elements of a program, they will adopt.

Although EPA determined at the time of proposal that Executive Order 13175 did not apply to this rule, EPA contacted tribal environmental professionals during the development of this rule. The EPA staff participated in the regularly scheduled Tribal Air call sponsored by the National Tribal Air Association during the summer and fall of 2005 as the proposal was under development, as well as the call in the spring of 2006 during the public comment period on the proposed rule. The EPA sent individual letters to all federally recognized Tribes within the lower 48 states and Alaska to give Tribal leaders the opportunity for consultation, and EPA staff also participated in Tribal public meetings, such as the National Tribal Forum meeting in April 2006, where Tribes discussed their concerns regarding the proposed rule. Furthermore, the Administrator discussed the proposed PM NAAQS with members of the National Tribal Caucus and with leaders of individual Tribes during the spring and summer of 2006, in advance of his final decision.

During the course of these meetings and in written comments submitted to the Agency, Tribal commenters expressed significant concerns about the implications of the proposed rule for Tribes. In particular, Tribes strongly opposed the proposed qualified $PM_{10-2.5}$ indicator and the proposed monitor site-suitability requirements, especially the requirement that monitors used for comparison with the NAAQS be located within urbanized areas with a minimum population of 100,000. Tribal commenters pointed out that this would virtually exclude Tribes from applying the $PM_{10-2.5}$ standards because very few Tribal sites would meet this criterion. Tribes stated that EPA had violated its Trust Responsibility to Tribes in three ways. First, the commenters claimed that EPA had failed to engage in meaningful consultation with Tribal leaders regarding the proposed qualified $PM_{10-2.5}$ indicator and other aspects of the proposed rule. Second, commenters claimed that the proposed 24-hour $PM_{10-2.5}$ standard would have serious adverse impacts on the existing level of health protection for Tribes. Third, Tribal commenters objected to the proposed exclusion of "agricultural sources, mining sources, and other similar sources of crustal material" from the proposed $PM_{10-2.5}$ indicator; like States, Tribes felt this provision was illegal and Tribal commenters argued this violated Tribal sovereignty. The EPA notes that its final decision to retain the current 24-hour PM_{10} standard, for the reasons noted above in Section III, without any qualifications or changes to the monitor siting requirements, effectively resolves the concerns raised by these commenters.

EPA has determined that this final rule does not have Tribal implications, as specified in Executive Order 13175. It does not have a substantial direct effect on one or more Indian Tribes, since Tribes are not obligated to adopt or implement any NAAQS. Thus, Executive Order 13175 does not apply to this rule.

8.8 Executive Order 13045: Protection of Children from Environmental Health & Safety Risks

Executive Order 13045, "Protection of Children from Environmental Health Risks and Safety Risks" (62 FR 19885, April 23, 1997) applies to any rule that: (1) is determined to be "economically significant" as defined under Executive Order 12866, and (2) concerns an environmental health or safety risk that EPA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, the Agency must evaluate the environmental health or safety effects of the rule on children, and explain why the regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the Agency.

This rule is subject to Executive Order 13045 because it is an economically significant regulatory action as defined by Executive Order 12866, and we believe that the environmental health risk addressed by this action may have a disproportionate effect on children. The NAAQS constitute uniform, national standards for PM pollution; these standards are designed to protect public health with an adequate margin of safety, as required by CAA section 109. However, the protection offered by these standards may be especially important for children because children, along with other sensitive population subgroups such as the elderly and people with existing heart or lung disease, are potentially susceptible to health effects resulting from PM exposure. Because children are considered a potentially susceptible population, we have carefully evaluated the environmental health effects of exposure to PM pollution among children. These effects and the size of the population affected are summarized in section 9.2.4 of the Criteria Document and section 3.5 of the Staff Paper, and the results of our evaluation of the effect of PM pollution on children are discussed in sections II and III of the preamble to this rule.

8.9 Executive Order 13211: Actions that Significantly Affect Energy Supply, Distribution or Use

This rule is not a "significant energy action" as defined in Executive Order 13211, "Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use" (66 FR 28355 (May 22, 2001)) because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. The purpose of this rule is to establish NAAQS for PM. The rule does not prescribe specific pollution control strategies by which these ambient standards will be met. Such strategies will be developed by States on a case-by-case basis, and EPA cannot predict whether the control options selected by States will include regulations on energy suppliers, distributors, or users. Thus, EPA concludes that this rule is not likely to have any adverse energy effects and does not constitute a significant energy action as defined in Executive Order 13211.

8.10 National Technology Transfer Advancement Act

Section 12(d) of the National Technology Transfer Advancement Act of 1995 (NTTAA), Public Law No. 104-113, §12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (e.g., materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

The final rule establishes requirements for environmental monitoring and measurement. Specifically, it establishes the FRM for $PM_{10-2.5}$ measurement (and slightly amends the FRM for $PM_{2.5}$). The FRM is the benchmark against which all ambient monitoring methods are measured. While the FRM is not a voluntary consensus standard, the equivalency criteria established in 40 CFR part 53 do allow for the utilization of voluntary consensus standards if they meet the specified performance criteria.

To the extent feasible, EPA employs a Performance-Based Measurement System (PBMS), which does not require the use of specific, prescribed analytic methods. The PBMS is defined as a set of processes wherein the data quality needs, mandates or limitations of a program or project are specified, and serve as criteria for selecting appropriate methods to meet those needs in a cost-effective manner. It is intended to be more flexible and cost effective for the regulated community; it is also intended to encourage innovation in analytical technology and improved data quality. Though the FRM requirements utilize performance standards for some aspects of monitor design, multiple performance standards defined for many combinations of PM type, concentration, and environmental conditions would be required to be sure that monitors certified to purely performance-based standards actually performed similarly in the field, which would in turn require extensive testing of each candidate monitor design. Therefore, it is not practically possible to fully define the FRM in performance terms. Nevertheless, our approach in the past has resulted in multiple brands of monitors qualifying as FRM for PM, and we expect this to continue. Also, the FRM described in this final rule and the equivalency criteria contained in the revisions to 40 CFR part 53 do constitute performance based criteria for the instruments that will actually be deployed for monitoring $PM_{10-2.5}$. Therefore, for most of the measurements that will be made and most of the measurement systems that make them, EPA is not precluding the use of any method, whether it constitutes a voluntary consensus standard or not, as long as it meets the specified performance criteria.

8.11 Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," requires Federal agencies to consider the impact of programs, policies, and activities on minority populations and low-income populations. According to EPA guidance, agencies are to assess whether minority or low-income populations face a risk or a rate of exposure to hazards that are significant and that "appreciably exceeds or is likely to appreciably exceed the risk or rate to the general population or to the appropriate comparison group" (EPA, 1998).

In accordance with Executive Order 12898, the Agency has considered whether these decisions may have disproportionate negative impacts on minority or low-income populations. This rule establishes uniform, national ambient air quality standards for particulate matter, and is not expected to have disproportionate negative impacts on minority or low income populations. The EPA notes that some commenters expressed concerns that EPA had failed to adequately assess the environmental justice implications of its proposed decisions, and that the proposed revisions to the fine particle standards would violate the principles of environmental justice.

Further, some commenters were concerned that the proposed $PM_{2.5}$ standards would permit the continuation of disproportionate adverse health effects on minority and low-income populations because those populations are concentrated in urban areas where exposures are higher and are generally more susceptible (given lack of access to health care and prevalence of chronic conditions such as asthma). The EPA believes that the implications of the newly strengthened suite of $PM_{2.5}$ standards will reduce health risks precisely in the areas subject to the highest fine particle concentrations. Furthermore, the $PM_{2.5}$ NAAQS established in today's final rule are nationally uniform standards which in the Administrator's judgment protect public health with an adequate margin of safety. In making this determination, the Administrator expressly considered the available information regarding health effects among vulnerable and susceptible populations, such as those with preexisting conditions. Thus it remains EPA's conclusion that this rule is not expected to have disproportionate negative impacts on minority or low income populations.

8.12 References

U.S. Environmental Protection Agency (EPA). 1998. "Advisory Council on Clean Air Compliance Analysis Advisory on the Clean Air Act Amendments (CAAA) of 1990 Section 812 Prospective Study: Overview of Air Quality and Emissions Estimates: Modeling, Health and Ecological Valuation Issues Initial Studies." EPA-SAB-COUNCIL-ADV-98-003.

Chapter 9: Comparison of Benefits and Costs

Synopsis

This chapter compares estimates of the modeled and full attainment benefits with economic costs. Tables 9-1 through 9-2 compare the estimated benefits and costs across the east, west and California for the modeled and full attainment scenarios. The first of these two tables compares benefits to costs estimates by using benefits estimates derived based on a mortality function from the American Cancer Society . Finally, Table 9-3 presents net benefits of full attainment using Expert Elicitation derived mortality functions and morbidity functions from epidemiology literature.

Comparison of Costs and Benefits

Note that the estimates of net benefits in the tables that follow are derived by subtracting *social* costs from total benefits. Because these social cost estimates account for the economic impact of our illustrative control strategies, they differ from the engineering cost estimates found in the Executive Summary and Chapters 1 and 6.

Table 9-1. Comparison of Benefits and Costs of Partial and Full Attainment Scenarios for Revised Standards of 15/35 (Million 1999$)[a]

	Benefits	*Social Costs*	*Net benefits*
Partial Attainment			
3 percent discount rate			
East	$2,400	$710	$1,700
West	$680	$380	$300
California	$3,600	$55	$3,700
Total	$6,700	$1,200	$5,600
7 percent discount rate			
East	$2,100	$710	$1,400
West	$610	$380	$230
California	$3,100	$55	$3,100
Total	$5,800	$1,200	$4,700
Full Attainment			
3 percent discount rate			
East	$2,500	$710	$1,800
West	$800	$680	$120
California	$14,000	$4,000	$10,000
Total	$17,000	$5,400	$12,000
7 percent discount rate			
East	$2,200	$710	$1,500
West	$720	$680	$36
California	$12,000	$4,000	$7,600
Total	$14,500	$5,400	$9,000

[a] The benefits in this table are derived by using an effect estimate based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

Table 9-2. Comparison of Benefits and Costs of Partial and Full Attainment Scenarios for Alternative More Stringent Standards of 14/35 (Million 1999$)[a]

	Benefits	*Social Costs*	*Net benefits*
Partial Attainment			
3 percent discount rate			
East	$14,000	$2,900	$11,000
West	$690	$530	$160
California	$3,500	$84	$3,400
Total	$19,000	$3,500	$15,000
7 percent discount rate			
East	$12,300	$2,900	$9,400
West	$620	$530	$86
California	$3,100	$84	$3,000
Total	$16,000	$3,500	$12,000
Full Attainment			
3 percent discount rate			
East	$15,000	$2,900	$12,000
West	$820	$840	($20)
California	$14,000	$4,100	$10,000
Total	$30,000	$7,900	$22,000
7 percent discount rate			
East	$13,000	$2,900	$9,800
West	$730	$840	($100)
California	$12,000	$4,100	$8,000
Total	$26,000	$7,900	$18,000

[a] The benefits in this table are derived by using an effect estimate based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

Table 9-2. Comparison of Benefits and Social Costs: Expert Elicitation-Derived Estimates

	Net Benefits[a, b] (millions 1999$)	
	15/35 (µg/m3)	*14/35 (µg/m3)*
Using a 3% discount rate	$3,500 to $70,000	$8,700 to $130,000
Using a 7% discount rate	$2,400 to $59,000	$6,700 to $110,000

Discussion of Uncertainties and Limitations

Air Quality Modeling and Emissions

- Overall, the air quality model performs well in predicting monthly to seasonal concentrations, similar to other state-of-the-science air quality model applications for $PM_{2.5}$. However, there is less certainty in analyses involving 24-hour model predictions than those involving longer-term averages concentrations and performance is better for the Eastern U.S. than for the West. In both the East and West, secondary carbonaceous aerosols are the most challenging species for the modeling system to predict in terms of evaluation against ambient data.

- Underestimation biases in the mobile source emission inventories lead to uncertainty as to the relative contribution of mobile source emissions to overall PM levels.

- Additional uncertainty is introduced as a result of our limited understanding concerning the collective impact on future-year emission estimates from economic growth estimates, increases in technological efficiencies, and limited information on the effectiveness of future control programs.

- The regional scale used for air quality modeling can understate the effectiveness of controls on local sources in urban areas as compared to area-wide or regional controls. This serves to obscure local-scale air quality improvements that result from urban-area controls.

Controls and Cost

- The technologies applied and the emission reductions achieved in these analyses may not reflect emerging control devices that could be available in future years to meet any requirements in SIPs or upgrades to some current devices that may serve to increase control levels.

- The effects from "learning by doing" are not accounted for in the emission reduction estimates for point and area sources. It is possible that an emissions control technology may have better performance in reducing emissions due to greater understanding of how best to operate and maintain the technology. As a result, we may understate the emission reductions estimated by these analyses. The mobile source control measures do account for these learning by doing effects.

- The effectiveness of the control measures in these analyses is based on an assumption that these controls are well maintained throughout their equipment life (the amount of time they are assumed to operate). To the extent that a control measure is not well maintained, the control efficiency may be less than estimated in these analyses. Since these control measures must operate according to specified permit conditions, however, it is expected that the maintenance of controls should yield control efficiencies at or very close to those used in these analyses. As a result, we may overstate the emission reductions estimated by these analyses.

- The application of area source control technologies in these analyses assume that a constant estimate for emission reduction is reasonable despite variation in the extent or scale of application (e.g. dust control plans at construction sites). To the extent that there are economies of scale in area source control applications, we may overstate the emission reductions estimated by these analyses.

- The cost extrapolation method used to develop full attainment costs is highly uncertain and may significantly under or overstate future costs of full attainment.

Benefits

- This analysis assumes that inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been specifically identified, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality are explored using the results of the expert elicitation.

- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because the composition of PM produced via transported precursors emitted from EGUs may differ significantly from direct PM released from automotive engines and other industrial sources. In accordance with advice from the CASAC, EPA has determined that no clear scientific grounds exist for supporting differential effects estimates by particle type, based on information in the most recent Criteria Document. In chapter 5, we provide a decomposition of benefits by PM component species to provide additional insights into the makeup of the benefits associated with reductions in overall $PM_{2.5}$ mass (See Tables 5-32 and 5-33).

- This analysis assumes that the concentration-response (CR) function for fine particles is approximately linear within the range of ambient concentrations under consideration (above the assumed threshold of 10 $\mu g/m^3$). Thus, we assume that the CR functions are applicable to estimates of health benefits associated with reducing fine particles in areas with varied concentrations of PM, including both regions that are in attainment with $PM_{2.5}$ standards and those that do not meet the standards. However, we examine the impact of this assumption by looking at alternative thresholds in a sensitivity analysis.

- A key assumption underlying the entire analysis is that the forecasts for future emissions and associated air quality modeling are valid. Because we are projecting emissions and air quality out to 2020, there are inherent uncertainties in all of the factors that underlie the future state of emissions and air quality levels.

Conclusions and Insights

EPA's analysis has estimated the health and welfare benefits of reductions in ambient concentrations of particulate matter resulting from a set of illustrative control strategies to reduce emissions of $PM_{2.5}$ precursors. The results suggest there will be significant additional health and welfare benefits arising from reducing emissions from a variety of sources in and around projected nonattaining counties in 2020. While 2020 is the latest date by which states would generally need to demonstrate attainment with the revised standards, it is expected that benefits (and costs) will begin occurring earlier, as states begin implementing control measures to show progress towards attainment.

There are several important factors to consider when evaluating the relative benefits and costs of the attainment strategies for the revised 15/35 and alternative 14/35 standards:

- California accounts for a large share of the total benefits and costs for both of the evaluated standards (80 percent of the benefits and 78 percent of the costs of attaining the revised standards, and 50 percent of the benefits and 58 percent of the costs of attaining the alternative standards). Because we were only able to model a small fraction of the emissions controls that might be needed to reach attainment in California, the proportion of California benefits in the "residual attainment" category are large relative to other areas of the U.S. Both the benefits and the costs associated with the assumed reductions in California are particularly uncertain.

- The comparative magnitudes and distributions of benefits estimates for the revised and alternative standards are significantly affected by differences in assumed attainment strategies. As noted above, attainment with the revised standards was simulated using mainly local reductions, while a supplemental eastern regional SO2 reduction program was used for the alternative. Under the assumptions in the analyses, the regional strategy used in meeting the alternative standard resulted in significant additional benefits in attainment areas than the local area strategy used for the revised standard. This makes the difference in benefits between the revised and alternative standards larger than can be accounted for by only the 1 μg/m3 lower annual level for the alternative standards.

- Given current scientific uncertainties regarding the contribution of different components to the effects associated with $PM_{2.5}$ mass, this analysis continues to assume the contribution is directly proportional to their mass. In the face of uncertainties regarding this assumption, we believe that strategies which reduce a wide array of types of PM and precursor emissions will have more certain health benefits than strategies that are more narrowly focused. For this reason, the analysis provides a rough basis for comparing the assumed benefits associated with different components for different strategies. The illustrative attainment strategy for the revised standards results in a more balanced mix of reductions in different $PM_{2.5}$ components than does the regional strategy for the alterative standards. Until a more robust scientific basis exists for making reliable judgments about the relative toxicity of PM, it will not be possible to determine whether the strategy of reducing a wide array of PM types is the optimal approach.

- Because of the limitations and uncertainties in the emissions and air quality components of our assessment, the specific control strategies that might be the most effective in helping areas to reach attainment are still very uncertain. For example, the high likelihood of mobile sources emissions being significantly understated biases the analyses by requiring additional controls from other sources in both the base case and the analyses of the 1997, revised, and alternative standards.

- Previous analyses have focused on measuring cost-effectiveness by comparing control measures in terms of cost per ton of emissions reduced. In those analyses, direct PM controls usually appear to be less cost-effective because the cost per ton is in the tens of thousands of dollars per ton, while SO2 and NOx controls are on the order of thousands of dollars per ton. The current analysis demonstrates that when considered on a cost per microgram reduced basis, controls on directly emitted PM are often the most cost-effective, because of the significant local contribution of direct PM emissions to nonattaining monitors in urban areas. This finding suggests that states should consider ranking controls on a cost per microgram basis rather than a cost per ton basis to increase the overall cost-effectiveness of attainment strategies.

Appendix A: The Costs and Benefits of Attaining the 1997 Standards in 2015

A.1 Role of this Appendix in Supporting the $PM_{2.5}$ Implementation Rule

This Appendix includes a detailed attainment analysis of the costs and monetized human health benefits of meeting the 1997 standards by the 2015 attainment deadline. This separate analysis is intended to inform the public about the costs and benefits of the $PM_{2.5}$ implementation rule, and as such is included as a stand-alone document. We estimate that the total cost of our attainment scenario is approximately $6.7 billion (1999$) and the total benefits to be between $43 and $97 billion (1999$), using the lower and upper-bound benefits estimates. Below we summarize the important differences between this analysis and the one found in the main body of the RIA.

A.1.1 Differences between 2015 and 2020 Attainment Analysis for Current Standard

The design of the analysis in this appendix is in most respects identical to the main analysis, with the principle divergence being the baseline year used to model attainment. The main analysis used a baseline of 2020 to model attainment of 15/65 and then used that attainment scenario as the regulatory base case with which to model attainment of the revised and more stringent alternative standards. Conversely, this analysis uses a baseline year of 2015 in which to model attainment of 15/65. We selected 2015 as the modeling year for the implementation rule because that is the year when areas have to attain the current standard.

While the baseline years differ between the two analyses, this 2015 analysis shares the same control scenario that we used to simulate attainment of 15/65 in 2020. This 15/65 control scenario must be identical in both years, because our analysis assumes that states implement controls in 2015 to attain the standard in that same year and that states then supplement these same controls in 2020 to attain the revised and more stringent alternative standards.

A.1.2 Analytical Implications of Using 2015 as a Base Year

By 2015, key national and regional rules such as CAIR and the Non-Road rule will not yet be fully implemented. As a result, these rules will yield a smaller amount of the total expected emission reductions in 2015 versus 2020. Thus, most states must design control scenarios that reduce a larger quantity of emissions to attain the current standard of 15/65 in 2015 than they would if they were attaining the current standard in 2020. For this reason, our analysis assumes—and our air quality modeling indicates—that states will just attain the current standard in 2015 and then "over-attain" the current standard in 2020 as the requirements for these national rules are implemented.[1]

The use of a 2015 baseline also has implications for our cost analysis. While we are applying identical controls in 2015 and 2020, the engineering cost estimate varies for these two years due to discounting.

[1] See section 1.6 in the introduction for a comprehensive discussion of the affect of these national rules on attainment pathways.

A.2 Emission Controls Analyzed

The section below summarizes the control measures we applied to simulate attainment with the 1997 standards. EPA selected these control strategies on the basis of cost-effectiveness, using the techniques described in Chapter 3.

Several areas that do not currently attain the 1997 standards make significant progress by 2015 due to multiple national rules that are implemented by that date. Areas that CMAQ projects still not to attain the 1997 standards in 2015 include: Atlanta, Pittsburgh, Cincinnati, Cleveland, Detroit, Chicago, and several California counties.

EPA selected and applied emission controls in 2015 to attain the standard by the statutory deadline. According to the control hierarchy described in Chapters 1 and 3, to simulate attainment with these standards we applied control measures principally in and around the projected nonattaining urban areas.

To simulate attainment with the 1997 standards in the East, our control strategy consisted mainly of controls on directly-emitted $PM_{2.5}$. EPA determined that in general controls applied to direct $PM_{2.5}$ from point and area emissions are the most cost-effective—based on the cost per microgram of reduction/change—to reduce overall particulate matter concentrations in eastern nonattainment areas (defined as the CAIR region).[2] Examples of control technologies applied to $PM_{2.5}$ non-EGU point sources include: diesel particulate filters, continuous emissions monitor (CEM) upgrades and increased monitoring frequency (IMF) of PM controls, and Wet ESP's. We also applied controls to reduce $PM_{2.5}$ emissions from coal-fired EGU's with ESPs by adding two ESP collector fields to increase the surface area for particle collection. The control technologies applied most frequently to area sources of $PM_{2.5}$ included: catalytic oxidizers applied to commercial cooking sources, education and advisory programs, and NSPS compliant woodstoves.[3] See Table A-1 below for a breakdown of pollutant sector reductions by region.

[2] For a list of these cost per microgram estimates, see Appendix C.
[3] For a complete description of AirControlNET control technologies see AirControlNET 4.1 control measures documentation report, prepared by E.H. Pechan and Associates. May 2006.

Table A-1: 15/65 Standard Reduction by Region

Region	*Pollutant*	*Sector*	*% of Reductions*	*Tons*
East	$PM_{2.5}$	Area	9%	3,036
		non-EGU	35%	11,442
		EGU	56%	18,439
		Total East	100%	32,917
West	NO_x	Area	54%	9
	$PM_{2.5}$	Area	46%	7
		Total West	100%	16
California	NH_3	Area	24%	25,948
	NO_x	Area	4%	4,315
		EGU	<1%	146
		non-EGU	43%	47,036
	$PM_{2.5}$	Area	15%	16,653
		EGU	<1%	412
		non-EGU	2%	2,643
	SO_2	non-EGU	12%	12,892
		Total California	100%	110,061

In the West, outside of California, Lincoln County, Montana is the only projected nonattainment area. To achieve the current standard we applied controls to area sources emitting $PM_{2.5}$ as described above, and to area sources emitting NO_X. Examples of controls applied to area sources with NO_X emissions are RACT to 25 tpy (low NO_X burners, or LNB), and the combination of a new water heater and space heater that includes a low NO_X burner for improved NO_X control.

To attempt to simulate attainment with the current standard in California, due to the severity of the projected non-attainment problem, EPA applied all available control measures. Even with this level of control, we did not expect to model attainment with the 1997 standards. Forty-seven percent of the emission control measures applied in California are NO_X controls, half of that is from area and non-EGU point sources, and the remainder is from mobile national rules and local controls. Another 24% of the reductions are achieved through developmental controls placed on agricultural sources of ammonia emissions. According to local air pollution control officials in California, applying ammonia emissions controls in this area of California are not expected to result in large air quality benefits because this area is NO_x limited. California state officials have recommended focusing on sources of NO_x. Another 15% is achieved through controls placed on area sources of $PM_{2.5}$. We applied the remainder of to SO_2 non-EGU point sources and point sources emitting direct $PM_{2.5}$. When developing our control scenarios for each of these projected non-attainment areas, we exhausted our controls database for several counties in California as well as Chicago.

A.3 Air Quality Impacts

Table A-2 below summarizes the CMAQ-projected 2015 base and 2015 control design values for those counties projected to violate the 1997 standards in the base case.

Table A-2: Projected annual and daily $PM_{2.5}$ design values ($\mu g/m^3$) for scenarios modeled with CMAQ

		2015 Base		**2015 Control**	
State	**County**	*Annual*	*Daily*	*Annual*	*Daily*
California	Riverside Co	27.8	73.5	23.27	62.81
California	San Bernardino Co	24.6	65.7	21.62	57.54
California	Los Angeles Co	23.7	62.2	21.66	57.63
California	Kern Co	21.3	81.4	19.22	72.33
California	Tulare Co	21.2	77.2	19.51	69.53
California	Fresno Co	20.1	73.0	17.86	62.69
California	Orange Co	20.0	41.1	18.27	36.61
Michigan	Wayne Co	17.4	39.0	16.99	38.39
California	Kings Co	17.2	70.6	15.99	64.37
California	Stanislaus Co	16.6	61.9	14.96	54.61
Pennsylvania	Allegheny Co	16.5	53.4	16.15	52.26
Alabama	Jefferson Co	15.9	36.9	15.40	33.81
California	Merced Co	15.8	54.4	14.66	49.28
California	San Diego Co	15.8	40.7	13.98	35.63
Ohio	Scioto Co	15.6	34.3	15.40	33.96
Georgia	Fulton Co	15.5	32.2	15.20	31.57
Illinois	Cook Co	15.5	37.1	14.82	36.11
California	San Joaquin Co	15.4	51.1	13.92	44.78
Ohio	Cuyahoga Co	15.4	40.0	15.05	39.39
Illinois	Madison Co	15.2	35.5	14.79	34.80
Montana	Lincoln Co	15.0	42.4	14.90	42.24

We project that by 2015 Detroit and Pittsburgh will be the only two urban areas located outside of California to not attain the 1997 annual standard of 15 $\mu g/m^3$. Detroit is projected to exceed the current annual standard by about 2 $\mu g/m^3$ and Pittsburgh is projected to exceed the annual standard by about 1 $\mu g/m^3$. There are several reasons why our analysis projects these areas to remain in projected non-attainment.

There is a single monitor in Detroit (AIRS #26163003) that is projected to violate the 1997 standard of 15 $\mu g/m^3$. As the attainment determinations section of Chapter 4 describes, our analysis of emissions data indicates that this monitor is likely to be highly influenced by nearby emissions sources located within 3 km of the site. The course resolution of the CMAQ air quality modeling used to estimate the air quality at this monitor is unlikely to have characterized the impact of controlling these near-field sources. While the local-scale AERMOD modeling indicated that controlling local sources of direct $PM_{2.5}$ would have a substantial impact on the design value at the violating monitor, many of these sources may not have been characterized with the precision needed for a local scale assessment for these locations. Moreover, the source apportionment studies highlight the importance of mobile sources and suggest that we may not have fully captured the air quality benefits associated with controlling these sources. Taken together, these data argue that for the purpose of this illustrative analysis Detroit would attain the 1997 standards.

In Pittsburgh, a single monitor is projected to violate the annual 1997 standard of 15 $\mu g/m^3$ (AIRS #420030064). This monitor is situated close to several large industrial facilities, including Clairton Coke Works and U.S. Steel Irvin Plant. Pollution roses indicate that most of the highest $PM_{2.5}$ concentrations result when the wind blows from the southeast where the Clairton facilities are located. As with our analysis of Detroit, the course-scale CMAQ modeling is unlikely to have adequately captured the air quality impact of having controlled these sources. The local-scale AERMOD modeling results indicate high annual concentration gradients of primary $PM_{2.5}$ within typical photochemical modeling grid resolutions; the modeling also indicates that controlling these local sources may yield a substantial reduction in the projected annual design value. It is noteworthy that our 15/35 and 14/35 control strategies were successful in simulating attainment with the 1997 annual standard of $\mu g/m^3$, suggesting that Pittsburgh may attain the 1997 standards if it applies either of these control strategies. Thus, for the purposes of this illustrative analysis, we believe the monitoring, emissions and air quality monitoring data indicate that Pittsburgh would attain the 1997 standards in 2015.

A.4 Benefits Analysis and Results

This section reports EPA's analysis of a subset of the public health and welfare impacts and associated monetized benefits to society of illustrative implementation strategies to attain the 1997 fine particulate matter ($PM_{2.5}$) NAAQS by the year 2015. Accordingly, the analysis presented here attempts to answer two questions: (1) what are the estimated nationwide physical health and welfare effects of changes in ambient air quality resulting from reductions in precursors to particulate matter (PM) including directly emitted carbonaceous particles, NO_x, SO_2, and NH_3 emissions? and (2) what is the estimated monetary value of the changes in these effects?

The analysis presented here uses a methodology generally consistent with benefits analyses performed for the recent analysis of the Clean Air Interstate Rule (EPA, 2005).

The benefits analysis takes as inputs the results of air quality modeling designed for this rulemaking. Reductions in certain $PM_{2.5}$ precursors such as NO_x and VOC may also lead to changes in ambient concentrations of ozone. These changes in ozone will also have health and welfare effects. However, for this analysis, because the majority of the illustrative strategies evaluated do not affect NO_x and VOC emissions (with the exception of nonattainment areas in parts of the western U.S., where we do not have adequate models for ozone), we focus on estimating the health and welfare effects associated with changes in ambient $PM_{2.5}$. This adds some uncertainty to the overall results, but given the expected small magnitude of the impacts (due to the small amount of NOx controls applied); this uncertainty will likely be small relative to other modeling uncertainties.

A wide range of human health and welfare effects are linked to ambient concentrations of $PM_{2.5}$. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis [CB]). Welfare effects potentially linked to PM and its precursors include materials damage and visibility impacts, as well as the impacts associated with deposition of nitrates and sulfates. Although methods exist for quantifying the benefits associated with many of these human health and welfare categories, not all can be evaluated at this time because of limitations in methods and/or data. We estimate that the annual monetized health and welfare benefits associated with the illustrative implementation strategies for implementation of the 1997 PM 2.5 NAAQS in 2015, when the standards are expected to be fully attained. These strategies are evaluated after application of existing federal (such as CAIR), state, and local programs. These benefits are shown below.

Table A-3 Estimated Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the 1997 Standards (90 Percent Confidence Intervals Provided in Parentheses): Primary Estimate

	1997 Standards (15/65)	
Estimate	*Modeled Attainment*	*Full Attainment*
Mortality Based on American Cancer Society Cohort [a]	3,900 (1,500 - 6,200)	6,600 (2,600 - 11,000)
Chronic bronchitis (age >25 and over)	2,900 (550 - 5,300)	5,000 (940 - 9,000)
Nonfatal myocardial infarction (age >17)	7,300 (4,000 - 11,000)	12,000 (6,900 - 18,000)
Hospital admissions—respiratory (all ages)[b]	820 (410 - 1,200)	1,400 (700 - 2,100)
Hospital admissions—cardiovascular (age >17)[c]	1,600 (1,000 - 2,300)	2,800 (1,700 - 3,800)
Emergency room visits for asthma (age <19)	2,400 (1,400 - 3,300)	3,700 (2,200 - 5,200)
Acute bronchitis (age 8–12)	8,200 (-290 - 16,000)	15,000 (-520 - 29,000)
Lower respiratory symptoms (age 7–14)	82,000 (40,000 - 120,000)	150,000 (75,000 - 230,000)
Upper respiratory symptoms (asthmatic children, age 9–18)	61,000 (19,000 - 100,000)	110,000 (36,000 - 190,000)
Asthma exacerbation (asthmatic children, age 6–18)	75,000 (8,300 - 220,000)	140,000 (16,000 - 400,000)
Work loss days (age 18–65)	540,000 (470,000 - 610,000)	980,000 (850,000 - 1,100,000)
Minor restricted-activity days (age 18–65)	3,200,000 (2,700,000 - 3,700,000)	5,800,000 (4,900,000 - 6,600,000)

[a] Based on Pope et al 2002, used as primary estimate in recent RIAs.

Table A-4. Estimated Monetary Valuation of Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the 1997 Standards (90 Percent Confidence Intervals Provided in Parentheses): Primary Estimate

	1997 Standards (15/65)	
Estimate	*Modeled Attainment*	*Full Attainment*
Mortality Based on American Cancer Society Cohort [a]		
3% discount rate	\$28,000 (\$6,100 - \$57,000)	\$43,000 (\$9,700 - \$90,000)
7% discount rate	\$23,000 (\$5,200 - \$48,000)	\$37,000 (\$8,200 - \$76,000)
Chronic bronchitis (age >25 and over)	\$1,500 (\$120 - \$5,400)	\$2,400 (\$190 - \$8,300)
Nonfatal myocardial infarction (age >17)		
3% discount rate	\$790 (\$220 - \$1,700)	\$1,200 (\$340 - \$2,600)
7% discount rate	\$760 (\$200 - \$1,700)	\$1,200 (\$310 - \$2,600)
Hospital admissions—respiratory (all ages)[b]	\$16.0 (\$8.2 - \$25.0)	\$26.0 (\$13.0 - \$39.0)
Hospital admissions—cardiovascular (age >17)[c]	\$45.0 (\$28.0 - \$62.0)	\$68.0 (\$43.0 - \$94.0)
Emergency room visits for asthma (age <19)	\$0.81 (\$0.44 - \$1.20)	\$1.20 (\$0.64 - \$1.80)
Acute bronchitis (age 8–12)	\$3.80 (-\$0.14 - \$10.00)	\$6.10 (-\$0.24 - \$15.00)
Lower respiratory symptoms (age 7–14)	\$1.60 (\$0.61 - \$3.00)	\$2.70 (\$1.00 - \$5.10)
Upper respiratory symptoms (asthmatic children, age 9–18)	\$2.00 (\$0.51 - \$4.20)	\$3.40 (\$0.89 - \$7.20)
Asthma exacerbation (asthmatic children, age 6–18)	\$3.70 (\$0.40 - \$12.00)	\$6.50 (\$0.70 - \$21.00)
Work loss days (age 18–65)	\$77 (\$67 - \$87)	\$130 (\$120 - \$150)
Minor restricted-activity days (age 18–65)	\$93 (\$8 - \$180)	\$160 (\$14 - \$310)

[a] Based on Pope et al 2002, used as primary estimate in recent RIAs.

The tables below summarize the estimates of mortality and morbidity that use effect estimates derived from the expert elicitation effort described above in section 1.3.4. In these tables we provide incidence and valuation estimates based on data-derived and expert-elicitation derived mortality functions, for both our modeled and full attainment scenarios. The expert-elicitation derived incidence and valuation estimates include upper and lower-bound estimates based on the two experts who provided the highest and lowest mortality impact functions. Chapter 5 of this RIA complements these summary tables by including the results of the full-scale study.

Table A-5. Estimated Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the 1997 Standards

Modeled Attainment

Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature[a]

3,900

Confidence Intervals

(1,500 - 6,200)

Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature

Lower-bound EE:
1,400
Upper-bound EE:
13,000

Confidence Intervals

CI for lower bound EE result:
(0 - 6,600)
CI for upper bound EE result:
(6,800 - 20,000)

Full Attainment

Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature[a]

6,600

Confidence Intervals

(2,600 - 11,000)

Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature

Lower-bound EE:
2,300
Upper-bound EE:
22,000

Confidence Intervals

CI for lower bound EE result:
(0 - 11,000)
CI for upper bound EE result:
(11,000 - 32,000)

[a] Based on Pope et al 2002, used as primary estimate in recent RIAs.

Table A-6. Estimated Monetary Valuation of Reduction in Incidence of Adverse Health and Welfare Effects Associated with Attaining the 1997 Standards (billions 1999$)

Based on Mortality Function from American Cancer Society and Morbidity Functions from Epidemiology Literature[a]	
Using a 3% discount rate	$48 + B *Confidence Intervals* ($11 - $100)
Using a 7% discount rate	$41 + B *Confidence Intervals* ($9.5 - $88)
Based on Expert Elicitation Derived Mortality Functions and Morbidity Functions from Epidemiology Literature	
Using a 3% discount rate	$20 + B to $160 + B CI for lower bound EE result ($1.4--95) CI for upper bound EE result ($39—$310)
Using a 7% discount rate	$18 + B to $130 + B CI for lower bound EE result ($1.4—$82) CI for upper bound EE result ($33—$260)

[a] Based on Pope et al 2002, used as primary estimate in recent RIAs.

A.5 Engineering Cost Estimates

In this section, we provide engineering cost estimates of the control strategies identified above that include control technologies on non-EGU stationary sources, area sources, electric generating units, and mobile sources. Engineering costs generally refer to the capital equipment expense, the site preparation costs for the application, and annual operating and maintenance costs. The total annualized cost of each control scenario is provided in Table 13 and reflects the engineering costs across sectors that are annualized at an interest rate of 7% and 3%, respectively. Total annualized costs of meeting the 1997 standards based on our illustrative analysis is approximately $6.7 billion (1999$).

As is discussed throughout this report, the technologies and control strategies selected for analysis are illustrative of one way in which nonattainment areas can meet the revised standards. There are numerous ways to compile and evaluate potential control programs to comply with the standards, and EPA anticipates that State and Local governments will consider those programs that are best suited for local conditions. As such, the costs described in this chapter generally cover the costs of purchasing and installing the referenced technologies. Because we are not certain of the specific actions that State Agencies will take to design State Implementation Plans to meet the revised standards, we do not present estimated costs that government agencies may incur for managing the requirement and implementation of these control strategies or for offering incentives that may be necessary to encourage or motivate the implementation of the technologies, especially for technologies that are not necessarily market driven. Control measure costs referred to as "no cost" may require limited government agency resources for administration and oversight of the program, but those costs are outweighed by the saving to the industrial, commercial, or private sector. This analysis does not assume specific control measures that would be required in order to implement these technologies on a regional or local level.

Table A-6: Comparison of Total Annualized Costs Across PM NAAQS Scenarios from Attaining the 1997 Standards (millions of 1999 dollars, 7% interest rate)

Source Category	*1997 Standards: 15/65 μg/m^3*
EGU's	
Local Controls on direct PM	$130
Local Controls for NO_X	< $1
Total	
Mobile Sources	
National Rules	$1,400
Local Rules	$20
Total	**$1,400**
Non-EGU's	
Point Sources (Ex: Pulp & Paper, Iron & Steel, Cement, Chemical Manu.)	
Local Known Controls	$450
Area Sources (Ex: Res. Woodstoves, Agriculture)	$50
Developmental Controls	$50
Total	**$600**
Incremental Cost of Residual Nonattainment	
California	$4,600
Grand Total	**$6,700**

Using a 3% discount rate the overall costs would not be significantly different given the degree of precision in these estimates. For the purposes of comparing the costs to benefits in the subsequent section we use the $6.7 billion figure.

Table A-7: Total Annualized Costs Applied to Non-EGU Stationary Sources (millions of $1999)

State	*Pollutant*	*Total Annualized Cost of 15/65*	*Comments & Notations*
Alabama	$PM_{2.5}$	$12	Controls were selected to meet the annual standards of 15.
	Total	***$12***	
California	NO_x	$230	All available controls are applied to meet 15/65.
	$PM_{2.5}$	$19	
	SO_2	$160	
	Total	***$410***	
Georgia	$PM_{2.5}$	<$1	
	Total	***<$1***	
Illinois	$PM_{2.5}$	$4	
	Total	***$4***	
Indiana	$PM_{2.5}$	$14	
	Total	***$14***	
Kentucky	$PM_{2.5}$	$69	
	Total	***$69***	
Michigan	$PM_{2.5}$	$5	
	Total	***$5***	
Ohio	$PM_{2.5}$	$6	
	Total	***$6***	
Pennsylvania	$PM_{2.5}$	$4	Control strategies required non-EGU stationary controls.
	Total	***$4***	
West Virginia	$PM_{2.5}$	$2	Although West Virginia attains the scenarios analyzed, controls strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	Total	$2	
Wisconsin	$PM_{2.5}$	<$1	Although Wisconsin attains the current standard, control strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	Total	***<$1***	
Total Annualized Costs for the Non-EGU point source sector		***$456***	

Table A-8: Total Annualized Costs Applied to Non-EGU Area Sources (millions of $1999)

State	*Pollutant*	*Total Annualized Cost of 15/65*	*Observations*
California	NH_3	$41	All available controls are applied to meet 15/65.
	NO_x	$6	
	$PM_{2.5}$	$36	
	SO_2	<$1	
	Total	***$82***	
Georgia	$PM_{2.5}$	$2	
	Total	***$2***	
Illinois	$PM_{2.5}$	$4	
	Total	***$4***	
Indiana	$PM_{2.5}$	<$1	
	Total	***<$1***	
Kentucky	$PM_{2.5}$	<$1	
	Total	***<$1***	
Michigan	$PM_{2.5}$	$5	Controls for direct $PM_{2.5}$ emissions are most effective to meet the current standard.
	Total	***$5***	
Montana	NO_x	<$1	
	$PM_{2.5}$	<$1	
	Total	***<$1***	
Ohio	$PM_{2.5}$	$4	
	Total	***$4***	
Pennsylvania	$PM_{2.5}$	$1	
	Total	***$1***	
West Virginia	$PM_{2.5}$	<$1	Although West Virginia attains the scenarios analyzed, controls strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	Total	***<$1***	
Wisconsin	$PM_{2.5}$	$2	Although Wisconsin attains the current standard, control strategies identified areas that may contribute to nonattainment issues in other locations. This analysis assumes State authorities will coordinate to define control strategies that bring an area into attainment at the lowest social cost.
	Total	***$2***	
Total Annualized Cost for the Area Source Sector		***$100***	

A.5.2 EGU Sources

Costs of Controls Outside the CAIR Region and Costs of Direct PM Controls Nationwide

Controls selected are focused on those controls that are not considered part of the CAIR rule, such as direct $PM_{2.5}$ control technologies, and in the Western U.S. controls for NO_x emissions from these sources. The direct PM and NO_x controls for EGU's were selected only when this sector was identified as a cost-effective and cost-efficient category for control strategies. In Table A-9, incremental EGU controls for the selected standard are chosen only in a limited number of States, including: Ohio, Pennsylvania, Utah, and Washington, and are selected to help these areas attain a more stringent daily standard.

Table A-9: Total Incremental Annualized Costs Applied to EGU Sources using AirControlNET

State	*Pollutant*	*Total Annualized Cost of 15/65*
California	NO_x	$441,684
	$PM_{2.5}$	$16,529,576
	Total	*$16,971,260*
Georgia	$PM_{2.5}$	$15,249,636
Illinois	$PM_{2.5}$	$421,706
Indiana	$PM_{2.5}$	$4,713,815
Kentucky	$PM_{2.5}$	$2,831,073
Michigan	$PM_{2.5}$	$39,323,118
Ohio	$PM_{2.5}$	$33,284,252
Pennsylvania	$PM_{2.5}$	$8,727,457
West Virginia	$PM_{2.5}$	$11,884,446
Wisconsin	$PM_{2.5}$	$509,499
Total Annualized Cost for EGU sources from ACNet		***$133,474,578***

A.5.3 Mobile Sources

This section presents cost information for each mobile source control technology included in the analysis. Costs for the individual technologies are in terms of $/ton of emissions reduced and are based on a 7% discount rate. These values were applied to the tons of emissions reduced in each geographic area and were then summed to determine total costs for each scenario. Note that control technologies or measures that affect emissions from mobile sources frequently have impacts on multiple pollutants. Where this is the case, we attempt to provide information on our cost calculation methodology with respect to the pollutants of concern.

Note Regarding Mobile Source Air Toxics Rule

The recent proposal to reduce mobile source air toxics (71 FR 15804, March 29, 2006) discusses data showing that direct $PM_{2.5}$ emissions from gasoline vehicles are elevated at cold temperatures. The proposed vehicle hydrocarbon standards contained in the March 29, 2006 action would also reduce these elevated PM emissions. This RIA does not include the effects of this proposed rule because we do not currently have the data to model the impacts of elevated cold-temperature PM emissions across the entire in-use fleet. As a result, these cold-temperature emissions are not included in our baseline emission inventories, which may understate the baseline—and consequently projected—inventory of mobile source $PM_{2.5}$ emissions. The final mobile source air toxics rule would thus reduce $PM_{2.5}$ emissions, and improve air quality, by an amount not reflected in our analysis of these standards and may make compliance easier by reducing the need for some control strategies. EPA is currently analyzing these data from a large collaborative test program with industry, and our next emissions model (MOVES) will include cold temperature effects for PM.

Geographical Scope of Mobile Source Controls

It is important to clarify the sequence by which mobile source control measures were applied within the broader context of all control measures. In applying the cost information for the 15/65 scenario, we first applied cost-effective local stationary source (point and area) controls and national mobile source control rules. Next, due to time and analytical constraints, we applied local mobile source control measures only in areas that we had identified as needing a small additional amount of emission reductions would to reach attainment (in this case, only in Chicago) and areas where all available control measures were needed (e.g., parts of southern California). However, this does not imply that State and local authorities will sequence application of control measures in a similar fashion. State and local governments may have numerous reasons for employing mobile source control strategies *before* a set of measures that control point or area sources (for example, further point source controls would be less cost-effective than mobile measures, and/or an area's stationary sources are already well-controlled).

Table A-10: Geographic Areas to which Mobile Source Controls were applied for 15/65

Geographic Area	15/65 Scenario
National Rules	All counties in the U.S.
Local Measures	Southern California Chicago MSA

We divide control costs into two broad categories: national rules and local measures.

Estimated Costs of National Rules

The national mobile source rules discussed in this analysis are at various stages of regulatory development, but in all cases they are pre-proposal. Therefore, EPA has not developed new cost estimates. Rather, the costs used in this analysis are based on cost-per-ton estimates of previous EPA rulemakings for controls of similar sources using similar control technologies. No new analysis has been performed as of yet since regulatory development is still underway. We therefore assume for the purposes of this analysis that the costs of controls on these sources to be on the same order of magnitude as our experience in recent mobile source rulemakings, but these cost estimates are based on limited information and broad assumptions about the measures we would include for the final rulemaking.

PM and NOx cost-per-ton estimates for diesel locomotives and diesel marine categories 1 and 2 engines are based on the estimates developed by EPA for the highway heavy-duty 2007 rule and the nonroad land-based diesel Tier 4 rule. These cost-per-ton values are shown in Table A-11 below. In both cases, these previous rule cost estimates were based on the application of advanced PM and NOx after treatment systems (e.g., catalyzed diesel particulate filters and NOx catalysts).

Table A-11: Cost-per-ton Estimates from EPA's Highway Heavy-duty 2007 Rule and Nonroad Land-based Diesel Tier 4 Rule

	30-yr discounted life-time cost-per ton (7% discount)	
Previous National Mobile Source Rule	*PM*	*NMHC+NOx*
Highway HD 2007 (66 FR 5102, 1999$)	$13,607	$2,149
Nonroad Diesel Tier 4 (69 FR 39131, 2002$)	$11,800	$1,160

For the C3 marine Scenario 1, 50% reduction from today's ocean-going vessels for NOx and PM were based on EPA's nonroad land-based diesel Tier 2 and Tier 3 standards. The nonroad land-based Tier 2 and Tier 3 program cost-per-ton estimates were based on in-cylinder control technologies such as improved fuel injection systems, intake charge-air-cooling, and exhaust gas recirculation. The nonroad land-based diesel Tier 2 and 3 standards cost-per-ton estimates were in the $400 - $600/ton range for NMHC+NOx. The nonroad land-based diesel Tier 2 cost-per-ton estimate for PM was $2,300/ton. For PM, EPA did not estimate any addition reduction from the land-based diesel Tier 3 program, and the PM $/ton estimate for the Tier 2 land-based diesel program was a combined estimate for the Tier 1 and Tier 2 standards.

The estimate used in this analysis for a national mobile source rule covering small gasoline engines less than 25 horsepower and gasoline marine engines was based on previous rulemakings for these two source categories. EPA's small gasoline engine Phase 2 standards for nonhandheld engines estimated a cost-per-ton for HC+NOx was $2,000, excluding any cost-savings due to improved fuel consumption. EPA's existing gasoline outboard and personal watercraft marine engine program estimated a cost-per-ton of $2,000 for HC. These estimates of cost-effectiveness for mobile source national rules can be found in Table A-12.

Note that some of these rules, especially the small gasoline engine rule, have little impact on PM but were included in an attempt to be as comprehensive as possible.

Table A-12: Cost Effectiveness of Mobile Source National Rules

	Estimated cost ($/ton)		
National Rule	*PM*	*HC*	*NOx*
Diesel locomotive and marine C1&C2	$10,000		$2,000
C3 marine, Scenario 1 (50% reduction)	$2,500		$500
C3 marine, Scenario 2 (90% reduction)	$10,000		$2,000
Small gasoline and recreational gasoline marine		$2,000	$2,000
Ocean-going vessels (SO_x: cost info TBD)			

*Note: While SOx reduction from residual oil in ocean-going vessels could be accomplished by a variety of measures, the cost presented above is taken from a technology similar to the option of applying a scrubber. As a surrogate we use the cost for flue-gas desulfurization (FGD) scrubbing at an industrial boiler greater than 250 MMBtu/hr (AirControlNET Documentation Report, May 2006).

The recent proposal to reduce mobile source air toxics (71 FR 15804, March 29, 2006) discusses data showing that direct PM2.5 emissions from gasoline vehicles are elevated at cold temperatures. The proposed vehicle hydrocarbon standards contained in the March 29, 2006 action would reduce these elevated PM emissions. This RIA does not include the effects of this proposed rule because we do not currently have the data to model the impacts of elevated cold-temperature PM emissions across the entire in-use fleet. As a result, these emissions are not included in our baseline emission inventories. We are currently analyzing the data from a large collaborative test program with industry, and our next emissions model (MOVES) will include cold temperature effects for PM.

Estimated Costs of Local Measures

Diesel Retrofits and Vehicle Replacement - For purposes of modeling, we divided the retrofit measure into two categories: the 1st 50% of retrofit potential (low end) and the 2nd 50% of retrofit potential (high end) to provide modeling and analytical flexibility with how such measures are applied. For example, such a division would help when applying retrofit measures to a nonattainment area in which only 50% of retrofit potential is adequate to achieve attainment. We categorize the low end as the most cost-effective retrofits since, ideally, states and local governments would first retrofit the most cost-effective fleets in terms of expected emissions reduction (based on vehicle miles traveled or VMT, expected life, model year, engine type, etc.) and cost of retrofit (based on technology and installation costs).

The cost-effectiveness ($/ton of PM) estimates for retrofits are based on EPA's recent study of DOC and catalyzed DPF (CDPF) retrofits for school buses as well as class 6, 7, and 8b trucks; and just DOC retrofits for 250 hp bulldozers (the "C-E study"). The C-E study is available at http://www.epa.gov/cleandiesel/documents/420s06002.pdf. For purposes of this analysis, we believe this study is the best source of information since it is based on the most current data available. However, the C-E study was intentionally narrow in scope, and in using its data for an analysis as comprehensive as this analysis, raises a number of limitations that affect the data's applicability. For example:

- The C-E study does not address several categories of engines analyzed in the retrofit measure for this analysis (e.g. Class 5 trucks, most nonroad engines).
- The C-E study does not estimate cost-effectiveness for repower or replacement, which are both included in the retrofit measure for this analysis.
- The C-E study is based on 2007 costs for technologies and emissions data for fleets. VMT, technology costs, and other variables will be different in 2015 and 2020.
- For highway engines, the C-E study is based on emission factors from recent testing which are roughly 2.3 times higher than emissions factors found in MOBILE 6.2. EPA used the MOBILE 6.2 model to develop the inventory for this analysis and to analyze emissions reduction potential from retrofits. EPA will integrate the recent highway vehicle testing data into the next highway emissions model, MOVES. In the meantime, states and local governments will continue to use MOBILE 6.2 to estimate highway vehicle emissions for SIP and transportation conformity purposes.

For estimating the more cost-effective highway vehicle retrofits, we averaged the low end of the cost-effectiveness range of both measures (DOC and CDPF) for all three groups of highway vehicles in the C-E study (school buses, class 6 & 7 trucks, and class 8b trucks). For estimating the less cost-effective highway retrofits, we used the average of the range of cost-effectiveness of both measures and all three groups of vehicles. We used the average, rather than the high end of the cost-effectiveness range, because we believe that technology and installation costs are likely to decrease by 2015.

For the estimate of the cost-effectiveness of the low end potential of nonroad engine retrofits, we used the low end of the cost-effectiveness range for DOC retrofits of 250 hp bulldozers. For the estimate of the cost-effectiveness of the high end potential of nonroad engine retrofits, we used the average of the range of cost-effectiveness for DOC retrofits of 250 hp bulldozers. Again, we used the average, rather than the high end of the cost-effectiveness range, because we believe that technology and installation costs are likely to decrease by 2015. The results are presented in Table A-13 below:

Table A-13. Cost Effectiveness for Diesel Retrofit Scenarios

Summary of Cost-Effectiveness for Various Diesel PM Retrofit Scenarios (April 2006 EPA Study) $/ton PM				
	Measure	**Min**	**Max**	**Average**
School Bus	DOC	$12,000	$49,100	$30,550
	CDPF	$12,400	$50,500	$31,450
Class 6&7 Truck	DOC	$27,600	$67,900	$47,750
	CDPF	$28,400	$69,900	$49,150
Class 8b Truck	DOC	$11,100	$40,600	$25,850
	CDPF	$12,100	$44,100	$28,100
250 hp Bulldozer	DOC	$18,100	$49,700	$33,900

Application to PM NAAQS RIA Package of Retrofit Measures (DOC, DPF, Repower, Replace) $/ton PM	
Highway (low end)	**$17,267**
Highway (high end)	**$35,475**
Nonroad (low end)	**$18,100**
Nonroad (high end)	**$33,900**

Note that these $/ton PM estimates are applied across the board for all types of retrofit measures (DOCs, CDPFs, repower, replacement) and highway vehicle and nonroad engine types.

The overall cost-effectiveness of this measure is estimated to be:

- Highway 1st 50% - $17,267/ton PM
- Highway 2nd 50% - $35,475/ton PM
- Nonroad 1st 50% - $18,100/ton PM
- Nonroad 2nd 50% - $33,900/ton PM

Eliminating Long Duration Truck Idling - For purposes of this analysis, we identified this measure as a no cost strategy: that is to say, at $0/ton PM. Both truck stop and terminal electrifications and mobile idle reduction technologies have upfront capital costs, but for the most part these costs can be fully recovered by fuel savings. The examples below illustrate the potential rate of return on investments in idle reduction strategies.

Truck Stop and Terminal Electrifications (TSEs) The average price of TSE technology is $11,500 per parking space. The average service life of this technology is 15 years. Truck engines at idle consume approximately 1 gallon per hour of idle. Current TSE projects are operating in environments where trucks are idling, on average, for 8 hours per day per space for 365 days per year (or about 2,920 hours per year). Since TSE technology can completely eliminate long duration idling at truck spaces (i.e. a 100% fuel savings), this translates into 2,920 gallons of fuel saved per year per space. At current diesel prices ($2.90/gallon), this fuel savings translates into $8,468. Therefore, an $11,500 capital investment should be recovered within about 17 months. In this scenario, TSE investments offer over a 70% annual rate of return over the life of the technology.

While it is technically feasible to electrify all parking spaces that support long duration idling trucks, we should note that TSE technology is generally deployed at a minimum of 25-50 parking spaces per location to maximize economies of scale. The financial attractiveness of installing TSE technology will depend on the demonstrated truck idling behavior – the greater the rates of idling, the greater the potential emissions reductions and associated fuel and cost savings.

Mobile Idle Reduction Technologies (MIRTs). The price of MIRT technologies ranges from $1,000-$10,000. The most popular of these technologies is the auxiliary power unit (APU) because it provides air conditioning, heat, and electrical power to operate appliances. The average price of an APU is $7,000. The average service life of an APU is 10 years. An APU consumes two-tenths of a gallon per hour, so the net fuel savings is 0.80 gallons per hour. EPA estimates that trucks idle for 7 hours per rest period, on average, and about 300 days per year (or 2,100 hours per year). Since idling trucks consume 1 gallon of fuel per hour of idle, APUs can reduce fuel consumption for truck drivers/owners by approximately 1,680 gallons per year. At current diesel prices ($2.90/gallon), truck drivers/owners would save $4,872 on fuel if they used an APU. Therefore, a $7,000 capital investment should be recovered within about 18 months. In this scenario, APU investments offer almost a 70% annual rate of return over the life of the technology.

Intermodal Transport - We believe that a 1% shift is viable and could occur at a low or no cost, since rail is likely to be less expensive than truck transport due primarily to lower fuel costs. For purposes of economic analysis, we identified this measure as a no cost strategy ($0/ton PM). A certain level of intermodal shifting may require new investments in rail infrastructure, but these costs should be fully recovered over time by the fuel and other transport cost savings. We did not have adequate data to conduct a more detailed cost analysis. Our understanding of costs is based on anecdotal evidence and confidential business information from partners in EPA's SmartWay Transport Partnership program. There will be a great deal of variability in the financial attractiveness of transitioning to intermodal transport versus truck-only transport based on the capacity of current rail infrastructure; willingness of rail and truck companies to cooperate; the rail industry's ability to make capital investments; and local government support for accommodating additional rail lines, rail facilities, and rail operation flexibility.

Best Workplaces for Commuters (BWC) - We used the Transportation Research Board's (TRB) cost-effectiveness analysis of Congestion Mitigation and Air Quality Improvement Program (CMAQ) projects to estimate the cost-effectiveness of this measure.[4] TRB conducted an extensive literature review and then synthesized the data to develop comparable estimates of cost-effectiveness of a wide range of CMAQ-funded measures. We took the average of the median cost-effectiveness of a sampling of CMAQ-funded measures and then applied this number to the overarching BWC measure. The CMAQ-funded measures we selected were:

- regional rideshares

[4] Transportation Research Board, National Research Council, 2002. *The Congestion Mitigation and Air Quality Improvement Program: assessing 10 years of experience*, Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program.

- vanpool programs
- park-and-ride lots
- regional transportation demand management
- employer trip reduction programs

We felt that these measures were a representative sampling of BWC incentive programs. There is a great deal of variability, however, in the type of programs and the level of incentives that BWC employers offer, which can impact both the amount of emissions reductions and the cost of BWC incentive programs.

We chose to apply the resulting average cost-effectiveness estimate to one pollutant – NO_x – in order to be able to compare BWC to other NO_x reduction strategies. TRB reported the cost-effectiveness of each measure, however, as a $/ton reduction of both VOC and NOx by applying the total cost of the program to a 1:4 weighted sum of VOC and NOx [total emissions reduction = (VOC * 1) + (NO_x * 4)]. There was not enough information in the TRB study to isolate the $/ton cost-effectiveness for just NO_x reductions, so we used the combined NO_x and VOC estimate.

We chose to report the cost-effectiveness of controlling NO_x over PM 2.5 for two reasons. First, BWC has a greater impact on NO_x emissions than PM 2.5 since it targets light-duty gasoline vehicles which have very low levels of PM 2.5 emissions. Second, the TRB study did not report cost-effectiveness information for PM 2.5 due to the lack of available data. The results are presented in Table A-14 below:

Table A-14. Cost-Effectiveness for Best Workplaces for Commuters Programs

	Low	*High*	*Median*
Regional Rideshare	$1,200	$16,000	$7,400
Vanpool Programs	$5,200	$89,000	$10,500
Park-and-ride lots	$8,600	$70,700	$43,000
Regional TDM	$2,300	$33,200	$12,500
Employer trip reduction programs	$5,800	$175,500	$22,700
Average of All Measures	$4,620	$76,900	**$19,200**

The overall cost-effectiveness of this measure is estimated as $19,200 per ton of NOx reduced.

Table A-15: Total Annualized Costs Applied to Mobile Sources for 15/65 (millions of 1999$)

Geographic Area	*PM2.5*	*NOx*	*VOC*
Eastern U.S.			
- National Rules	$ 88	$ 400	$440
- Local Measures	$ 2.7	$ 3	$0
Western U.S. (except CA)			
- National Rules	$50	$140	$120
- Local Measures	$0	$0	$0
California			
- National Rules	$13	$69	$57
- Local Measures	$7.1	$7.9	$0
Total Annualized Cost for Mobile Sources	***$160***	***$620***	***$610***

<u>Estimating the Attainment Cost for California</u>

To estimate the cost for California to attain the 1997 standards, we employed the same cost-estimation methodology found in Chapter 6. Table A-16 below summarizes these full attainment costs.

Table A-16: Cost Estimate for California to Meet 1997 Standards in 2015 (million 1999$)[5]

Standard	*NOx Controls Only*	*PM Controls Only*	*NOx and PM Controls*
1997 Standards of 15/65 in 2015			
Modeled	$660	$660	$660
Full	$7,800	$2,900	$4,600
Total	$8,500	$3,600	$5,300

A.6 Comparison of Benefits and Costs

Table A-17: Comparison of Benefits with Social Costs (Million 1999$): Primary Estimate Using Concentration-Response Function Developed from ACS Study Estimate of Mortality

	1997 Standards of 15/65 (µg/m³)[a]		
	Benefits	*Costs*	*Net benefits*
3 percent discount rate**			
East	$9,200	$1,200	$8,000
West	$200	$340	($140)
California	$39,000	$5,400	$34,000
Total	***$48,000***	***$7,000***	***$41,000***
7 percent discount rate			
East	$7,900	$1,200	$6,700
West	$180	$340	($160)
California	$33,000	$5,400	$28,000
Total	***$41,000***	***$7,000***	***$35,000***

[a] The effect estimate used to derive benefits in this table is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[5] Note: numbers may not total due to rounding.

Table A-18. Estimate of Net Benefits Using Expert Elicitation-Derived Estimates, Derived Using Social Cost (Millions 1999$)

Using a 3% discount rate	150,000 to 14,000
Using a 7% discount rate	120,000 to 11,000

APPENDIX B

Local-Scale Assessment of Primary PM2.5 for Five Urban Areas

This assessment quantifies the impacts of local sources of primary PM2.5 within selected urban areas. Local-scale air quality modeling is used to examine the spatial variability of direct PM2.5 concentrations associated with emissions of primary PM2.5 within each urban area and to quantify the impact of specific emissions source groups to ambient PM2.5 concentrations at Federal Reference Method (FRM) monitoring sites. We focused this assessment on five urban areas: Birmingham, Seattle, Detroit, Chicago and Pittsburgh. An assessment for the first three of these areas had been presented in the RIA for the propose rule and has updated here based on an updated emission inventory. Each of these areas has different characteristics in terms of the mixture of emissions sources, meteorology, and associated PM2.5 air quality issues. As such, they are representative of other areas across the eastern and western US and therefore this assessment provides insights that may be applicable to these other areas. This assessment has a future focus on the incremental impacts of direct PM2.5 sources within these areas after implementation of the Clean Air Interstate Rule (CAIR), Clean Air Mercury Rule (CAMR), and Clean Air Visibility Rule (CAVR).

Based on 2001 meteorology data and a 2015 base inventory (denoted "2015bi") for primary PM2.5 which incorporates CAIR/CAMR/CAVR impacts, the AERMOD modeling system was applied to each urban area to provide concentration estimates of directly emitted PM2.5 by species across a specified network of receptors within each urban area. AERMOD computes concentrations by individual sources and/or source groups that can then be used to analyze the relative impacts of different types of emissions sources. The modeling domain encompasses each urban area and surrounding areas that have large point source emissions. It includes both an emissions domain, which consists of the urban area and surrounding counties, and a receptor grid, which consists of a set of evenly-spaced receptors within the urban core and at individual monitoring sites [i.e., Federal Reference Method (FRM) and Speciation Trends Network (STN) monitors].

For each area, AERMOD inputs include 2001 meteorological data from the nearest National Weather Service (NWS) Station, geographic information on terrain, the 2015bi emission inventory for direct PM2.5 for counties comprising the emissions domain, and receptor locations. Based on these inputs, AERMOD provides an estimate of the pollutant fate and transport in the atmosphere. This modeling predicts how the directly emitted PM2.5 is transported, dispersed, and deposited over the area of interest. Initially, the fate of the directly emitted PM2.5 is largely determined by the source release characteristics. After being emitted into the atmosphere, its transport, dispersion, and deposition are determined by meteorological conditions, terrain characteristics, and deposition rates of the direct PM2.5. The concentration for each PM2.5 species and total mass from each source is estimated at each receptor.

Section I provides an overview of the AERMOD modeling system and the inputs used for this local-scale assessment, while Section II details the results of applying the AERMOD modeling system in evaluating these direct PM2.5 controls for each urban area.

I. AERMOD Modeling System and Inputs

In 1991, the American Meteorological Society (AMS) and the United States Environmental Protection Agency (EPA) initiated a formal collaboration to develop a state-of-the-science dispersion model that reflected advances in planetary boundary layer (PBL) meteorology and science. This joint effort resulted in the development of the AMS/EPA Regulatory Model (AERMOD), which is a steady-state plume dispersion model for air quality assessments of inert pollutants that are directly emitted from a variety of sources[1,2,3,4]. Based on an advanced characterization of the atmospheric boundary layer turbulence structure and scaling concepts, AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including point, area, or volume sources). The model employs hourly sequential preprocessed meteorological data to estimate concentrations at receptor locations for averaging times from one hour to one year. AERMOD incorporates both dry and wet particle and gaseous deposition as well as source or plume depletion. Through final rulemaking (effective December 9, 2005), the Agency established AERMOD as the preferred air dispersion model in its "Guideline on Air Quality Models." (40 CFR 51, Appendix W)

Figure 1 shows the flow and processing of the complete AERMOD modeling system, which consists of the AERMOD dispersion model and two pre-processors: AERMET and AERMAP. The AERMOD meteorological pre-processor, AERMET, is a stand-alone program that uses meteorological information and surface characteristics to calculate the boundary layer parameters for use by AERMOD to generate the needed meteorological variables.[5] In addition, AERMET passes all meteorological observations to AERMOD. The AERMOD mapping program, AERMAP, is a stand-alone terrain pre-processor that characterizes terrain and generates receptor grids for use by AERMOD.[6]

AERMOD is a steady-state plume dispersion model in that it assumes that concentrations at all distances during a modeled hour are governed by the set of hourly averaged meteorology inputs (Cimorelli et al, 2005; Perry et al, 2005). In the stable boundary layer, AERMOD assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. AERMOD constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships. Vertical profiles of wind speed, wind direction, turbulence, temperature, and temperature gradient are estimated using all available meteorological observations. AERMOD has been designed to handle the computation of pollutant impacts in both flat and complex terrain within the same modeling framework. In general, AERMOD models a plume as a combination of two limiting cases: a horizontal plume (terrain impacting) and a terrain-following, or responding, plume. Therefore, for all situations, the total concentration, at a receptor, is bounded by the concentration predictions from these two states.

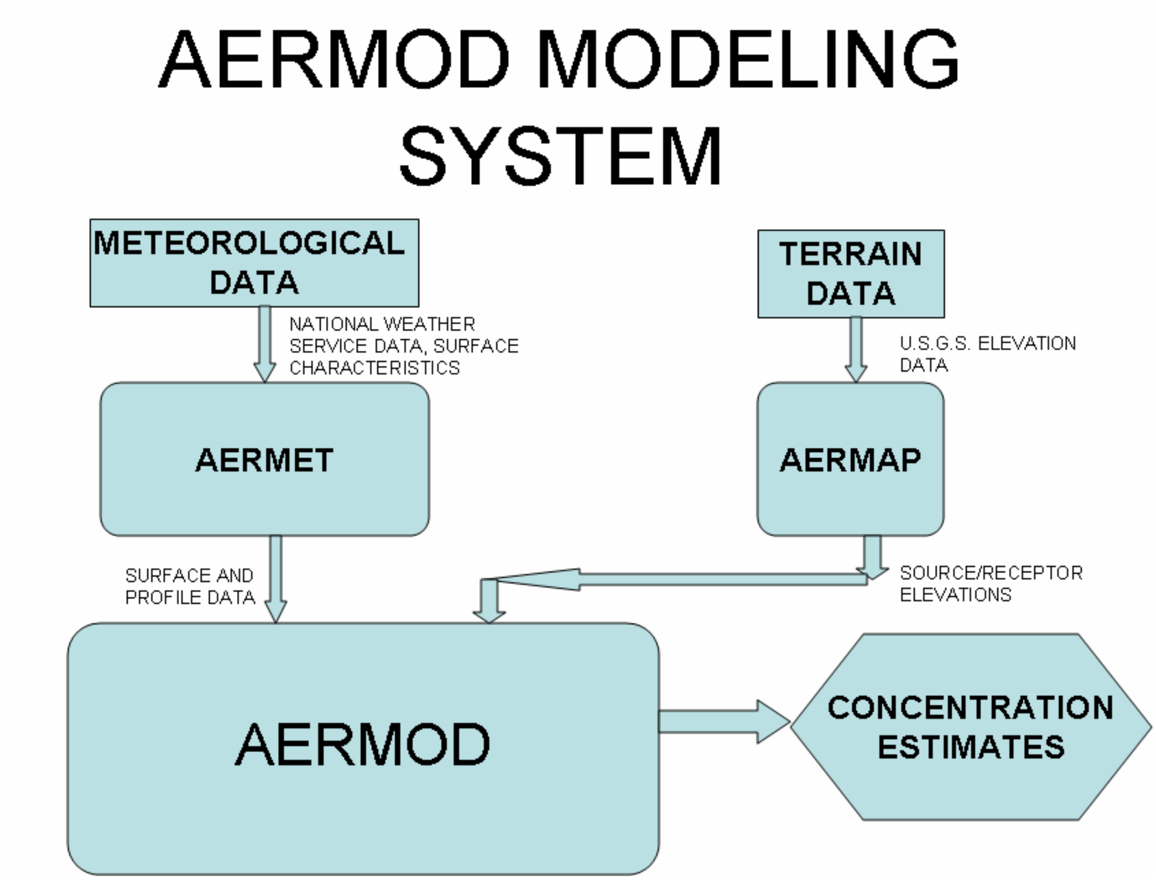

Figure 1. Flow Diagram of the AERMOD Modeling System

I.A Modeling Domain and Receptors

Modeling domains were developed for each of the five urban areas: Birmingham, Detroit Seattle, Chicago, and Pittsburgh. These modeling domains were defined such that the urban geographic area and significant sources of direct PM2.5 were captured, and such that receptors within the urban area were placed to determine the spatial gradient with additional receptors placed at monitor locations to allow for the evaluation of impacts of potential controls. The modeling domain consists of an emission domain, defined by counties surrounding the urban area, and a receptor "grid", that includes equally spaced receptors within the urban area and specific receptors placed at individual PM2.5 monitoring sites. Figures 2 thru 6 present the modeling domain for each urban area including the associated emissions domain (encircled counties) and receptor grid (boxed area within urban core). As shown in Figure 6, for Pittsburgh, the receptors were distributed in a ring around the monitor of interest.

I.A.1 Emissions Domain

For each urban area, an emission domain was developed comprised of counties whose emissions were expected to potentially contribute to the modeled concentrations in the urban area based on their proximity to the receptor “grid”. The emission domain was developed by visually examining maps of the area, the location of Federal Reference Method (FRM) monitors, and the urban characteristics. Counties comprising the emission domain for each urban area are shown in each figure.

I.A.2 Receptor Grid

A receptor grid domain was placed at the core of the urban areas, with receptors placed at 1 km spacing across a square (e.g., 36 x 36 km in Birmingham) or rectangular area (e.g., 36 by 108 km in Seattle), depending upon the particular urban area. Given that AERMOD can predict PM2.5 concentrations for each of these receptor locations, this dense network of receptors allows for the prediction of the urban gradient for primary PM2.5 based on the AERMOD model results. Additional receptors were also placed at FRM monitoring sites in order to evaluate the contribution of sources to PM2.5 levels at these monitor locations and effectiveness of controls in progressing towards attainment of alternative NAAQS standard options. The receptor grids for each urban area are shown in each figure.

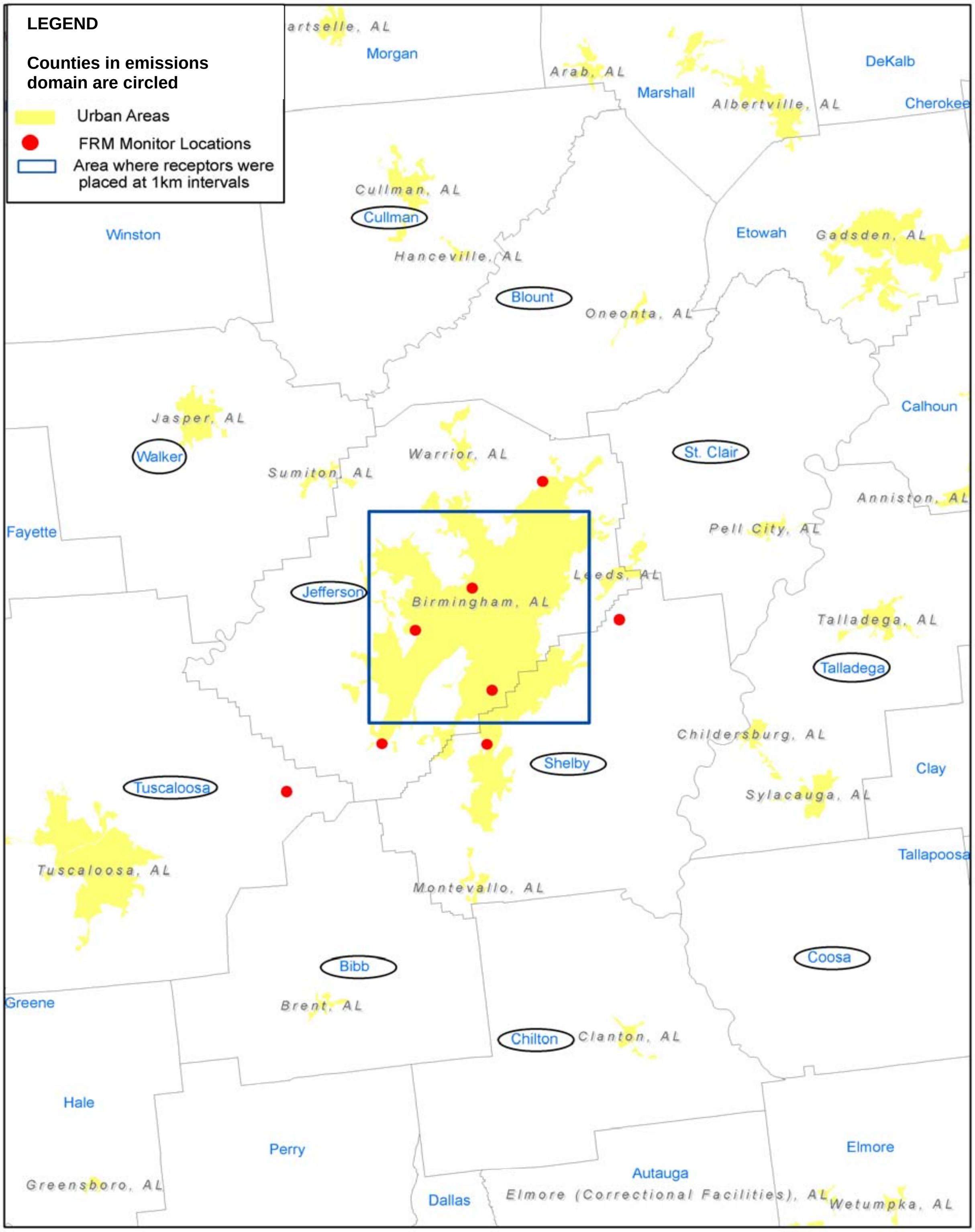

Figure 2: Birmingham Modeling Domain: Emissions Domain by County and Receptor Grid within Urban Area and at Monitoring Sites

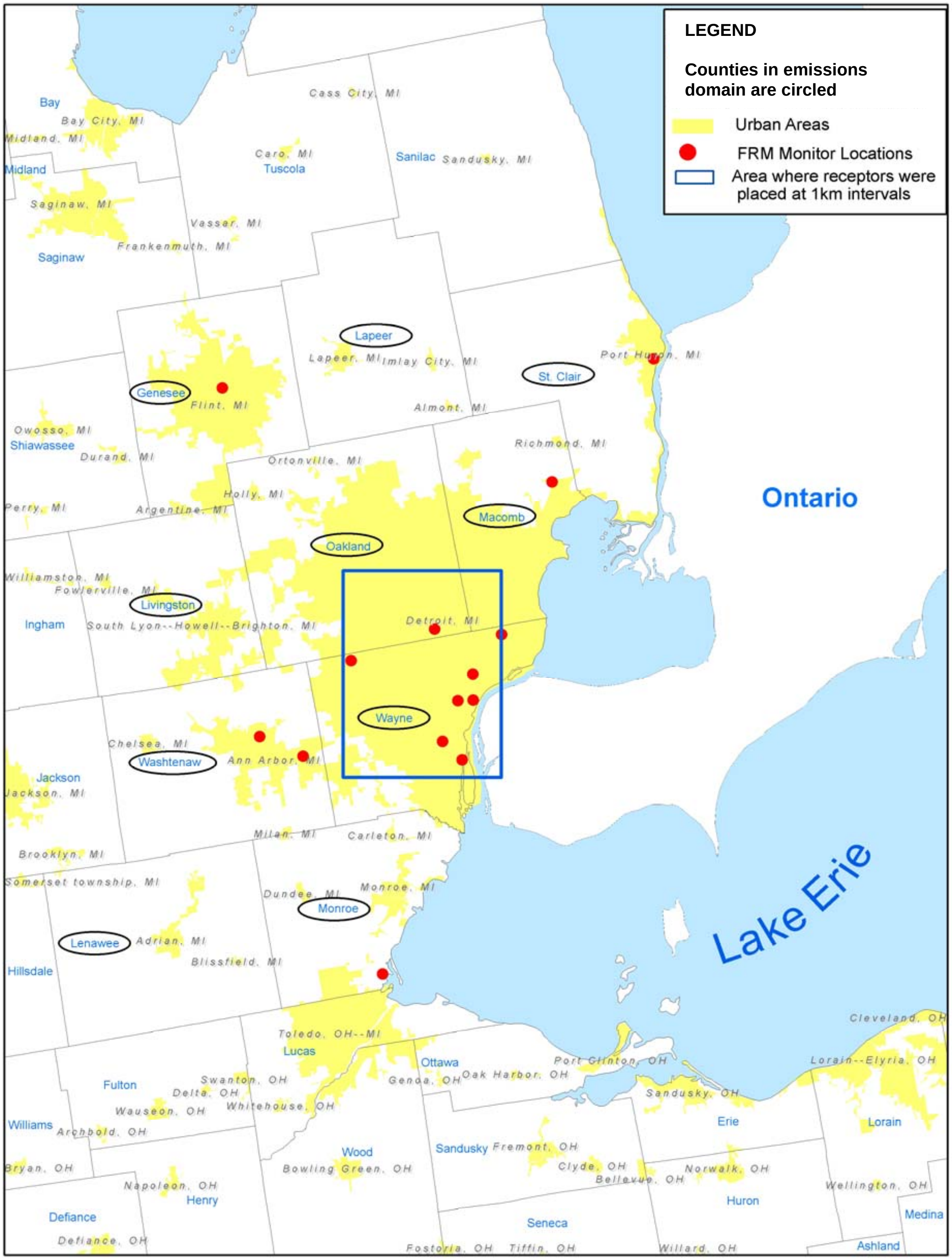

Figure 3: Detroit Modeling Domain: Emissions Domain by County and Receptor Grid within Urban Area and at Monitoring Sites

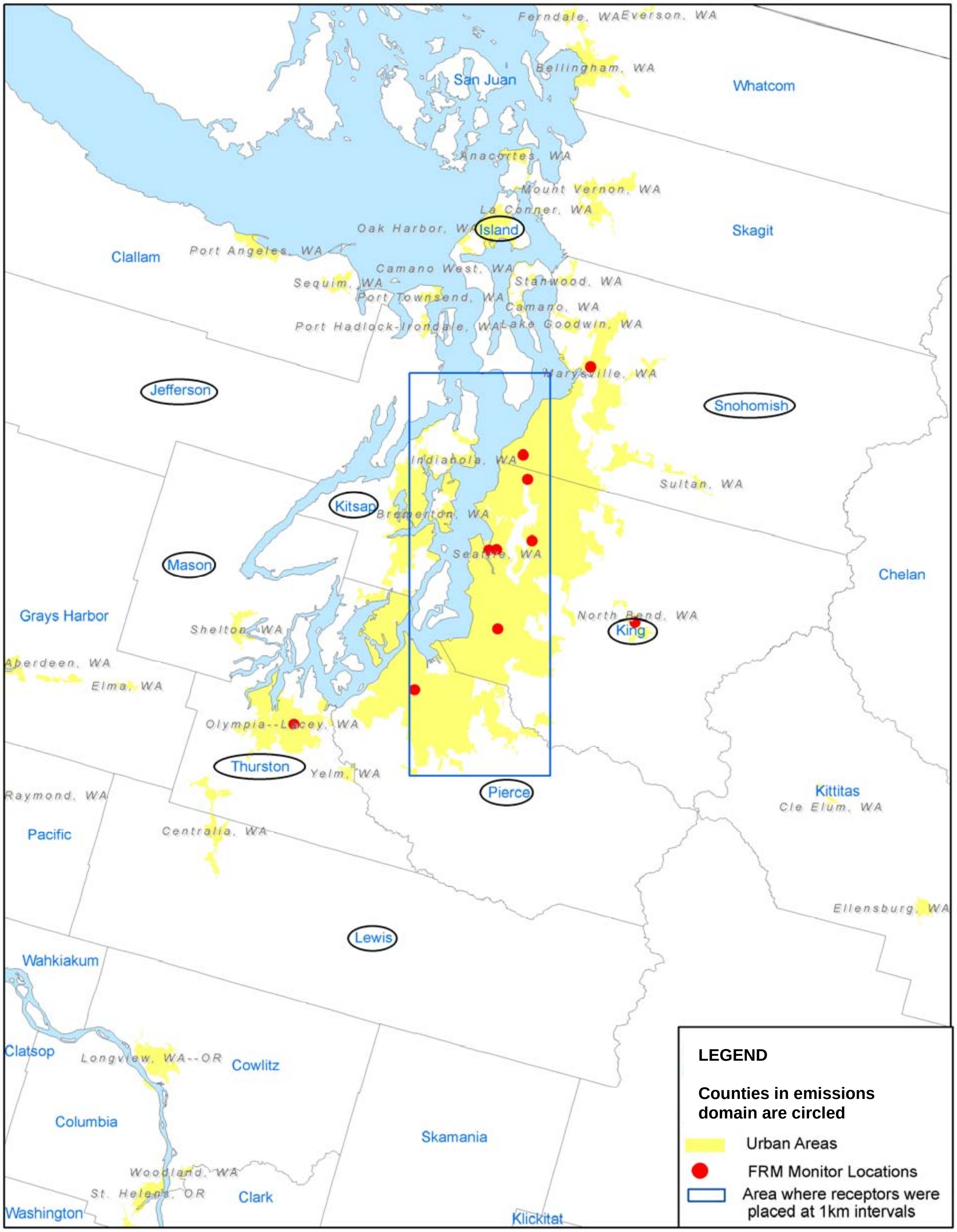

Figure 4: Seattle Modeling Domain: Emissions Domain by County and Receptor Grid within Urban Area and at Monitoring Sites

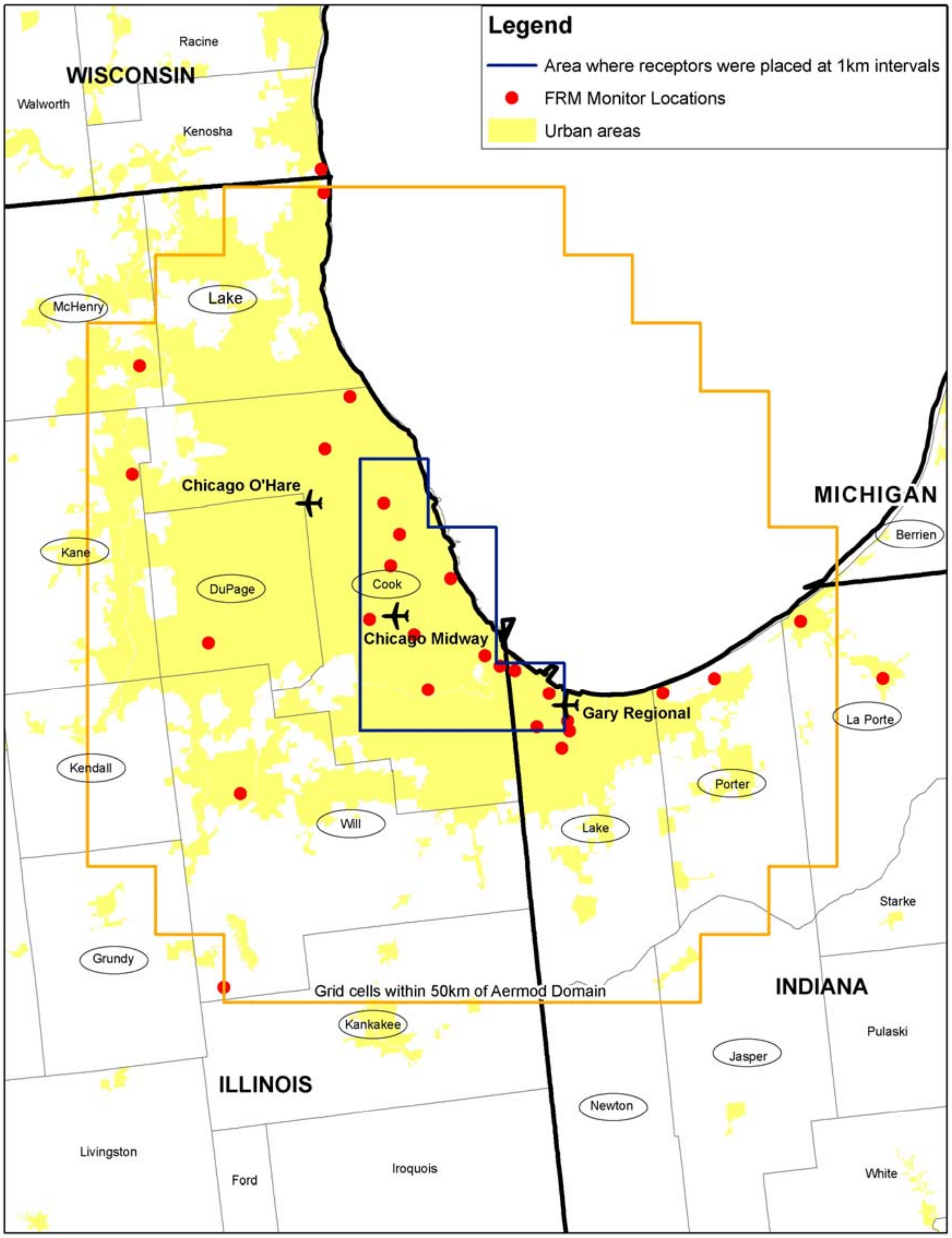

Figure 5: Chicago Modeling Domain: Emissions Domain by County and Receptor Grid within Urban Area and at Monitoring Sites

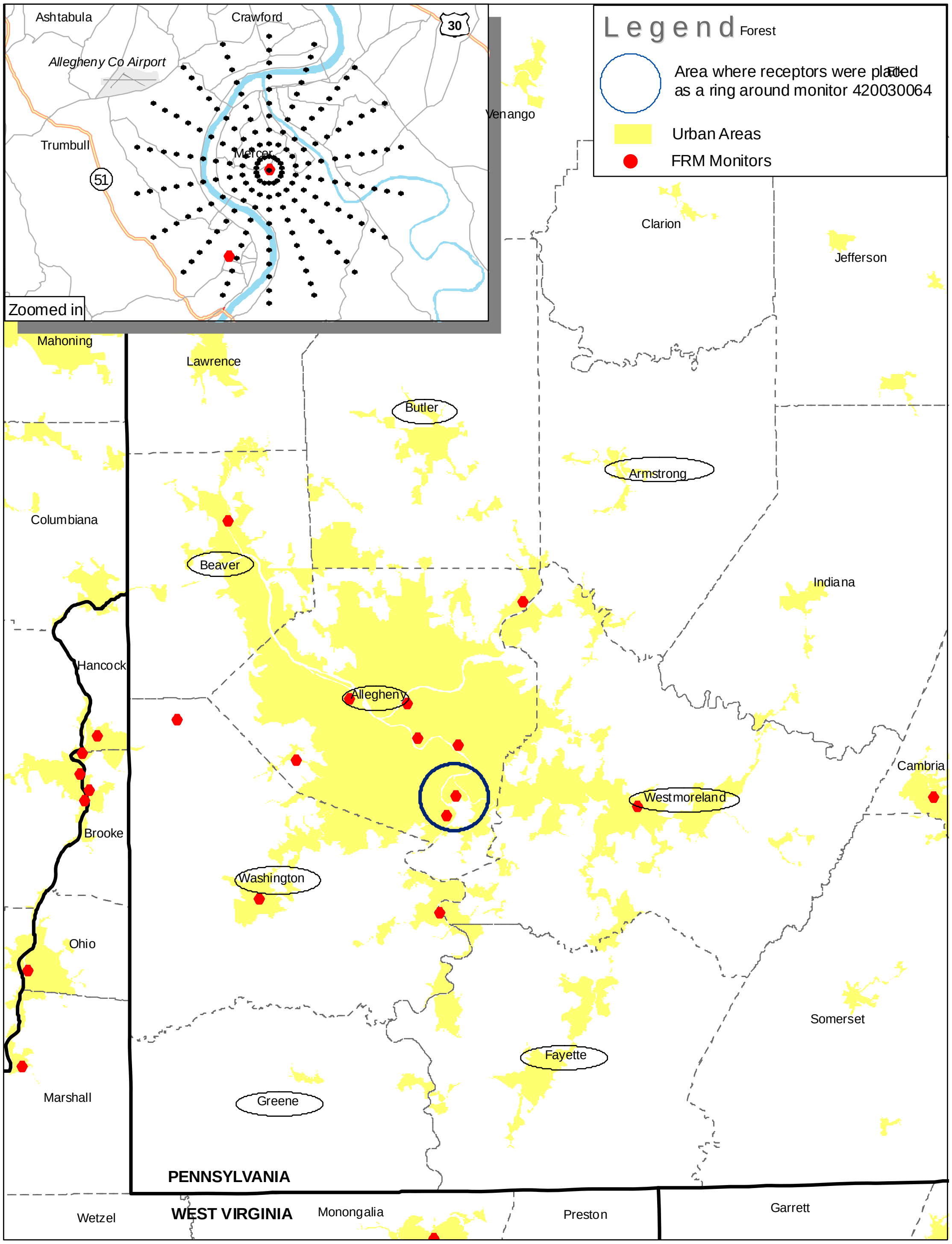

Figure 6: Pittsburh Modeling Domain: Emissions Domain by County and Receptor Grid within Urban Area and at Monitoring Sites

I.B Emissions Inventory and Processing

The emissions input data used for this local-scale modeling are based on the projected 2015 national emissions inventory reflecting implementation of the Clean Air Interstate Rule, the Clean Air Visibility Rule and the Clean Air Mercury Rule (CAIR/CAVR/CAMR http://www.epa.gov/airmarkets/mp/cair_camr_cavr.pdf). This inventory, denoted 2015bi, is consistent with the inventory used in the Community Multiscale Air Quality (CMAQ) photochemical modeling of PM2.5 for this rule. As such, it should be noted that this national-scale inventory is not a local scale inventory in that it does not contain all of the parameters typical for use in a local-scale assessment such as building parameters, fugitive and area source release parameters, and dimensions and locations for individual stacks. In addition, although stack-level emissions are provided for facilities in this national inventory, these estimates do not include detailed site specific stack parameters for all sources because, in many situations, stack parameters were defaulted based on either the process or industrial characterization for the facilities. In lieu of a detailed local scale inventory for each of these areas, we employed the national inventory and accepted its inherent limitations.

The SMOKE modeling system was used to generate temporalized and speciated PM2.5 emissions and sulfuric acid (SULF) from all source sectors emitting these pollutants emissions. The species of PM2.5 emissions generated here are the following:

- PSO4—Primary sulfate,
- PNO3—Primary nitrate,
- POA—Primary organic aerosol,
- PEC—Primary elemental carbon, and
- PMFINE— Primary “other” reflecting the remaining mass not included in above categories.

In addition to the above PM2.5 species, SULF (sulfuric acid), which is generated during SMOKE emissions modeling from SO2, was added to the SMOKE generated PSO4 prior to modeling in AERMOD as this is the approach used in CMAQ modeling.

Table 1 provides the source sectors of primary PM2.5 for the emissions inventory as processed by SMOKE. For each area, the following source sectors were modeled with AERMOD:

- Birmingham—all source sectors
- Detroit—all source sectors
- Seattle—ptipm, ptnonipm and certain oarea (residential wood, commercial cooking and natural gas combustion) and nonroad (airport-related sources and commercial marine vessel).
- Chicago – all source sectors
- Pittsburgh – ptipm, ptnonipm and pfdust (small but included in order to maintain all emissions at the facilities being modeled)

These source sectors (other than pfdust) were selected based on a review of their importance from an emissions standpoint within each urban area (see Table 3 for emissions data by sector).

Table 1. Inventory Sectors of Primary PM2.5 Emission Inventory

SMOKE Inventory Sector	Description
ptipm	Point sources: Electric Generating Units from the IPM 2015 bi case
ptnonipm	Point sources: nonEGU
ptfdust	Point sources: fugitive dust
oarea	Stationary non-point sources excluding fugitive dust and fires (county-level)
afdust	Stationary non-point fugitive dust sources (county-level)
avgfires	Fires–average fires used for wildfires and prescribed burning, and open burning (county-level)
Mobile	Onroad mobile sources (county-level)
Nonroad	Nonroad mobile sources (county-level)

The temporal resolution of the emissions generated from SMOKE was different for different source sectors. For fugitive dust sectors, hourly emissions were provided for a representative day for each season. For avgfires, hourly emissions were provided for a representative day for each month. For all other sectors, hourly emissions were provided from SMOKE for a representative Saturday, Sunday, Monday and Tuesday, as well as any special days, mostly holidays in the month. Tuesday was used as a representative weekday (excluding Monday).

The SMOKE generated hourly emissions for representative days were mapped to every day for the relevant months. For each urban area, emissions for four individual months representing each season, were generated for input into AERMOD as follows:

- Birmingham — February, April, June and September,
- Detroit — January, April, July and November, and
- Seattle — January, April, August and November
- Chicago — January, April, July and October
- Pittsburgh —, January, April, July and October

AERMOD computes concentrations by source groups that can then be used to analyze the relative impacts of different types of emissions sources. We assigned source groups within the SMOKE source sectors listed in Table 1 to capture the relative impacts of more refined source groups. The general approach was to capture the largest facilities (i.e., emissions greater than 50 tons per year in the inventory) and large groups of county-level emissions within the other SMOKE source sectors.

Table 2 shows the detailed source groupings used for each urban area except Pittsburgh as processed by SMOKE in developing model-ready emissions inputs to AERMOD. For Pittsburgh, point sources were individually grouped based on size / location from monitor of interest. As shown, for example, area fugitive dust sector is composed of four sub-groupings including agriculture-related, construction-related, road-related, and other. Furthermore, "IPM" and "nonIPM" source groups in Table 2 are an aggregate of those individual point sources not individually distinguished as a separate stationary point source. Tables 3 and 4 provide sector and county total emission summaries of primary PM2.5 emissions for the emission domains for each area.

Table 2. Detailed source groups used for each urban area in emission processing, Birmingham, Detroit, Seattle, and Chicago

Group Number	SMOKE Inventory Sector	Detailed Source Group
00	IPM	IPM sources not categorized as individual sources
01	non IPM	non IPM sources not categorized as individual sources
02	point fugitive dust	point fugitive dust
03	area fugitive dust	area fugitive dust other (i.e., not agriculture, construction or road-related)
04	area fugitive dust	area fugitive dust, agriculture-related
05	area fugitive dust	area fugitive dust, construction-related
06	area fugitive dust	area fugitive dust, road-related (paved/unpaved roads)
07	nonroad	aircraft
08	nonroad	Commercial marine vessel
09	nonroad	locomotives
10	nonroad	nonroad gasoline
11	nonroad	other nonroad (diesel (not including locomotives), CNG, LPG)
12	mobile	onroad gasoline
13	mobile	onroad diesel
14	avgfires	Wildfires
15	avgfires	prescribed burning
16	avgfires	agricultural burning
17	avgfires	open burning
18	oarea	residential wood burning
19	oarea	commercial cooking
20	oarea	natural gas combustion
21	oarea	residential waste burning
22	oarea	other oarea
41-70	individual IPM sources	individual IPM sources
80-99	individual non IPM sources	individual non IPM sources

Table 3. Sector Emissions Summary for Birmingham, Detroit, Seattle, Chicago, and Pittsburgh AERMOD Emission Domains

	Pollutant Emissions (tons) modeled through AERMOD							
	Sector	**POA**	**PEC**	**PMFINE**	**PNO3**	**PSO4**	**SULF**	**Total PM 2.5**
Birmingham 11-county area	**NonEGU**	1,982	183	6,025	44	2,361	212	10,807
	EGU	1,238	62	3,869	31	990	2,489	8,679
	Afdust	253	20	3,435	3	7	0	3,718
	Other Area	913	163	1,788	4	194	60	3,121
	Average Fire	2,848	451	511	9	63	0	3,883
	Nonroad	297	303	32	3	17	0	651
	On-Road	178	155	56	1	9	0	399
	Pfdust	10	1	154	0	0	0	165
Detroit 10-county area	**EGU**	2,417	121	7,545	60	1,932	5,941	18,016
	Afdust	676	52	9,505	10	18	0	10,261
	Other Area	1,497	181	2,148	4	296	303	4,429
	NonEGU	698	96	1,912	13	874	74	3,668
	Nonroad	822	868	161	7	162	0	2,020
	On-Road	533	431	170	2	27	0	1,164
	Average Fire	338	28	122	1	6	0	495
	Pfdust	1	0	14	0	0	0	15
	Total	6,983	1,777	21,578	96	3,315	6,318	40,067
Seattle 9-county area	**Other Area**	3,128	319	2,488	9	298	23	6,264
	EGU	548	23	1,449	12	395	271	2,698
	Nonroad	882	911	191	7	267	0	2,258
	NonEGU	364	70	1,055	7	536	11	2,043
	Average Fire	1,230	189	234	4	27	0	1,685
	Afdust	96	8	1,206	1	4	0	1,314
	On-Road	403	345	126	1	20	0	896
	Pfdust	0	0	0	0	0	0	0
	Total	6,652	1,865	6,748	41	1,547	306	17,159
Chicago 15-county area	**Other Area**	2,313	210	1,953	6	397	250	5,128
	EGU	123	95	4,447	1	4,662	4,021	13,349
	Nonroad	1,862	1,960	326	16	390	0	4,554
	NonEGU	6,238	346	16,956	355	5,096	221	29,212
	Average Fire	152	12	55	1	3	0	222
	Afdust	549	41	8,388	9	12	0	8,998
	On-Road	741	501	278	2	46	0	1,568
	Pfdust	20	2	222	0	1	0	245
	Total	11,998	3,165	32,626	389	10,606	4,492	63,277

		Pollutant Emissions (tons) modeled through AERMOD						
	Sector	**POA**	**PEC**	**PMFINE**	**PNO3**	**PSO4**	**SULF**	**Total PM 2.5**
Pittsburgh 8-county area (only point sources modeled)	**NonEGU**	614	60	2,152	112	848	35	3,822
	EGU	46	29	1,341	0	196	217	1,828
	Pfdust	1	0	17	0	0	0	19
	Total	661	89	3,510	113	1,044	252	5,669

Table 4. County-level Emissions Summary in Birmingham, Detroit, Chicago, and Pittsburgh AERMOD Emission Domains

		Pollutant Emissions (tons) modeled through AERMOD						
	County	**POA**	**PEC**	**PMFINE**	**PNO3**	**PSO4**	**SULF**	**Total PM 2.5**
Birmingham Counties	Bibb	304	65	191	1	20	1	582
	Blount	231	53	573	1	24	2	885
	Chilton	287	67	337	1	26	4	722
	Coosa	211	46	154	1	12	0	423
	Cullman	317	72	922	2	26	8	1,347
	Jefferson	2,574	392	6,866	45	2,003	1,153	13,034
	St Clair	300	76	492	2	70	3	943
	Shelby	1,196	169	2,531	19	651	652	5,217
	Talladega	510	124	999	4	316	212	2,165
	Tuscaloosa	959	164	766	4	80	21	1,993
	Walker	831	111	2,039	14	414	704	4,112
Detroit Counties	Genesee	399	133	1,570	3	57	35	2,196
	Lapeer	163	57	1,054	1	26	5	1,306
	Lenawee	186	56	1,359	2	26	6	1,635
	Livingston	363	82	1,540	3	62	5	2,056
	Macomb	498	156	1,110	4	98	51	1,916
	Monroe	1,385	160	5,555	34	1,335	2,781	11,250
	Oakland	797	290	1,528	4	94	104	2,818
	St Clair	1,020	160	3,494	20	664	2,020	7,378
	Washtenaw	339	110	1,346	2	47	24	1,868
	Wayne	1,834	574	3,021	23	906	1,287	7,644
Seattle Counties	Island	192	53	466	1	19	0	731
	Jefferson	266	48	219	2	140	1	676
	King	2,171	774	957	10	345	14	4,271
	Kitsap	574	105	680	2	34	2	1,398
	Lewis	866	112	1,844	14	409	215	3,460
	Mason	237	50	277	1	16	1	582
	Pierce	902	319	874	7	435	70	2,606
	Snohomish	951	288	894	4	105	2	2,243
	Thurston	494	116	536	2	44	1	1,193
	Seattle Total	**6,652**	**1,865**	**6,748**	**41**	**1,547**	**306**	**17,159**

.		Pollutant Emissions (tons) modeled through AERMOD						
	County	**POA**	**PEC**	**PMFINE**	**PNO3**	**PSO4**	**SULF**	**Total PM 2.5**
Chicago Counties ***(*=partial county modeled)***	Cook, IL	4,537	1,532	6,071	33	1,931	738	14,842
	DuPage, IL	695	301	1,078	4	91	27	2,196
	Grundy, IL	67	10	229	48	21	2	376
	Kane, IL	516	117	1,555	3	76	12	2,279
	Kankakee, IL	146	26	760	2	25	1	960
	Kendall, IL	110	22	580	1	14	3	730
	Lake, IL	644	194	1,460	4	461	382	3,146
	McHenry, IL	135	29	650	1	38	1	856
	Will, IL	797	212	4,650	8	1,741	1,317	8,724
	Jasper, IN	85	37	1,561	0	985	793	3,462
	Lake, IN	2,167	426	7,416	30	3,628	785	14,452
	La Porte, IN	174	39	788	3	435	293	1,731
	Newton, IN	10	3	76	0	1	0	91
	Porter, IN	1,867	215	5,638	251	1,141	138	9,250
	Pulaski, IN	35	2	15	0	9	0	61
	Starke, IN	2	0	2	0	0	0	5
	Berrien, MI	11	1	96	0	7	0	115
	Chicago Total	**11,998**	**3,165**	**32,626**	**389**	**10,606**	**4,492**	**63,277**
Pittsburgh Counties ***(*=only sources within 50 km of monitor; italics= counties w/ all point sources modeled)***								
	Allegheny	539	65	2,400	10	801	137	3,952
	Armstrong*	2	1	20	0	4	0	27
	Beaver*	2	0	2	0	0	0	4
	Butler*	0	0	1	0	0	0	1
	Fayette*	4	0	37	0	27	0	68
	Greene*	2	0	1	0	1	0	4
	Washington	55	17	879	102	142	114	1,309
	Westmoreland*	56	4	170	1	70	2	304
	Pittsburgh Total	**661**	**89**	**3,510**	**113**	**1,044**	**252**	**5,669**

I.C Meteorological Inputs and Surface Characteristics

Meteorological inputs for AERMOD were generated by AERMET, which is the meteorology pre-processing program that inputs meteorological and surface information to calculate the boundary layer parameters for use by AERMOD to generate profiles of the needed meteorological variables.[5] AERMET uses meteorological measurements representative of the modeling domain to compute certain boundary layer parameters needed to estimate profiles of wind, turbulence and temperature. For this assessment, we used 2001 meteorological observations for each urban area from National Weather Service (NWS) surface and corresponding upper air stations. Table 5 provides information on the NWS station sites that were used as representative of each of the five urban areas. The surface station sites were chosen based on their geographic representation of the area of interest, while the upper air stations were chosen based on their proximity and their meteorological compatibility with the corresponding surface station.

Table 5. Summary of National Weather Service Station Sites For Each Urban Area

WBAN #	Station Name	Lat (degrees)	Lon (degrees)	Elevation (m)
Surface Station Sites				
13876	Birmingham Municipal	+33.57	-86.75	+189
14819	Chicago Midway	+41.78	-87.75	+187
9484	Detroit Metro. Airport	+42.22	-83.35	+194
94823	Pittsburgh	+40.50	-80.23	+351
24233	Seattle-Tacoma Intl	+47.47	-122.32	+122
Upper Air Station Sites				
53823	Birmingham	+33.17	-86.77	
94982	Davenport	+41.60	-90.57	
4830	Detroit/Pontiac	+42.70	-83.47	
94823	Pittsburgh	+40.50	-80.23	
94240	Quillayute	+47.95	-124.55	

AERMET processes the meteorological data in the following three stages:

1) The first stage extracts meteorological data from archive data files and processes the data through various quality assessment checks.
2) The second stage merges all data available for 24-hour periods (NWS and site-specific data) and stores these data together in a single file.
3) The third stage reads the merged meteorological data and estimates the necessary boundary layer parameters for use by AERMOD.

The parameterization of the boundary layer and the dispersion of pollutants within it are influenced on a local scale by surface characteristics such as surface roughness, reflectivity (albedo), and the availability of surface moisture (Bowen ratio).

These surface characteristics depend on land-use type (e.g., urban area, deciduous/coniferous forest, cultivated land, calm waters) and vary with the seasons and wind direction. We used land use data at a 30m resolution from the National Land Cover Dataset (NLCD) provided by USGS and the Earth Resources Observation & Science (EROS).[1] Based on this data, Table 6 provides the percentage of each dense receptor domain falling in each of seven land use categories.

[1] Descriptions of this data can be found at http://landcover.usgs.gov/natllandcover.asp and data can be downloaded at http://edcftp.cr.usgs.gov/pub/data/landcover/states/.

Table 6: Distribution of Land Use within Modeling Domain for each Urban Area

Land Use Category		Percent of Domain (%)				
NLCD Land Use Category[1]	AERMET Land Use Category[2]	Birmingham	Chicago	Detroit	Pittsburgh	Seattle
Commercial/Industrial/Transportation	Industrial (Urban)	20	12	34	3	20
Low & High Intensity Residential	Residential (Urban)	50	81	42	11	55
Deciduous Forest & Mixed Forest[3]	Deciduous Forest	20	3	10	41	7
Evergreen Forest & Mixed Forest[3]	Coniferous Forest	5	0	0	2	7
Grasslands/Herbaceous, Pasture Hay, Row Crops, Small Grains & Fallow	Cultivated Land	5	3	6	35	5
Open Water	Water[4]	0	0	2	8	6
Woody Wetlands & Emergent Herbaceous Wetlands	Swamp	0	1	6	0	0

[1] NLCD land use categories not listed in the table were either not present or minimally represented in the domain.
[2]The surface roughness values for the industrial (1m) and residential (0.5m) land use categories were taken from the CALPUFF User's Guide and the same values were applied for all four seasons. The seasonal albedo and Bowen ratio values were taken from the AERMET User's Guide for urban land use.
[3]For areas labeled by NLCD as mixed forest, 50% of the area was listed as being deciduous forest and 50% as coniferous forest.
[4]To avoid biasing the surface roughness low, the water land use category was incorporated as the percentage of land bordering water, instead of the percentage of the actual domain covered by water.

After having determined the land use categories describing each dense receptor grid and the associated surface characteristic values for each of these categories, we calculated the seasonal surface characteristic values for each area as shown in Table 7.

Table 7: Surface Characteristics Used in AERMET for each Urban Area.

Urban Area	Season	Albedo	Bowen Ratio	Roughness (m)
Birmingham	Winter	0.40	0.5	0.62
	Spring	0.14	0.4	0.72
	Summer	0.15	0.8	0.79
	Fall	0.16	0.8	0.68
Chicago	Winter	0.36	1.5	0.93
	Spring	0.14	1.0	0.95
	Summer	0.16	1.9	0.96
	Fall	0.18	1.9	0.94

Detroit	Winter	0.37	1.5	0.61
	Spring	0.14	0.9	0.66
	Summer	0.16	1.6	0.70
	Fall	0.17	1.7	0.65
Pittsburgh	Winter	0.48	0.9	0.31
	Spring	0.09	0.4	0.52
	Summer	0.09	0.4	0.64
	Fall	0.10	0.7	0.44
Seattle	Winter	0.36	1.5	0.61
	Spring	0.14	0.9	0.64
	Summer	0.15	1.6	0.67
	Fall	0.17	1.7	0.62

Note: Winter corresponds to December, January and February; Spring corresponds to March, April and May; Summer corresponds to June, July and August; and Fall corresponds to September, October and November.

In addition to the boundary layer parameters, AERMET passes all meteorological measurements of wind, temperature, and turbulence in a form AERMOD needs. Meteorological data for each area were processed by AERMET for the following months:

- Birmingham — February, April, June and September,
- Detroit — January, April, July and November, and
- Seattle — January, April, August and November.
- Chicago—January, April, July, and October.
- Pittsburgh— January, April, July, and October.

Tables 8 through 12 provide 2001 monthly summary statistics for meteorological variables for each of these urban areas.

Table 8. Monthly Summary Statistics for Meteorological Variables in Birmingham: 2001.

MET Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Avg. Daily Temp (^{0}F)	40.1	51.0	49.7	64.5	70.5	75.3	80.1	78.5	71.6	60.6	58.6	49.3	62.5
Total Precipitation (in)	5.2	4.4	8.4	7.3	5.3	7.5	3.6	7.4	6.3	2.4	4.2	4.8	66.7
Mean Wind Speed (mph)	5.9	6.8	7.7	6.9	5.4	5.0	4.5	4.2	4.7	5.5	5.0	6.2	5.7
Prevailing Wind Direction	NW	N	N	SW	SW	SE	N	NE	NE	SE	SE	N	N

Table 9. Monthly Summary Statistics for Meteorological Variables in Detroit: 2001.

MET Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Avg. Daily Temp (⁰F)	26.2	29.7	35.1	51.2	61.2	69.6	73.6	74.1	62.3	52.5	47.6	35.9	51.6
Total Precipitation (in)	0.7	2.9	0.9	3.2	3.7	3.4	1.2	2.9	4.3	6.8	2.4	2.2	34.5
Mean Wind Speed (mph)	9.5	11.0	9.7	9.8	8.6	7.4	7.6	7.5	8.2	11.0	9.9	10.2	9.2
Prevailing Wind Direction	SW	NW	NW	E	SW	S	NE	S	NE	SW	SW	SW	SW

Table 10. Monthly Summary Statistics for Meteorological Variables in Seattle: 2001.

MET Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Avg. Daily Temp (⁰F)	42.0	40.7	45.4	48.0	55.4	57.6	62.5	64.8	59.8	50.9	46.7	41.5	51.3
Total Precipitation (in)	2.7	2.1	2.7	3.2	1.4	3.1	1.0	2.3	0.8	3.1	9.3	5.9	37.6
Mean Wind Speed (mph)	6.8	6.8	7.7	7.5	6.4	6.0	5.5	5.6	5.0	7.9	7.1	9.3	6.8
Prevailing Wind Direction	SE	N	SW	SW	SW	SW	SW	SW	N	SW	SW	SE	SW

Table 11. Monthly Summary Statistics for Meteorological Variables in Chicago: 2001.

MET Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Avg. Daily Temp (⁰F)	24.6	26.1	34.2	52.5	60.0	67.4	74.6	73.2	61.9	52.1	48.2	43.4	50.7
Total Precipitation (in)	1.1	2.6	1.3	2.8	3.3	2.6	3.0	12.3	6.1	8.5	1.2	1.0	45.8
Mean Wind Speed (mph)	9.4	10.5	10.3	11.3	9.2	7.6	7.4	7.5	8.3	10.4	9.4	9.6	9.2
Prevailing Wind Direction	SW	W	NE	SW	SW	SW	SW	SW	NE	W	SW	W	W

Table 12. Monthly Summary Statistics for Meteorological Variables in Pittsburgh: 2001.

MET Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Avg. Daily Temp (^{0}F)	28.4	35.1	35.3	54.3	60.0	68.4	70.2	73.1	62.1	54.2	48.2	37.5	52.5
Total Precipitation (in)	1.4	1.1	3.3	3.8	2.1	3.4	3.2	7.1	2.2	2.3	3.5	2.4	35.7
Mean Wind Speed (mph)	7.3	9.5	9.5	8.3	6.6	5.7	6.2	5.4	6.1	8.2	6.8	7.7	7.3
Prevailing Wind Direction	WSW	WNW	W	SW	ESE	WSW	SW	SW	N	SSW	SSW	SW	SW

I.D Terrain and Elevation Inputs

Terrain and elevation inputs were generated by AERMAP, which is a terrain pre-processor program to AERMOD that reads terrain data from United States Geological Survey (USGS) Digital Elevation Model (DEM) files. Receptor, monitor, and source locations are read into AERMAP to calculate the approximate elevation for each location as well as critical hill height values for each receptor.

The terrain around Birmingham, Detroit , Seattle, Chicago, and Pittsburgh was examined to determine whether or not terrain data was required for AERMOD simulations, i.e.,

- Birmingham lies at the southern end of the Appalachian Mountain chain. The area consists of valleys and ridges that run generally northeast to southwest. Differences in elevations between valley floors and the surrounding ridge tops are on the order of several hundred feet and so would require terrain as part of the analysis.

- Detroit is on the western side of the Detroit River that flows between Lake St. Clair and Lake Erie. The terrain is relatively flat with a variation of less than 100 feet between minimum and maximum elevations in and around the Detroit area. An area of rolling hills lies in a west-southwest to east-northeast direction with the closest hills located about 20 miles away to the north-northwest of the city.

- Seattle lies along the eastern shore of Puget Sound. On the western shore, mountains rise up to over 7,000 feet. To the east, the terrain rises into the Cascade Mountains where mountain heights are generally over 7,000 feet. These mountain ranges are oriented north-south and are about 40 miles away from Seattle.

- Pittsburgh lies in the foothills of the Allegheny Mountains at the confluence of the Allegheny and Monongahela Rivers. River valleys are very steep sided with numerous cliffs and sharp drop-offs. Differences in elevation between the river bottom and plateau tops are on the order of several hundred feet. There are many streams cutting through the plateau; feeding the three major rivers in the area.

- Chicago is located along the southwestern shore of Lake Michigan on top of the glacial moraine left over from the last Ice Age. The terrain is very flat with differences measured in tens of feet over large distances.

Where terrain is significant, AERMOD needs to account for terrain effects on air dispersion. Therefore, we prepared terrain data for Birmingham and Seattle and it was preprocessed through AERMAP. Detroit, Chicago, and Pittsburgh were modeled as flat terrain and therefore did not require any preprocessing from AERMAP.

II. Modeling Results

This section provides results of the local-scale modeling for each urban area. We determined percent reductions for the specific groups modeled using the same data used in the CMAQ modeling for 15/65, 15/35 and 14/35 scenarios. The modeling shows large spatial concentration gradients within the urban areas that are not predicted by the regional-scale, photochemical grid modeling (i.e., CMAQ). Therefore, the local modeling provides important complementary modeling results in evaluating the ability of areas to attain future PM2.5 standards. The results indicate that primary PM2.5 emissions from local sources are a significant contributor to PM2.5 concentrations. The most influential sources varied by receptor location depending on proximity to sources, especially in the case of the daily standard.

This assessment shows that controls on primary PM2.5 emissions from local sources can play an important role in attaining the PM2.5 standards. It demonstrates that known controls can provide significant reductions in incremental concentrations of PM2.5 required to meet an annual and daily standard. The following sections provide the detailed modeling results for each area including tables with source contributions of primary PM2.5 to monitors of interest (i.e., potential annual and daily exceedences of proposed standard) and graphs illustrating the spatial gradient of primary PM2.5 for the urban area.

Birmingham

Tables 15 and 16 show the AERMOD modeling results for primary PM2.5 impacts at monitor locations in Jefferson County exceeding the proposed annual (15 ug/m^3) and daily (35 ug/m^3) standards, respectively. In addition, Figure 7 provides the spatial gradient of primary PM2.5 for the urban area associated with emissions from all sources. For the annual standard, as shown in Table 15, the Jefferson County monitor #10730023 is expected to exceed 15 ug/m^3 by 0.99 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 4.8 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 1.2 ug/m^3 reduction with no additional controls for 15/35 or 14/35. Metal processing, mineral/rock wool manufacturing, and other industrial sources contribute significantly to this monitor with a combined contribution of 2.6 ug/m^3 of the 4.8 ug/m^3 total contribution from all modeled sources, or 55 percent. Table 15 also shows that the Jefferson County monitor #10732003 is expected to exceed 15 ug/m^3 by roughly 1.2 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 4.3 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 1.8 ug/m^3 reduction in annual PM2.5 concentrations here with no additional controls for 15/35 or 14/35. Metal processing and other industrial sources contribute significantly to this monitor with a combined contribution of 2.84 ug/m^3 of the 4.3 ug/m^3 total contribution from all modeled sources, or 66 percent. The AERMOD predicted reductions in primary PM2.5 presented here for each of these monitors is 3 to 5 times greater than the CMAQ prediction for Jefferson County which was roughly 0.36 ug/ m^3 for the 15/65 scenario.

For the daily standard, as shown in Table 16, the Jefferson County monitor #10732003 is expected to exceed 35 ug/m^3 by 3.4 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 10.3 ug/m^3 to this monitor location, and that the application of controls for the 15/65 scenario would yield a 5.6 ug/m^3 reduction in PM2.5 concentrations here with no additional controls for 15/35 and 14/35. As with the annual concentrations at this monitor, the most significant contributors are metal processing and other industrial sources in addition to point fugitive dust.

Table 15. Summary of Modeled Source Contributions of Primary PM2.5 to Monitors with Potential Annual Exceedences in Birmingham: 2015

Source Sectors	Primary PM2.5 Emissions (ton/yr)	Model Predicted Annual Concentrations (ug/m3)			
		Primary PM2.5 Contribution	15/65 Control Scenario	15/35 Control Scenario	14/35 Control Scenario
Jefferson County Monitor #10730023, Annual DV = 15.99**					
Metal Processing	5,109	1.509	0.521	0.000	0.000
Mineral/Rock Wool	409	0.753	0.000	0.000	0.000
Other industrial sources	1,630	0.380	0.352	0.000	0.000
Point fugitive dust	166	0.352	0.000	0.000	0.000
Other area	686	0.328	0.000	0.000	0.000
Commercial cooking	285	0.261	0.000	0.000	0.000
Mining	1,242	0.252	0.245	0.000	0.000
Area fugitive dust	3,717	0.244	0.000	0.000	0.000
Nonroad (gasoline and diesel)	505	0.148	0.039	0.000	0.000
Onroad (gasoline and diesel)	400	0.115	0.000	0.000	0.000
Residential wood burning	927	0.096	0.000	0.000	0.000
Prescribed/open burning	2,461	0.080	0.000	0.000	0.000
CMV, Aircraft, Locomotive	146	0.069	0.034	0.000	0.000
Power Sector	8,679	0.057	0.000	0.000	0.000
Wildfires	1,404	0.041	0.000	0.000	0.000
Paper and Forest Products	1,115	0.030	0.000	0.000	0.000
Natural gas combustion*	1,196	0.026	0.000	0.000	0.000
Residential waste burning	28	0.025	0.000	0.000	0.000
Cement Manufacturing	617	0.013	0.000	0.000	0.000
Structural Clay and Bricks	249	0.009	0.009	0.000	0.000
Agricultural burning	18	0.000	0.000	0.000	0.000
Total, All Sources	30,989	4.787	1.201	0.000	0.000
Jefferson County Monitor #10732003, Annual DV = 16.22					
Metal Processing	5,109	2.543	1.369	0.000	0.000
Other industrial sources	1,630	0.299	0.260	0.000	0.000
Area fugitive dust	3,717	0.228	0.000	0.000	0.000
Point fugitive dust	166	0.209	0.000	0.000	0.000
Other area	686	0.156	0.000	0.000	0.000
Commercial cooking	285	0.129	0.000	0.000	0.000
Mining	1,242	0.128	0.116	0.000	0.000
Prescribed/open burning	2,461	0.094	0.000	0.000	0.000
Nonroad (gasoline and diesel)	505	0.081	0.015	0.000	0.000
Onroad (gasoline and diesel)	400	0.070	0.000	0.000	0.000
Power Sector	8,679	0.065	0.000	0.000	0.000
Mineral/Rock Wool	927	0.058	0.000	0.000	0.000
Residential wood burning	1,404	0.048	0.000	0.000	0.000
Wildfires	409	0.048	0.000	0.000	0.000
CMV, Aircraft, Locomotive	146	0.033	0.018	0.000	0.000
Structural Clay and Bricks	1,196	0.024	0.000	0.000	0.000
Residential waste burning	249	0.023	0.023	0.000	0.000
Cement Manufacturing	1,115	0.017	0.000	0.000	0.000
Paper and Forest Products	617	0.016	0.000	0.000	0.000
Natural gas combustion*	28	0.014	0.000	0.000	0.000
Agricultural burning	18	0.000	0.000	0.000	0.000
Total, All Sources	30,989	4.283	1.800	0.000	0.000

*Natural gas combustion emissions are adjusted here to reflect 94 percent reduction in baseline emissions due to new emissions factor.
**Major point sources adjusted to reduce overestimate bias and better reflect incremental contribution to this monitor.

Table 16. Summary of Modeled Source Contributions of Primary PM2.5 to Monitors with Potential Daily Exceedences in Birmingham: 2015

Source Sectors	Primary PM2.5 Emissions (ton/yr)	Model Predicted Daily Concentrations (ug/m3)* Primary PM2.5 Contribution	15/65 Control Scenario	15/35 Control Scenario	14/35 Control Scenario
Jefferson County Monitor #10732003, Daily DV = 38.4**					
Metal Processing	5,109	8.233	5.242	0.000	0.000
Point fugitive dust	166	0.964	0.000	0.000	0.000
Other industrial sources	1,630	0.308	0.237	0.000	0.000
Area fugitive dust	3,717	0.158	0.000	0.000	0.000
Residential wood burning	927	0.124	0.000	0.000	0.000
Other area sources	686	0.110	0.000	0.000	0.000
Commercial cooking	285	0.087	0.000	0.000	0.000
Structural Clay and Bricks	400	0.057	0.000	0.000	0.000
Onroad (gasoline and diesel)	505	0.051	0.007	0.000	0.000
Nonroad (gasoline and diesel)	1,404	0.050	0.000	0.000	0.000
Wildfires	249	0.046	0.046	0.000	0.000
Cement Manufacturing	2,461	0.038	0.000	0.000	0.000
Prescribed/open burning	617	0.031	0.000	0.000	0.000
CMV, Aircraft, Locomotive	146	0.026	0.016	0.000	0.000
Natural Gas Combustion	1,242	0.011	0.006	0.000	0.000
Mining	1,196	0.009	0.000	0.000	0.000
Residential waste burning	8,679	0.003	0.000	0.000	0.000
Mineral/Rock Wool	409	0.003	0.000	0.000	0.000
Power Sector	1,115	0.001	0.000	0.000	0.000
Paper and Forest Products	18	0.001	0.000	0.000	0.000
Agricultural burning	28	0.001	0.000	0.000	0.000
Total, All Sources	30,989	10.315	5.554	0.000	0.000

*Natural gas combustion emissions are adjusted here to reflect 94 percent reduction in baseline emissions due to new emissions factor.
**Daily results reflect the 98th percentile day or the 3rd highest day modeled with AERMOD so for monitor #10732003 that day is Feb 14th.

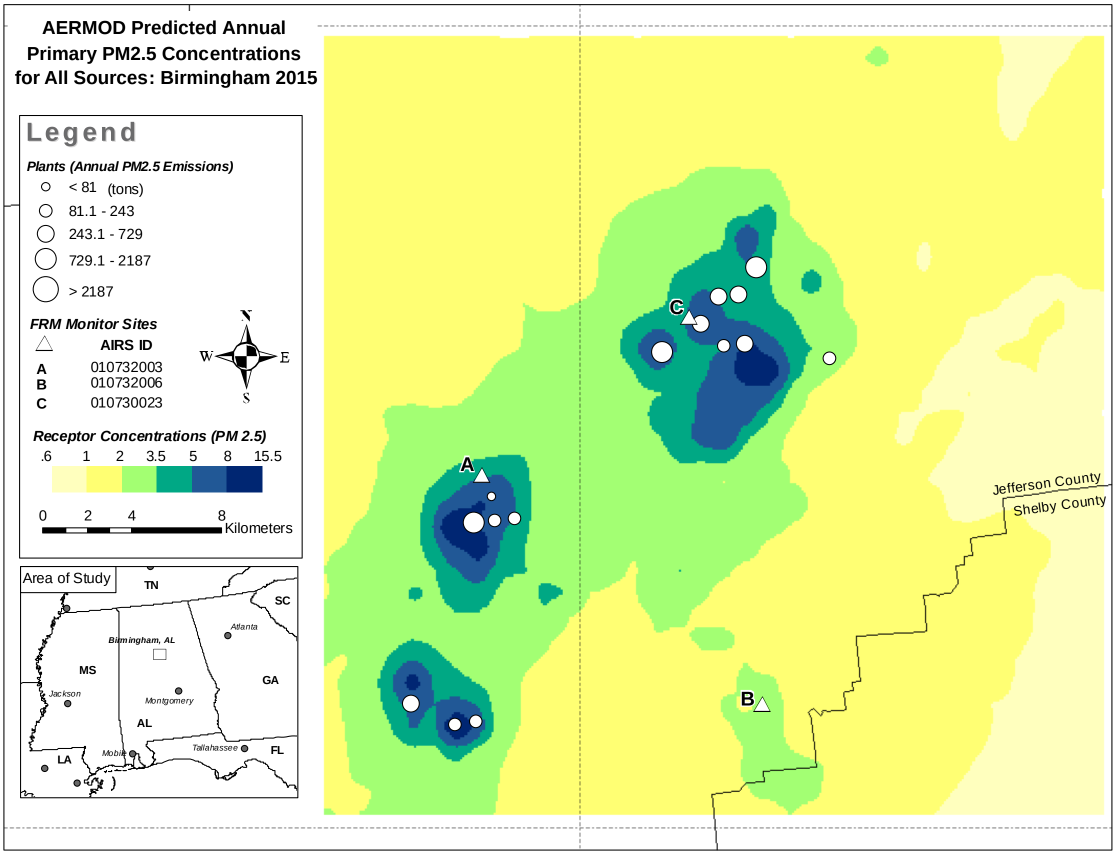

Figure 7. Spatial Gradient in Birmingham, AL of AERMOD Predicted Annual Primary PM2.5 Concentrations (ug/m^3) for All Sources: 2015
Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

Detroit

Tables 17 and 18 show the AERMOD modeling results for primary PM2.5 impacts at monitor locations in Wayne County exceeding the proposed annual (15 ug/m^3) and daily (35 ug/m^3) standards, respectively. In addition, Figure 8 provides the spatial gradient of primary PM2.5 for the urban area associated with emissions from all sources. For the annual standard, as shown in Table 17, the Wayne County monitor #261630033 is expected to exceed 15 ug/m^3 by 2.4 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 3.3 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 0.56 ug/m^3 reduction in PM2.5 concentrations. The modeling results indicate little additional reductions at this monitor for the 15/35 scenario but an additional 0.46 ug/m^3 reduction in PM2.5 concentrations for the 14/35 scenario. Table 17 also shows that Wayne County monitor #261630015 is expected to exceed 15 ug/m^3 by roughly 0.7 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 3.0 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 0.55 ug/m^3 reduction in PM2.5 concentrations here. Table 17 shows little additional reductions for the 15/35 scenario but an additional 0.32 ug/m^3 reduction in PM2.5 concentrations for the 14/35 scenario.

Based on application of the 15/65 control set in Detroit, AERMOD predicted reductions in annual direct PM2.5 that were roughly 2 times higher than that predicted by CMAQ, i.e., a reduction in predicted direct PM2.5 concentrations by 0.56 µg/m^3 versus 0.26 µg/m^3. The models produced similar reductions in direct PM2.5 concentrations for the 15/35 control set, i.e., a reduction in predicted direct PM2.5 concentrations by 0.043 µg/m^3 versus 0.057 µg/m^3. For the 14/35 control set, the AERMOD predicted reductions were again higher than the CMAQ predictions like the 15/65 control set. The difference in results here are due to the nature of the controls so that when controls are applied to stationary point sources there will be greater differences while controls applied to more dispersed sources like area and mobile will result in more similar results.

Table18 summarizes the AERMOD daily concentrations at monitors expected to exceed 35 ug/m^3 in 2015. As shown in the table, the Wayne County monitor #261630033, which shows the highest daily design value (DV), is expected to exceed 35 ug/m^3 by 4.1 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 6.4 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 1.3 ug/m^3 reduction in PM2.5 concentrations. Table 18 shows little additional reductions for the 15/35 scenario but an additional 0.97 ug/m^3 reduction in PM2.5 concentrations for the 14/35 scenario. Results are also shown for Wayne County monitor #261630015 and indicate similar impacts of the 15/65 and 15/35 control sets but additional reductions under the 14/35 control set.

Table 17. Summary of Modeled Source Contributions of Primary PM2.5 to Monitors with Potential Annual Exceedences in Detroit: 2015

Source Sectors	Primary PM2.5 Emissions (ton/yr)	Model Predicted Annual Concentrations (ug/m3)			
		Primary PM2.5 Contribution	15/65 Control Scenario	15/35 Control Scenario	14/35 Control Scenario
Wayne County Monitor #261630033, Annual DV = 17.4					
Other industrial sources	1,375	0.712	0.171	0.000	0.222
CMV, Aircraft, Locomotive	638	0.540	0.191	0.000	0.000
Metal Processing	852	0.484	0.037	0.000	0.000
Onroad (gasoline and diesel)	1,187	0.336	0.000	0.025	0.025
Commercial cooking	984	0.271	0.050	0.000	0.000
Area fugitive dust	10,270	0.237	0.000	0.000	0.000
Power Sector	18,016	0.233	0.059	0.000	0.014
Other area	888	0.210	0.000	0.000	0.168
Nonroad (gasoline and diesel)	1,603	0.197	0.033	0.019	0.019
Natural gas combustion	119	0.034	0.000	0.000	0.000
Residential wood burning	703	0.026	0.005	0.000	0.000
Residential waste burning	1,741	0.015	0.000	0.000	0.007
Glass Manufacturing	334	0.010	0.000	0.000	0.000
Cement Manufacturing	700	0.009	0.009	0.000	0.000
Auto Industry	413	0.005	0.000	0.000	0.000
Prescribed/open burning	444	0.004	0.000	0.000	0.003
Point fugitive dust	15	0.001	0.000	0.000	0.000
Wildfires	51	0.001	0.000	0.000	0.000
Total, All Sources	40,333	3.324	0.556	0.043	0.459
Wayne County Monitor #261630015, Annual DV = 15.69					
CMV, Aircraft, Locomotive	638	0.727	0.257	0.000	0.000
Metal Processing	852	0.399	0.031	0.000	0.000
Other industrial sources	1,375	0.395	0.094	0.000	0.125
Commercial cooking	984	0.365	0.068	0.000	0.000
Power Sector	18,016	0.311	0.064	0.000	0.031
Onroad (gasoline and diesel)	1,187	0.214	0.000	0.016	0.016
Area fugitive dust	10,270	0.183	0.000	0.000	0.000
Other area	888	0.154	0.000	0.000	0.123
Nonroad (gasoline and diesel)	1,603	0.147	0.025	0.014	0.014
Residential wood burning	703	0.024	0.005	0.000	0.000
Residential waste burning	1,741	0.013	0.000	0.000	0.007
Glass Manufacturing	334	0.009	0.000	0.000	0.000
Cement Manufacturing	700	0.008	0.008	0.000	0.000
Auto Industry	413	0.005	0.000	0.000	0.000
Prescribed/open burning	444	0.003	0.000	0.000	0.003
Natural gas combustion	119	0.002	0.000	0.000	0.000
Point fugitive dust	15	0.001	0.000	0.000	0.000
Wildfires	51	0.000	0.000	0.000	0.000
Total, All Sources	40,333	2.962	0.550	0.030	0.319

*Natural gas combustion source category results are adjusted to reflect new emissions factor (94 percent reduction).

Table 18. Summary of Modeled Source Contributions of Primary PM2.5 to Monitors with Potential Daily Exceedences in Detroit: 2015

		Model Predicted Daily Concentrations (ug/m3)*			
Source Sectors	**Primary PM2.5 Emissions (ton/yr)**	**Primary PM2.5 Contribution**	**15/65 Control Scenario**	**15/35 Control Scenario**	**14/35 Control Scenario**
	Wayne County Monitor #261630033, Daily DV = 39.06**				
Power Sector	18,016	0.896	0.344	0.000	0.021
Metal Processing	852	0.623	0.048	0.000	0.000
Cement Manufacturing	700	0.024	0.024	0.000	0.000
Glass Manufacturing	334	0.025	0.000	0.000	0.000
Auto Industry	413	0.014	0.000	0.000	0.000
Other industrial sources	1,375	1.691	0.378	0.000	0.579
CMV, Aircraft, Locomotive	638	0.833	0.297	0.000	0.000
Nonroad (gasoline and diesel)	1,603	0.296	0.041	0.030	0.030
Onroad (gasoline and diesel)	1,187	0.475	0.000	0.035	0.035
Residential waste burning	1,741	0.022	0.000	0.000	0.011
Residential wood burning	703	0.038	0.008	0.000	0.000
Commercial cooking	984	0.587	0.109	0.000	0.000
Prescribed/open burning	444	0.006	0.000	0.000	0.005
Wildfires	51	0.000	0.000	0.000	0.000
Area fugitive dust	10,270	0.522	0.000	0.000	0.000
Point fugitive dust	15	0.002	0.000	0.000	0.000
Other area	888	0.362	0.000	0.000	0.289
Natural gas combustion	119	0.003	0.000	0.000	0.000
Total, All Sources	40,333	6.418	1.250	0.065	0.970
	Wayne County Monitor #261630015, Daily DV = 38.6**				
Power Sector	18,016	0.730	0.149	0.000	0.083
Metal Processing	852	1.604	0.123	0.000	0.000
Cement Manufacturing	700	0.003	0.003	0.000	0.000
Glass Manufacturing	334	0.008	0.000	0.000	0.000
Auto Industry	413	0.003	0.000	0.000	0.000
Other industrial sources	1,375	0.844	0.264	0.000	0.153
CMV, Aircraft, Locomotive	638	2.082	0.725	0.000	0.000
Nonroad (gasoline and diesel)	1,603	0.118	0.017	0.012	0.012
Onroad (gasoline and diesel)	1,187	0.189	0.000	0.014	0.014
Residential waste burning	1,741	0.021	0.000	0.000	0.011
Residential wood burning	703	0.015	0.003	0.000	0.000
Commercial cooking	984	0.534	0.099	0.000	0.000
Prescribed/open burning	444	0.005	0.000	0.000	0.004
Wildfires	51	0.000	0.000	0.000	0.000
Area fugitive dust	10,270	0.159	0.000	0.000	0.000
Point fugitive dust	15	0.003	0.000	0.000	0.000
Other area	888	0.160	0.000	0.000	0.128
Natural gas combustion	119	0.024	0.000	0.000	0.000
Total, All Sources	40,333	6.502	1.383	0.026	0.406

*Natural gas combustion source category results are adjusted to reflect new emissions factor (94 percent reduction).
**Each daily results reflects the 98th percentile day or the 3rd highest day modeled with AERMOD so for monitor #261630015 that day is Nov 18th, for monitor #261630033 that day is Jan 1st.

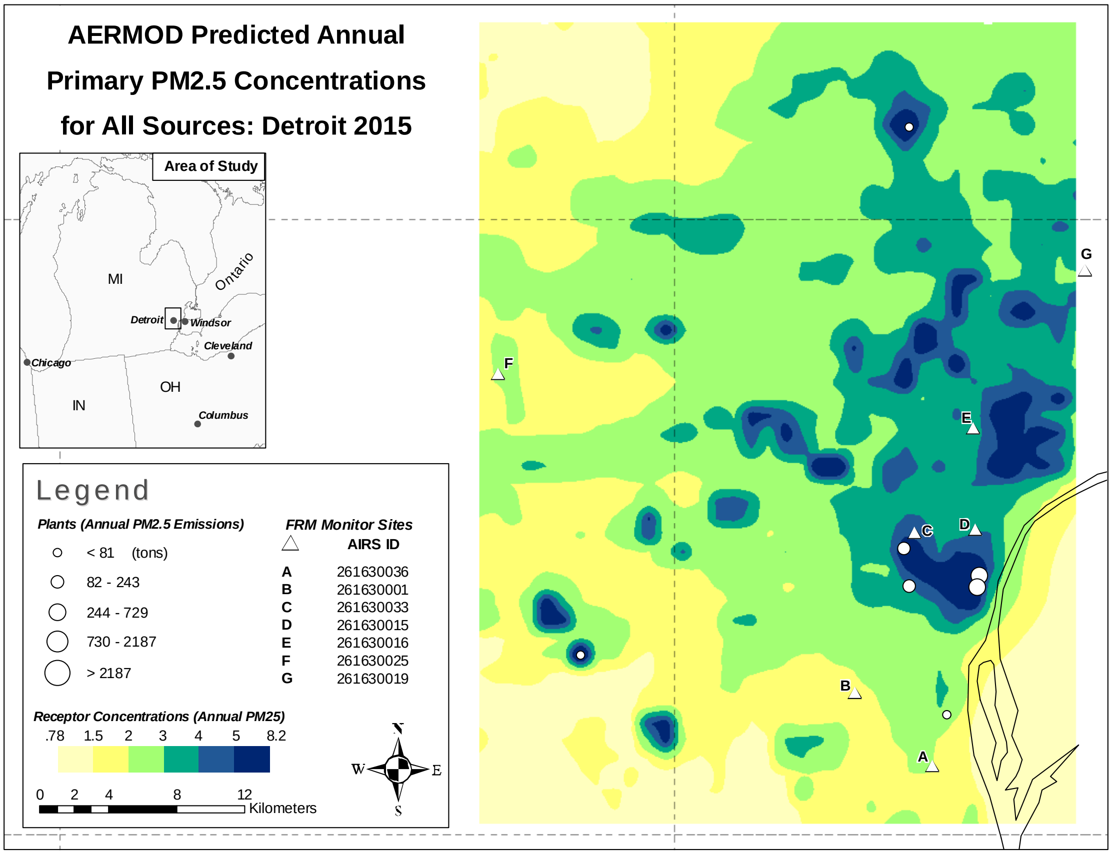

Figure 8. Spatial Gradient in Detroit, MI of AERMOD Predicted Annual Primary PM2.5 Concentrations (ug/m^3) for All Sources: 2015

Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

Seattle

Table 19 shows the AERMOD modeling results for primary PM2.5 impacts at monitor locations in Pierce County exceeding the proposed daily (35 ug/m^3) standard. In addition, Figure 9 provides the spatial gradient of primary PM2.5 for the urban area associated with emissions from all modeled sources. For the daily standard, as shown in Table 19, the Pierce County monitor #530330029 is expected to exceed a 35 ug/m^3 daily standard by 8 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 2.4 ug/m^3 to this monitor location, and that the application of controls to meet the 15/35 and 14/25 standard levels would yield a 1.1 ug/m^3 reduction in PM2.5 concentration here. Paper and forest products plants, commercial and marine vessels, residential wood burning, and commercial cooking contribute significantly to the Pierce County monitor's daily value with a combined contribution of just over 2 ug/m^3 of the 2.4 ug/m^3 total contribution from all modeled sources, or 85 percent. Table 19 also shows that the Snohomish County monitor #530611007 is expected to exceed a 35 ug/m^3 daily standard by 5.2 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 3.4 ug/m^3 to this monitor location, and that the application of controls to meet the 15/35 and 14/25 standard levels would yield a 1.5 ug/m^3 reduction in PM2.5 concentration here. Residential wood and waste burning contribute significantly to the Snohomish County monitor's daily value with 3 ug/m^3 of the 3.4 ug/m^3 total contribution from all modeled sources, or almost 90 percent.

As discussed in the proposal RIA, the Seattle urban area was also evaluated using photochemical grid modeling through application of the Response Surface Model (RSM). There are important differences across these modeling approaches that limit the direct comparability of these modeling results. A major difference is that the RSM includes background and transported concentrations of direct PM2.5 within the urban area but focused only on organic components of primary PM2.5 whereas the AERMOD modeling was limited to only those emissions sources in the city and surrounding counties but included other direct species of PM2.5 like crustal materials. Despite these differences a comparison of results from these assessments provides insights of use here. For comparison purposes, in Snohomish county, the RSM suggested that direct PM2.5 emissions of carbon contribute around 2.2 ug/m^3 to the daily design value in 2015 whereas the AERMOD estimate for modeled sources in the proposal RIA was 3.3 ug/m^3. This comparison suggests that there is an additional 50 percent contribution of direct PM2.5 attributable to a combination of direct PM2.5 emissions of crustal materials (which were not evaluated with the RSM approach) and the effect of "local" modeling that provides a more resolved spatial gradient within this urban area. Furthermore, both AERMOD and RSM predict that residential wood burning, which is an area source, is the major contributor at this monitor location. In King County, the RSM suggested that direct PM2.5 emissions of carbon contribute around 2.5 ug/m^3 to the daily design value which was comparable to the AERMOD prediction of 2.4 ug/m^3 from all modeled sources of direct PM2.5 emissions within Seattle. This indicates that background or transported concentrations of primary PM2.5 may be more important at this monitor location.

Table 19. Summary of Modeled Source Contributions of Primary PM2.5 to Monitors with Potential Daily Exceedences in Seattle: 2015

		Model Predicted Daily Concentrations (ug/m3)**			
Source Sectors	**Primary PM2.5 Emissions (ton/yr)**	**Primary PM2.5 Contribution**	**15/65 Control Scenario**	**15/35 Control Scenario**	**14/35 Control Scenario**
	Pierce County Monitor #530330029, Daily DV = 43.0				
Paper and Forest Products	965	0.748	0.000	0.707	0.707
CMV	648	0.476	0.160	0.000	0.000
Residential wood burning	2,115	0.417	0.000	0.202	0.202
Commercial cooking	1,646	0.388	0.000	0.072	0.072
Other industrial sources	458	0.116	0.000	0.110	0.110
Power Sector	2,671	0.065	0.000	0.000	0.000
Residential waste burning	1,696	0.059	0.000	0.030	0.030
Metal Processing	283	0.036	0.000	0.001	0.001
Aircraft	114	0.027	0.000	0.000	0.000
Natural gas combusion	29	0.025	0.000	0.000	0.000
Cement and Mining	233	0.013	0.000	0.000	0.000
Nonroad (gasoline and diesel)	10	0.003	0.000	0.000	0.000
Naval Shipyards	107	0.000	0.000	0.000	0.000
Total, All Sources	10,976	2.373	0.160	1.122	1.122
	Snohomish County Monitor #530611007, Daily DV = 40.2				
Residential wood burning	2,115	2.114	0.000	1.025	1.025
Residential waste burning	1,696	0.891	0.000	0.446	0.446
Natural gas combusion	29	0.221	0.000	0.000	0.000
Commercial cooking	1,646	0.171	0.000	0.032	0.032
Aircraft	114	0.006	0.000	0.000	0.000
Paper and Forest Products	965	0.005	0.000	0.002	0.002
Other industrial sources	458	0.002	0.000	0.002	0.002
Metal Processing	283	0.001	0.000	0.000	0.000
Cement and Mining	233	0.001	0.000	0.000	0.000
Naval Shipyards	107	0.001	0.000	0.000	0.000
Power Sector	2,671	0.000	0.000	0.000	0.000
CMV	648	0.000	0.000	0.000	0.000
Nonroad (gasoline and diesel)	10	0.000	0.000	0.000	0.000
Total, All Sources	10,976	3.412	0.000	1.507	1.507

*Natural gas combustion emissions are adjusted here to reflect 94 percent reduction in baseline emissions due to new emissions factor.

**Each daily results reflects the 98th percentile day or the 3rd highest day modeled with AERMOD so for monitor #530330029 that day is Jan 11th and for monitor 530611007 that day is Jan 16th.

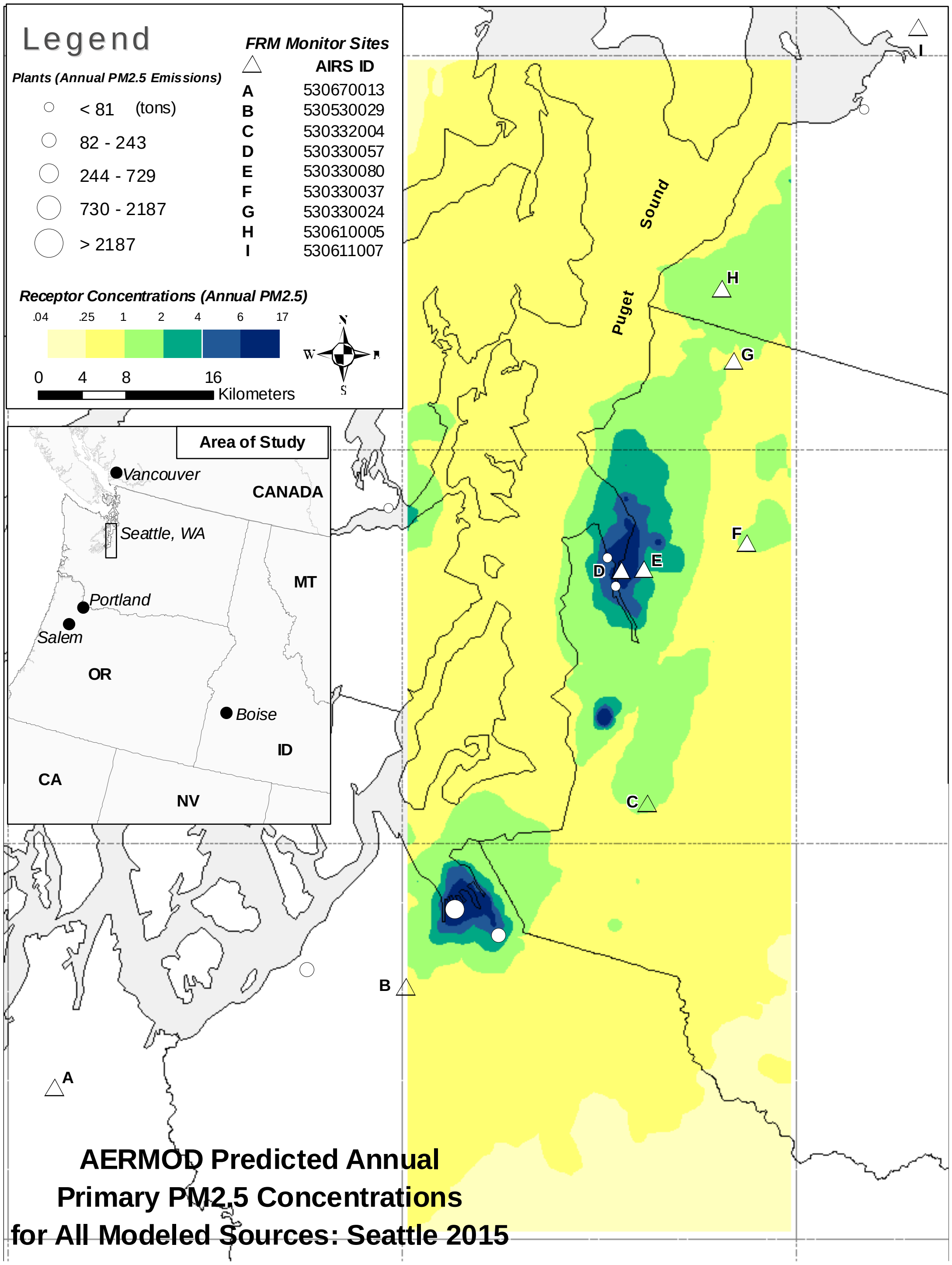

Figure 9. Spatial Gradient in Seattle, WA of AERMOD Predicted Annual Primary PM2.5 Concentrations (ug/m^3) for All Modeled Sources: 2015

Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

Chicago

Table 20 shows the AERMOD modeling results for primary PM2.5 impacts at monitoring site #170310052 Cook County exceeding the proposed annual (15 ug/m^3) and daily (35 ug/m^3) standards, respectively. In addition, Figure 8 provides the spatial gradient of primary PM2.5 for the urban area associated with emissions from all sources. For the annual standard, as shown in Table 20, the Cook County monitor #170310052 is expected to exceed 15 ug/m^3 by 0.5 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 3.9 ug/m^3 to this monitor location and that the application of controls for the 15/65 scenario would yield a 1.09 ug/m^3 reduction in PM2.5 concentrations. The modeling results indicate little additional reductions at this monitor for the 15/35 and 14/35 scenarios. For the daily standard, as shown in Table 20, this monitor is expected to exceed a 35 ug/m^3 daily standard by 2.1 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5 contribute 11.35 ug/m^3 to this monitor location and that the application of controls to meet the 15/65 scenario would yield a 3.0 ug/m^3 reduction in PM2.5 concentrations. The modeling results indicate that the 15/35 and 14/25 scenarios show little additional reductions, i.e., almost 0.05 ug/m^3 reduction in PM2.5 concentration here.

Table 20. Summary of Modeled Source Contributions of Primary PM2.5 to Monitor with Potential Exceedences in Chicago: 2015

Source Sectors	Primary PM2.5 Emissions (ton/yr)	Model Predicted Concentrations (ug/m3) Primary PM2.5 Contribution	15/65 Control Scenario	15/35 Control Scenario	14/35 Control Scenario
Cook County Monitor #170310052, Annual DV = 15.5					
Power Sector	8,514	0.100	0.005	0.000	0.000
Metal Processing	17,625	0.344	0.123	0.000	0.000
Stone, Clay, Cement	561	0.013	0.005	0.000	0.000
Chemical Manufacturing	1,392	0.056	0.016	0.000	0.000
Petroleum industry	1,939	0.051	0.016	0.000	0.000
Paper and Allied Products	181	0.006	0.000	0.000	0.000
Food and Kindred Products	1,609	0.080	0.000	0.000	0.000
Other industrial sources	8,386	0.928	0.592	0.000	0.000
CMV, Aircraft, Locomotive	1,435	0.167	0.045	0.000	0.000
Nonroad (gasoline and diesel)	3,119	0.555	0.114	0.028	0.028
Onroad (gasoline and diesel)	1,568	0.286	0.028	0.001	0.001
Residential waste burning	400	0.003	0.000	0.000	0.000
Residential wood burning	877	0.209	0.062	0.000	0.000
Commercial cooking	1,699	0.434	0.080	0.000	0.000
Prescribed/open burning/wildfire	222	0.002	0.000	0.000	0.000
Area fugitive dust	8,998	0.425	0.000	0.000	0.000
Other area	729	0.228	0.000	0.000	0.000
Total, All Sources	59,255	3.887	1.086	0.029	0.029
Cook County Monitor #170310052, Daily DV = 37.1*					
Power Sector	8,514	0.432	0.034	0.000	0.000
Metal Processing	17,625	0.538	0.075	0.000	0.000
Stone, Clay, Cement	561	0.030	0.004	0.000	0.000
Chemical Manufacturing	1,392	0.104	0.022	0.000	0.000
Petroleum industry	1,939	0.237	0.075	0.000	0.000
Paper and Allied Products	181	0.030	0.000	0.000	0.000
Food and Kindred Products	1,609	0.301	0.000	0.000	0.000
Other industrial sources	8,386	2.596	1.732	0.000	0.000
CMV, Aircraft, Locomotive	1,435	0.335	0.114	0.000	0.000
Nonroad (gasoline and diesel)	3,119	1.007	0.252	0.043	0.043
Onroad (gasoline and diesel)	1,568	1.028	0.106	0.004	0.004
Residential waste burning	400	0.002	0.000	0.000	0.000
Residential wood burning	877	1.327	0.393	0.000	0.000
Commercial cooking	1,699	1.098	0.203	0.000	0.000
Prescribed/open burning/wildfire	222	0.002	0.000	0.000	0.000
Area fugitive dust	8,998	1.465	0.000	0.000	0.000
Other area	729	0.823	0.000	0.000	0.000
Total, All Sources	59,255	11.354	3.010	0.047	0.047

*Daily results reflect the 98th percentile day or the 3rd highest day modeled with AERMOD so for monitor #170310052 that day is January 11.

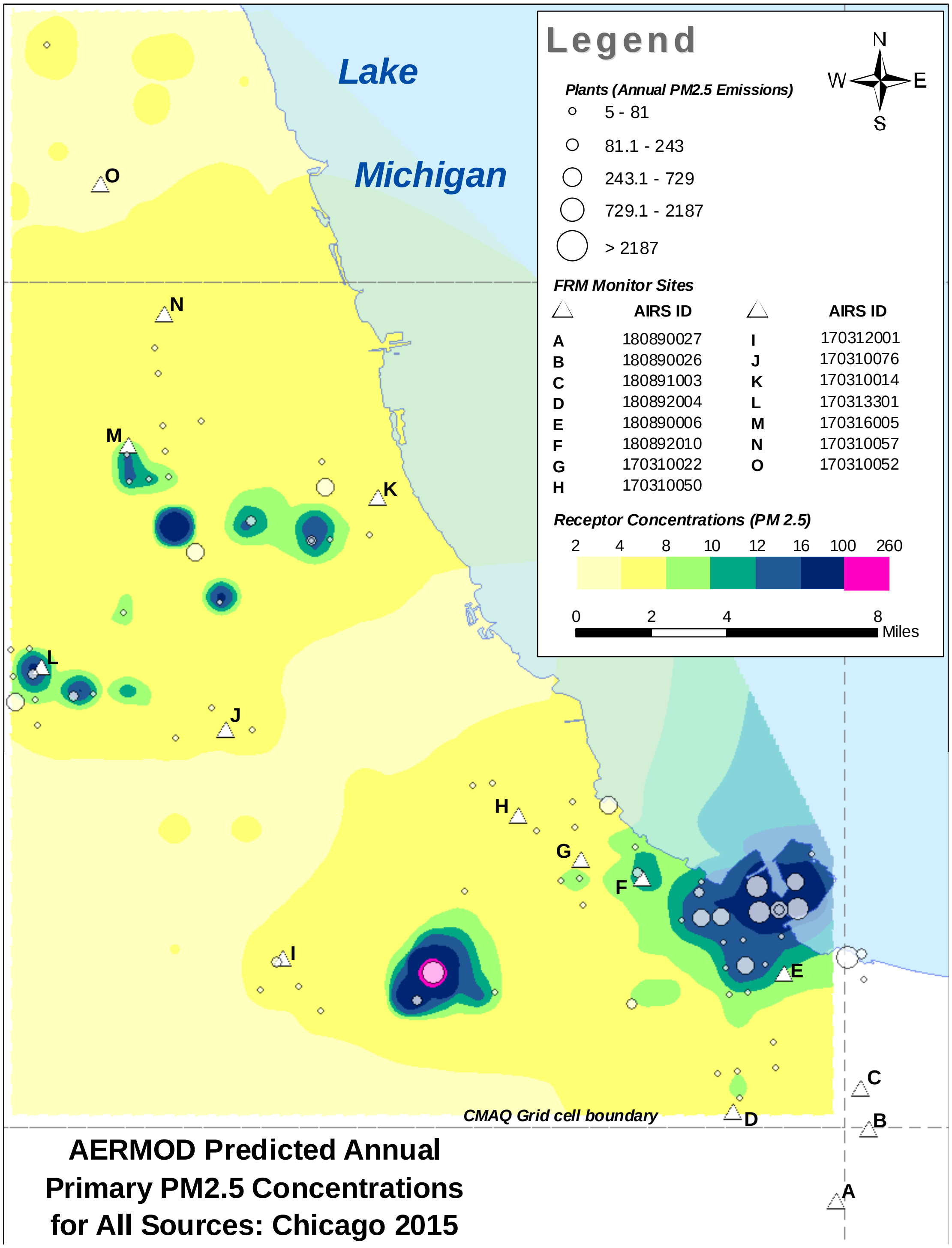

Figure 10. Spatial Gradient in Chicago, IL of AERMOD Predicted Annual Primary PM2.5 Concentrations (ug/m^3) for All Modeled Sources: 2015

Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

Pittsburgh

Table 21 shows the AERMOD modeling results for primary PM2.5 impacts at the monitor location in Allegheny County exceeding the proposed annual (15 ug/m^3) and daily (35 ug/m^3) standards, respectively. In addition, Figure 8 provides the spatial gradient of primary PM2.5 for the urban area associated with emissions from point sources within 50 km of this monitor. Local sources contributing to direct PM2.5 concentrations here include as metal manufacturing, coal combustion, and mining. As shown in the table, the Allegheny County monitor #420030064 is expected to exceed the annual standard of 15 ug/m^3 by 1.8 ug/m^3 and the daily standard of 35 ug/m^3 by 17.4 ug/m^3 in 2015. The modeling results indicate that local sources of primary PM2.5, which emit roughly 5,700 tons, contribute 1.75 ug/m^3 to the annual concentrations and 7.9 ug/m^3 to the 3rd highest daily concentration at this monitor location. However, the application of controls associated with 15/35 and 14/35 scenarios would yield roughly a 0.1 ug/m^3 reduction in annual concentrations and roughly a 0.25 ug/m^3 reduction in the daily concentration. Given the limited number of local sources modeled through AERMOD, the modeling results are not comparable to those obtained from CMAQ which included all regional and local sources of direct PM2.5 contributing to this monitoring site.

Table 21. Summary of Modeled Source Contributions of Primary PM2.5 to Monitor with Potential Exceedences in Pittsburgh: 2015

		Model Predicted Concentrations (ug/m3)			
Source Sectors	**Primary PM2.5 Emissions (ton/yr)**	**Primary PM2.5 Contribution**	**15/65 Control Scenario**	**15/35 Control Scenario**	**14/35 Control Scenario**
Allegheny County Monitor #420030064, Annual DV = 16.47					
Power Sector	1,828	0.077	0.009	0.017	0.004
Metal Processing	1,435	1.400	0.011	0.038	0.038
Other manufacturing	2,387	0.271	0.097	0.057	0.057
Point fugitive dust	19	0.003	0.000	0.000	0.000
Total, All Sources	5,669	1.751	0.116	0.112	0.099
Allegheny County Monitor #420030064, Daily DV = 53.43**					
Power Sector	1,828	0.217	0.029	0.035	0.009
Metal Processing	1,435	7.015	0.002	0.057	0.057
Other manufacturing	2,387	0.644	0.192	0.162	0.162
Point fugitive dust	19	0.000	0.000	0.000	0.000
Total, All Sources	5,669	7.877	0.223	0.254	0.228

*Natural gas combustion emissions are adjusted here to reflect 94 percent reduction in baseline emissions due to new emissions factor.

**Daily results reflect the 98th percentile day or the 3rd highest day modeled with AERMOD so for monitor #420030064 that day is July 23.

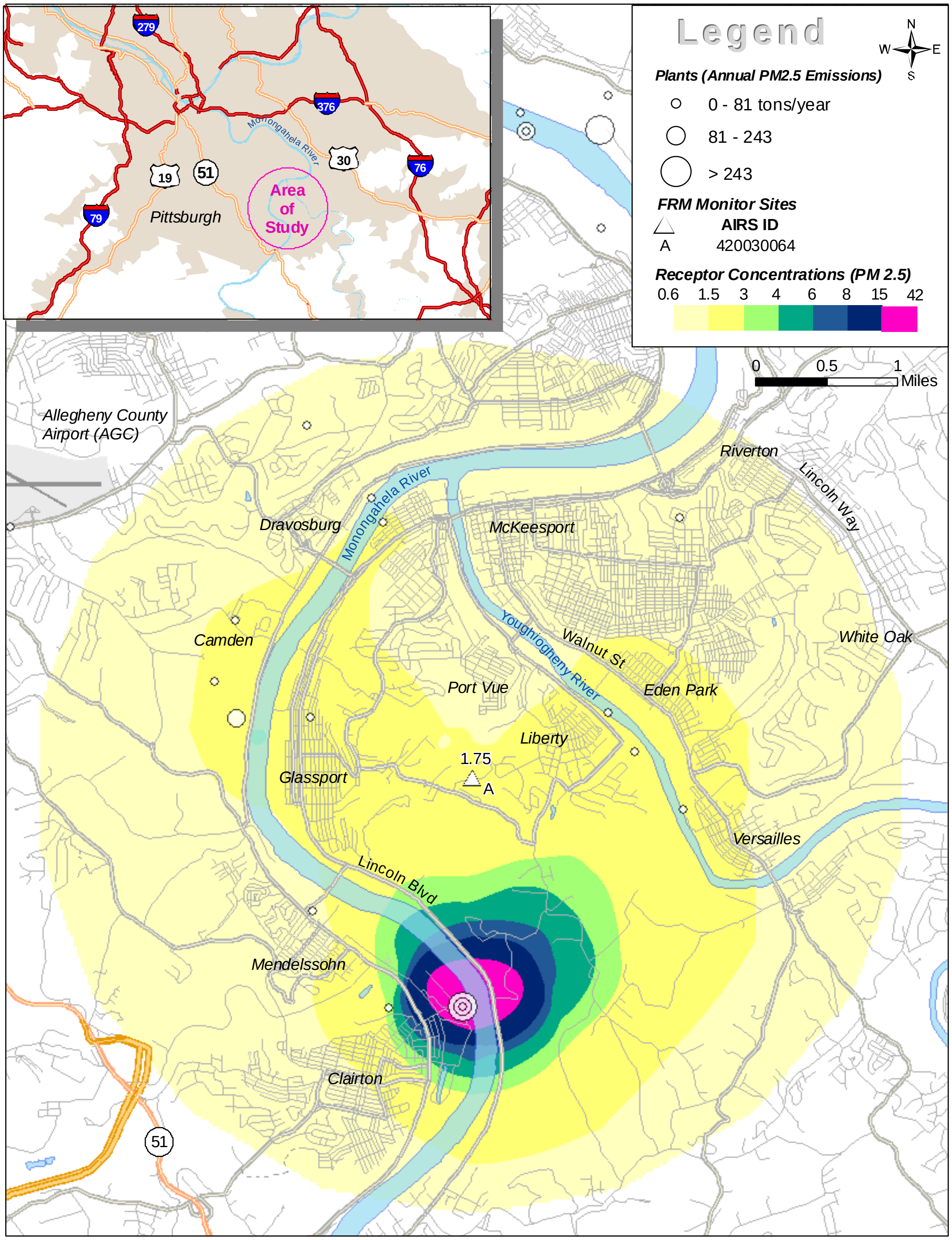

Figure 10. Spatial Gradient in Pittsburgh, PA of AERMOD Predicted Annual Primary PM2.5 Concentrations (ug/m^3) for Point Sources within 50km: 2015
Note: Dashed lines reflect the 36km grid cells from regional-scale modeling with CMAQ model.

References:

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Appendix C: $PM_{2.5}$ Impact per-Ton Estimates

This appendix summarizes the Response Surface Model-derived estimates of the incremental change in $PM_{2.5}$ associated with incremental changes in tons of $PM_{2.5}$ precursors. EPA developed these estimates for areas projected to not attain the 1997, revised and more stringent alternative standards.

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
ATLANTA						
Atlanta-Sandy Springs-Marietta, GA Metropolitan Statistical Area	annual	nox_negu_area		$2,571.07	–3.68176E-06	–$698,326,706.16
	annual	POC+PEC_area		$6,277.36	4.95456E-04	$12,669,850.13
	annual	POC+PEC_egu_negu		$16,987.27	2.47036E-04	$68,764,306.25
	annual	sox_negu_pt		$4,000.00	1.18953E-05	$336,266,222.51
BIRMINGHAM						
Birmingham-Hoover, AL Metropolitan Statistical Area	annual	nox_negu_area		$4,049.74	6.14607E-07	$6,589,155,994.23
	annual	POC+PEC_area		$1,922.93	5.49627E-04	$3,498,613.90
	annual	POC+PEC_egu_negu		$11,279.70	6.76329E-04	$16,677,844.74
	annual	sox_negu_pt		$24,474.07	1.40440E-05	$1,742,672,195.75
ST. LOUIS						
St. Louis, MO-IL Metropolitan Statistical Area	annual	nh3_area		$388.26	4.24796E-06	$91,398,809.20
	annual	nox_negu_area		$7,179.84	1.48918E-06	$4,821,332,507.26
	annual	POC+PEC_area		$27,413.73	1.83903E-04	$149,066,452.65
	annual	POC+PEC_egu_negu		$10,082.66	3.56097E-04	$28,314,363.53
	annual	sox_area		$2,207.05	5.39508E-06	$409,086,037.17
	annual	sox_negu_pt		$6,682.61	2.31531E-06	$2,886,266,087.67

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
CALIFORNIA						
Bakersfield, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	2.13771E-05	$10,269,326.05
	annual	nh3_area	Developmental	$1,579.10	2.13771E-05	$73,868,703.43
	annual	nox_egu		$1,419.57	2.45135E-05	$57,909,775.56
	annual	nox_negu_area		$4,482.87	1.57552E-05	$284,533,132.06
	annual	POC+PEC_area		$2,917.16	7.33446E-04	$3,977,331.67
	annual	POC+PEC_egu_negu		$27,281.47	6.37028E-04	$42,826,205.22
	annual	POC+PEC_area_PM10			7.33446E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	7.33446E-04	$4,044,034.29
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	6.37028E-04	$3,689,008.68
	annual	sox_area		$2,204.66	5.06882E-05	$43,494,554.49
	annual	sox_egu		$60,510.63	1.43091E-04	$422,883,365.82
	annual	sox_negu_pt		$12,689.73	1.04278E-05	$1,216,912,423.30
Fresno, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	2.33721E-05	$9,392,744.16
	annual	nh3_area	Developmental	$1,579.10	2.33721E-05	$67,563,326.90
	annual	nox_egu		$1,419.57	–4.09087E-06	–$347,009,218.38
	annual	nox_negu_area		$4,482.87	1.43636E-05	$312,100,639.96
	annual	POC+PEC_area		$2,917.16	5.88962E-04	$4,953,046.18
	annual	POC+PEC_egu_negu		$27,281.47	2.94214E-04	$92,726,712.04
	annual	POC+PEC_area_PM10			5.88962E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	5.88962E-04	$5,036,112.21
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	2.94214E-04	$7,987,390.99
	annual	sox_area		$2,204.66	5.55483E-05	$39,689,051.91
	annual	sox_egu		$60,510.63	2.51254E-04	$240,834,465.98
	annual	sox_negu_pt		$12,689.73	2.45551E-05	$516,786,441.99

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Hanford-Corcoran, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	1.42280E-05	$15,429,358.84
	annual	nh3_area	Developmental	$1,579.10	1.42280E-05	$110,985,543.43
	annual	nox_egu		$1,419.57	–6.09482E-06	–$232,914,011.16
	annual	nox_negu_area		$4,482.87	1.63691E-05	$273,861,810.76
	annual	POC+PEC_area		$2,917.16	2.11666E-04	$13,781,870.01
	annual	POC+PEC_egu_negu		$27,281.47	1.74456E-04	$156,380,629.69
	annual	POC+PEC_area_PM10			2.11666E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	2.11666E-04	$14,013,001.55
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	1.74456E-04	$13,470,479.06
	annual	sox_area		$2,204.66	2.54838E-05	$86,512,114.32
	annual	sox_egu		$60,510.63	6.04989E-05	$1,000,193,918.94
	annual	sox_negu_pt		$12,689.73	4.31756E-06	$2,939,098,361.44
Los Angeles-Long Beach-Glendale, CA Metropolitan Division	annual	nh3_area		$219.53	–1.42927E-05	–$15,359,530.72
	annual	nh3_area	Developmental	$1,579.10	–1.42927E-05	–$110,483,259.94
	annual	nox_egu		$1,419.57	2.05162E-05	$69,192,609.73
	annual	nox_negu_area		$4,482.87	4.29512E-06	$1,043,713,972.19
	annual	POC+PEC_area		$2,917.16	2.24700E-04	$12,982,472.14
	annual	POC+PEC_egu_negu		$27,281.47	3.08572E-04	$88,411,959.62
	annual	POC+PEC_area_PM10			2.24700E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	2.24700E-04	$13,200,197.22
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	3.08572E-04	$7,615,722.31
	annual	sox_area		$2,204.66	1.61722E-04	$13,632,379.42
	annual	sox_egu		$60,510.63	9.26093E-06	$6,533,969,968.76
	annual	sox_negu_pt		$12,689.73	1.12259E-05	$1,130,401,604.40

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Merced, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	7.37090E-06	$29,783,154.44
	annual	nh3_area	Developmental	$1,579.10	7.37090E-06	$214,234,409.57
	annual	nox_egu		$1,419.57	3.39880E-06	$417,667,270.73
	annual	nox_negu_area		$4,482.87	7.66415E-06	$584,914,538.06
	annual	POC+PEC_area		$2,917.16	2.10444E-04	$13,861,906.05
	annual	POC+PEC_egu_negu		$27,281.47	1.88605E-04	$144,649,048.03
	annual	POC+PEC_area_PM10			2.10444E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	2.10444E-04	$14,094,379.85
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	1.88605E-04	$12,459,931.75
	annual	sox_area		$2,204.66	4.42085E-05	$49,869,573.48
	annual	sox_egu		$60,510.63	1.19419E-04	$506,710,590.73
	annual	sox_negu_pt		$12,689.73	1.53218E-05	$828,213,070.83
Modesto, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	7.37942E-06	$29,748,763.79
	annual	nh3_area	Developmental	$1,579.10	7.37942E-06	$213,987,032.78
	annual	nox_egu		$1,419.57	8.11745E-06	$174,878,706.97
	annual	nox_negu_area		$4,482.87	6.00173E-06	$746,929,963.59
	annual	POC+PEC_area		$2,917.16	1.91399E-04	$15,241,241.81
	annual	POC+PEC_egu_negu		$27,281.47	1.63540E-04	$166,818,783.74
	annual	POC+PEC_area_PM10			1.91399E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	1.91399E-04	$15,496,848.03
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	1.63540E-04	$14,369,611.75
	annual	sox_area		$2,204.66	5.08232E-05	$43,378,994.77
	annual	sox_egu		$60,510.63	9.28966E-05	$651,375,908.26
	annual	sox_negu_pt		$12,689.73	1.27443E-05	$995,715,786.19

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Riverside-San Bernardino-Ontario, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	5.09196E-05	$4,311,277.26
	annual	nh3_area	Developmental	$1,579.10	5.09196E-05	$31,011,622.35
	annual	nox_egu		$1,419.57	7.19171E-05	$19,738,970.12
	annual	nox_negu_area		$4,482.87	7.65189E-06	$585,852,156.97
	annual	POC+PEC_area		$2,917.16	1.19385E-04	$24,434,965.71
	annual	POC+PEC_egu_negu		$27,281.47	–8.84176E-05	–$308,552,377.41
	annual	POC+PEC_area_PM10			1.19385E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	1.19385E-04	$24,844,757.07
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	–8.84176E-05	–$26,578,409.03
	annual	sox_area		$2,204.66	4.50740E-04	$4,891,199.08
	annual	sox_egu		$60,510.63	3.84733E-04	$157,279,403.75
	annual	sox_negu_pt		$12,689.73	3.14236E-05	$403,827,900.80
San Diego-Carlsbad-San Marcos, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	4.92402E-06	$44,583,197.96
	annual	nh3_area	Developmental	$1,579.10	4.92402E-06	$320,693,199.54
	annual	nox_egu		$1,419.57	1.67672E-05	$84,663,269.38
	annual	nox_negu_area		$4,482.87	2.89710E-06	$1,547,366,447.53
	annual	POC+PEC_area		$2,917.16	1.01821E-04	$28,649,808.32
	annual	POC+PEC_egu_negu		$27,281.47	1.67010E-04	$163,352,375.67
	annual	POC+PEC_area_PM10			1.01821E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	1.01821E-04	$29,130,285.52
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	1.67010E-04	$14,071,018.65
	annual	sox_area		$2,204.66	4.89029E-05	$45,082,411.05
	annual	sox_egu		$60,510.63	7.51047E-05	$805,683,113.47
	annual	sox_negu_pt		$12,689.73	1.91150E-05	$663,863,389.76

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Santa Ana-Anaheim-Irvine, CA Metropolitan Division	annual	nh3_area		$219.53	–7.86193E-06	–$27,922,990.26
	annual	nh3_area	Developmental	$1,579.10	–7.86193E-06	–$200,853,987.57
	annual	nox_egu		$1,419.57	1.23022E-05	$115,391,493.91
	annual	nox_negu_area		$4,482.87	3.55914E-06	$1,259,538,809.04
	annual	POC+PEC_area		$2,917.16	1.98222E-04	$14,716,648.49
	annual	POC+PEC_egu_negu		$27,281.47	7.54146E-05	$361,753,255.89
	annual	POC+PEC_area_PM10			1.98222E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	1.98222E-04	$14,963,456.92
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	7.54146E-05	$31,161,082.22
	annual	sox_area		$2,204.66	6.23109E-05	$35,381,606.27
	annual	sox_egu		$60,510.63	1.00220E-04	$603,780,619.82
	annual	sox_negu_pt		$12,689.73	1.76892E-05	$717,373,284.92
Visalia-Porterville, CA Metropolitan Statistical Area	annual	nh3_area		$219.53	2.46450E-05	$8,907,615.88
	annual	nh3_area	Developmental	$1,579.10	2.46450E-05	$64,073,731.11
	annual	nox_egu		$1,419.57	4.84365E-06	$293,078,546.29
	annual	nox_negu_area		$4,482.87	1.99979E-05	$224,167,146.26
	annual	POC+PEC_area		$2,917.16	7.22294E-04	$4,038,737.72
	annual	POC+PEC_egu_negu		$27,281.47	4.06670E-04	$67,085,081.87
	annual	POC+PEC_area_PM10			7.22294E-04	
	annual	POC+PEC_area	Developmental	$2,966.08	7.22294E-04	$4,106,470.16
	annual	POC+PEC_egu_negu	Developmental	$2,350.00	4.06670E-04	$5,778,645.30
	annual	sox_area		$2,204.66	6.14453E-05	$35,880,048.22
	annual	sox_egu		$60,510.63	2.06039E-04	$293,685,590.61
	annual	sox_negu_pt		$12,689.73	1.38684E-05	$915,007,636.68

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
CHICAGO						
Chicago-Naperville-Joliet, IL Metropolitan Division	annual	nh3_area		$931.28	8.82829E-06	$105,488,600.42
	annual	nox_negu_area		$4,613.40	–4.46005E-07	–$10,343,808,869.39
	annual	POC+PEC_area		$5,116.38	6.59998E-05	$77,521,124.51
	annual	POC+PEC_egu_negu		$26,899.29	8.26120E-05	$325,609,745.42
	annual	sox_area		$2,203.86	6.28360E-06	$350,732,474.85
	annual	sox_negu_pt		$21,821.15	1.62830E-06	$13,401,164,813.87
Gary, IN Metropolitan Division	annual	nh3_area		$931.28	7.52410E-07	$1,237,734,527.20
	annual	nox_negu_area		$4,613.40	2.63002E-07	$17,541,293,614.95
	annual	POC+PEC_area		$5,116.38	3.97849E-05	$128,601,172.85
	annual	POC+PEC_egu_negu		$26,899.29	4.38463E-05	$613,490,264.23
	annual	sox_area		$2,203.86	2.75020E-06	$801,347,521.17
	annual	sox_negu_pt		$21,821.15	7.79275E-07	$28,001,863,847.80
OHIO VALLEY & GREAT LAKES						
Cleveland-Elyria-Mentor, OH Metropolitan Statistical Area	annual	nh3_area		$713.42	5.93874E-07	$1,201,303,999.83
	annual	nox_negu_area		$3,765.04	8.95060E-08	$42,064,663,788.48
	annual	POC+PEC_area		$12,125.21	9.13094E-05	$132,792,536.92
	annual	POC+PEC_egu_negu		$33,145.19	4.30227E-05	$770,410,760.84
	annual	sox_area		$2,205.35	3.15342E-07	$6,993,518,396.13
	annual	sox_negu_pt		$7,371.23	3.78571E-07	$19,471,186,249.12

(continued)

Table C-1: 15/65 Current Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Detroit-Livonia-Dearborn, MI Metropolitan Division	annual	nh3_area		$713.42	7.60636E-07	$937,930,000.28
	annual	nox_negu_area		$3,765.04	8.21466E-08	$45,833,170,504.41
	annual	POC+PEC_area		$12,125.21	1.44813E-04	$83,729,932.68
	annual	POC+PEC_egu_negu		$33,145.19	3.90833E-05	$848,064,995.85
	annual	sox_area		$2,205.35	1.85535E-07	$11,886,432,060.15
	annual	sox_negu_pt		$7,371.23	3.39837E-07	$21,690,477,275.96
Pittsburgh, PA Metropolitan Statistical Area	annual	nh3_area		$713.42	5.79561E-07	$1,230,971,612.58
	annual	nox_negu_area		$3,765.04	6.94875E-08	$54,182,985,342.31
	annual	POC+PEC_area		$12,125.21	7.83701E-05	$154,717,226.95
	annual	POC+PEC_egu_negu		$33,145.19	1.06978E-04	$309,830,475.43
	annual	sox_area		$2,205.35	2.80084E-07	$7,873,871,932.80
	annual	sox_negu_pt		$7,371.23	3.38044E-07	$21,805,548,100.31
LINCOLN MT						
Lincoln Co, MT	annual	nh3_area		$73.49	–7.25638E-04	–$101,279.18
	annual	nox_negu_area		$1,011.65	4.88907E-04	$2,069,200.60
	annual	POC+PEC_area		$1,737.36	9.02025E-03	$192,606.81
	annual	sox_area		$2,208.75	–4.11836E-05	–$53,631,798.77

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
CALIFORNIA						
Bakersfield, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	7.73452E-06	$53,509,208.34
	daily	pocpec_egu_negu		$4,665.48	4.44573E-06	$1,049,430,467.97
	daily	nh3_area	Developmental	$4,653.69	5.60983E-07	$8,295,585,363.45
	daily	POCPEC_area	Developmental	$3,404.58	7.73452E-06	$440,179,276.50
	daily	POCPEC_egu_negu	Developmental	$1,832.51	4.44573E-06	$412,195,822.40
	daily	sox_area	Developmental	$—	2.73613E-05	$—
	daily	sox_negu_pt	Developmental	$—	3.08962E-06	$—
	daily_SJ	pocpec_area		$—	2.90120E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	8.93150E-04	$6,046,015.77
	daily_SJ	sox_area	Developmental	$—	1.69833E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–5.94129E-06	–$0.00
Chico, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.50250E-05	$16,538,184.59
	daily	pocpec_egu_negu		$4,665.48	9.57012E-06	$487,505,004.99
	daily	nh3_area	Developmental	$4,653.69	1.53702E-06	$3,027,739,857.65
	daily	POCPEC_area	Developmental	$3,404.58	2.50250E-05	$136,046,978.73
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.57012E-06	$191,482,458.91
	daily	sox_area	Developmental	$—	5.15157E-06	$—
	daily	sox_negu_pt	Developmental	$—	6.10457E-07	$—
	daily_SJ	pocpec_area		$—	–9.80789E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	1.22646E-06	$4,402,921,499.00
	daily_SJ	sox_area	Developmental	$—	5.96512E-07	$—
	daily_SJ	sox_negu_pt	Developmental	$—	1.02869E-05	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
El Centro, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	4.88931E-05	$8,464,760.20
	daily	pocpec_egu_negu		$4,665.48	9.86730E-06	$472,822,179.98
	daily	nh3_area	Developmental	$4,653.69	3.38222E-07	$13,759,244,513.51
	daily	POCPEC_area	Developmental	$3,404.58	4.88931E-05	$69,633,099.39
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.86730E-06	$185,715,331.58
	daily	sox_area	Developmental	$—	–6.17899E-07	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.56682E-06	$—
	daily_SJ	pocpec_area		$—	2.46101E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	6.10019E-06	$885,218,580.30
	daily_SJ	sox_area	Developmental	$—	4.03989E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–3.56935E-06	–$0.00
Fresno, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	6.78513E-06	$60,996,334.23
	daily	pocpec_egu_negu		$4,665.48	1.98551E-06	$2,349,767,760.15
	daily	nh3_area	Developmental	$4,653.69	1.89131E-06	$2,460,562,741.03
	daily	POCPEC_area	Developmental	$3,404.58	6.78513E-06	$501,770,127.10
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.98551E-06	$922,942,952.31
	daily	sox_area	Developmental	$—	2.38850E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.03621E-06	$—
	daily_SJ	pocpec_area		$—	2.76451E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	2.73284E-04	$19,759,691.91
	daily_SJ	sox_area	Developmental	$—	3.69744E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.45742E-05	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Hanford-Corcoran, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	6.49896E-06	$63,682,211.16
	daily	pocpec_egu_negu		$4,665.48	9.16665E-06	$508,962,249.02
	daily	nh3_area	Developmental	$4,653.69	–1.45302E-07	–$32,027,766,230.02
	daily	POCPEC_area	Developmental	$3,404.58	6.49896E-06	$523,864,779.66
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.16665E-06	$199,910,445.91
	daily	sox_area	Developmental	$—	2.12439E-05	$—
	daily	sox_negu_pt	Developmental	$—	3.95878E-06	$—
	daily_SJ	pocpec_area		$—	8.66795E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	3.94249E-04	$13,696,938.52
	daily_SJ	sox_area	Developmental	$—	1.70676E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	9.59128E-05	$—
Los Angeles-Long Beach-Glendale, CA Metropolitan Division	daily	pocpec_area		$413.87	4.05735E-05	$10,200,460.30
	daily	pocpec_egu_negu		$4,665.48	–4.95074E-06	–$942,380,152.38
	daily	nh3_area	Developmental	$4,653.69	–1.00213E-06	–$4,643,803,647.63
	daily	POCPEC_area	Developmental	$3,404.58	4.05735E-05	$83,911,374.75
	daily	POCPEC_egu_negu	Developmental	$1,832.51	–4.95074E-06	–$370,148,546.07
	daily	sox_area	Developmental	$—	9.98231E-06	$—
	daily	sox_negu_pt	Developmental	$—	8.83626E-06	$—
	daily_SJ	pocpec_area		$—	–1.95929E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.72676E-05	–$198,036,989.21
	daily_SJ	sox_area	Developmental	$—	2.27002E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–1.74127E-05	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Merced, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	1.72796E-05	$23,951,304.45
	daily	pocpec_egu_negu		$4,665.48	1.17795E-05	$396,067,789.59
	daily	nh3_area	Developmental	$4,653.69	3.41426E-06	$1,363,013,200.20
	daily	POCPEC_area	Developmental	$3,404.58	1.72796E-05	$197,029,038.39
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.17795E-05	$155,567,703.86
	daily	sox_area	Developmental	$—	4.30385E-06	$—
	daily	sox_negu_pt	Developmental	$—	1.96894E-06	$—
	daily_SJ	pocpec_area		$—	6.18317E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	4.74982E-04	$11,368,861.35
	daily_SJ	sox_area	Developmental	$—	1.75756E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.85750E-05	$—
Modesto, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.47389E-05	$16,729,458.92
	daily	pocpec_egu_negu		$4,665.48	1.57182E-05	$296,819,481.99
	daily	nh3_area	Developmental	$4,653.69	6.51515E-06	$714,286,892.44
	daily	POCPEC_area	Developmental	$3,404.58	2.47389E-05	$137,620,446.13
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.57182E-05	$116,584,904.11
	daily	sox_area	Developmental	$—	–7.73640E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	6.10820E-07	$—
	daily_SJ	pocpec_area		$—	2.12404E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	5.66538E-06	$953,157,269.98
	daily_SJ	sox_area	Developmental	$—	2.47653E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	1.08366E-04	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Oakland-Fremont-Hayward, CA Metropolitan Division	daily	pocpec_area		$413.87	2.32644E-05	$17,789,753.41
	daily	pocpec_egu_negu		$4,665.48	1.55483E-05	$300,064,187.06
	daily	nh3_area	Developmental	$4,653.69	3.24150E-06	$1,435,658,373.48
	daily	POCPEC_area	Developmental	$3,404.58	2.32644E-05	$146,342,676.89
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.55483E-05	$117,859,360.99
	daily	sox_area	Developmental	$—	5.98392E-06	$—
	daily	sox_negu_pt	Developmental	$—	1.04277E-06	$—
	daily_SJ	pocpec_area		$—	–5.15501E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–1.92864E-05	–$279,990,042.80
	daily_SJ	sox_area	Developmental	$—	1.51348E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.19907E-06	$—
Riverside-San Bernardino-Ontario, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.24467E-05	$18,437,797.53
	daily	pocpec_egu_negu		$4,665.48	1.66080E-05	$280,918,207.69
	daily	nh3_area	Developmental	$4,653.69	3.62696E-06	$1,283,082,541.27
	daily	POCPEC_area	Developmental	$3,404.58	2.24467E-05	$151,673,639.53
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.66080E-05	$110,339,193.67
	daily	sox_area	Developmental	$—	–8.36330E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.36143E-06	$—
	daily_SJ	pocpec_area		$—	3.43487E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–5.20033E-06	–$1,038,394,654.18
	daily_SJ	sox_area	Developmental	$—	7.02267E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	4.92793E-06	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Sacramento-Arden-Arcade-Roseville, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	3.24297E-05	$12,762,023.70
	daily	pocpec_egu_negu		$4,665.48	–2.29231E-06	–$2,035,276,951.80
	daily	nh3_area	Developmental	$4,653.69	5.35304E-06	$869,353,747.35
	daily	POCPEC_area	Developmental	$3,404.58	3.24297E-05	$104,983,395.10
	daily	POCPEC_egu_negu	Developmental	$1,832.51	–2.29231E-06	–$799,417,095.81
	daily	sox_area	Developmental	$—	2.78068E-05	$—
	daily	sox_negu_pt	Developmental	$—	1.77563E-06	$—
	daily_SJ	pocpec_area		$—	–2.29473E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–3.29080E-06	–$1,640,940,074.14
	daily_SJ	sox_area	Developmental	$—	3.46552E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.05420E-05	$—
San Francisco-San Mateo-Redwood City, CA Metropolitan Division	daily	pocpec_area		$413.87	2.49747E-05	$16,571,522.56
	daily	pocpec_egu_negu		$4,665.48	1.12818E-06	$4,135,420,644.69
	daily	nh3_area	Developmental	$4,653.69	1.01066E-06	$4,604,617,855.20
	daily	POCPEC_area	Developmental	$3,404.58	2.49747E-05	$136,321,224.66
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.12818E-06	$1,624,312,582.53
	daily	sox_area	Developmental	$—	9.93926E-06	$—
	daily	sox_negu_pt	Developmental	$—	3.11963E-06	$—
	daily_SJ	pocpec_area		$—	–4.13024E-07	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–4.16643E-06	–$1,296,074,822.38
	daily_SJ	sox_area	Developmental	$—	7.83322E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.39345E-06	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
San Jose-Sunnyvale-Santa Clara, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.37302E-05	$17,440,583.48
	daily	pocpec_egu_negu		$4,665.48	7.28727E-06	$640,222,985.44
	daily	nh3_area	Developmental	$4,653.69	6.06688E-07	$7,670,640,963.62
	daily	POCPEC_area	Developmental	$3,404.58	2.37302E-05	$143,470,323.29
	daily	POCPEC_egu_negu	Developmental	$1,832.51	7.28727E-06	$251,467,103.40
	daily	sox_area	Developmental	$—	1.26976E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.80488E-07	$—
	daily_SJ	pocpec_area		$—	–1.47085E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.23324E-05	–$241,801,033.52
	daily_SJ	sox_area	Developmental	$—	–1.59014E-06	–$0.00
	daily_SJ	sox_negu_pt	Developmental	$—	1.05576E-05	$—
Santa Rosa-Petaluma, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	4.48468E-05	$9,228,482.21
	daily	pocpec_egu_negu		$4,665.48	4.18355E-05	$111,519,553.74
	daily	nh3_area	Developmental	$4,653.69	4.82269E-07	$9,649,559,509.47
	daily	POCPEC_area	Developmental	$3,404.58	4.48468E-05	$75,915,655.40
	daily	POCPEC_egu_negu	Developmental	$1,832.51	4.18355E-05	$43,802,705.92
	daily	sox_area	Developmental	$—	–3.28269E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.97442E-06	$—
	daily_SJ	pocpec_area		$—	–2.98388E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–3.79326E-06	–$1,423,578,922.50
	daily_SJ	sox_area	Developmental	$—	–1.19397E-06	–$0.00
	daily_SJ	sox_negu_pt	Developmental	$—	2.29526E-06	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Stockton, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.22923E-05	$18,565,518.61
	daily	pocpec_egu_negu		$4,665.48	1.28722E-05	$362,447,303.08
	daily	nh3_area	Developmental	$4,653.69	5.72554E-06	$812,794,472.90
	daily	POCPEC_area	Developmental	$3,404.58	2.22923E-05	$152,724,303.07
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.28722E-05	$142,362,232.40
	daily	sox_area	Developmental	$—	–7.55842E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	–4.48950E-07	–$0.00
	daily_SJ	pocpec_area		$—	7.05877E-05	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–1.99618E-04	–$27,051,717.23
	daily_SJ	sox_area	Developmental	$—	1.95770E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.57364E-05	$—
Vallejo-Fairfield, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	2.47283E-05	$16,736,634.11
	daily	pocpec_egu_negu		$4,665.48	1.21109E-05	$385,231,115.94
	daily	nh3_area	Developmental	$4,653.69	3.38678E-06	$1,374,075,283.68
	daily	POCPEC_area	Developmental	$3,404.58	2.47283E-05	$137,679,470.90
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.21109E-05	$151,311,269.77
	daily	sox_area	Developmental	$—	5.19470E-07	$—
	daily	sox_negu_pt	Developmental	$—	6.25961E-07	$—
	daily_SJ	pocpec_area		$—	–2.06931E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.25966E-05	–$238,974,301.18
	daily_SJ	sox_area	Developmental	$—	5.27118E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	5.27013E-06	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Visalia-Porterville, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	4.69665E-06	$88,119,823.85
	daily	pocpec_egu_negu		$4,665.48	6.02814E-06	$773,950,864.29
	daily	nh3_area	Developmental	$4,653.69	–4.36443E-07	–$10,662,764,692.25
	daily	POCPEC_area	Developmental	$3,404.58	4.69665E-06	$724,894,303.45
	daily	POCPEC_egu_negu	Developmental	$1,832.51	6.02814E-06	$303,992,806.33
	daily	sox_area	Developmental	$—	2.72836E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.24116E-06	$—
	daily_SJ	pocpec_area		$—	3.01884E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	7.36748E-04	$7,329,505.12
	daily_SJ	sox_area	Developmental	$—	3.07092E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.68331E-06	$—
Yuba City, CA Metropolitan Statistical Area	daily	pocpec_area		$413.87	1.96091E-05	$21,105,886.90
	daily	pocpec_egu_negu		$4,665.48	1.06391E-05	$438,521,284.18
	daily	nh3_area	Developmental	$4,653.69	5.33627E-07	$8,720,861,267.54
	daily	POCPEC_area	Developmental	$3,404.58	1.96091E-05	$173,621,967.39
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.06391E-05	$172,242,608.62
	daily	sox_area	Developmental	$—	–3.76941E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.33278E-06	$—
	daily_SJ	pocpec_area		$—	2.05451E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–5.02853E-06	–$1,073,873,403.39
	daily_SJ	sox_area	Developmental	$—	5.36392E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–1.19726E-06	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
CLEVELAND						
Cleveland-Elyria-Mentor, OH Metropolitan Statistical Area	daily	nh3_area		$359.58	6.92841E-06	$51,898,987.62
	daily	nox_negu_area		$3,089.17		
	daily	POCPEC_area		$1,919.00	1.51470E-03	$1,266,917.17
	daily	POCPEC_egu_negu		$42,361.13	1.74260E-03	$24,309,191.91
	daily	sox_area		$2,205.26	1.69830E-06	$1,298,510,935.56
	daily	sox_negu_pt		$2,227.68	1.69830E-06	$1,311,712,009.72
	daily	nh3_area	Developmental	$2,652.47	6.92841E-06	$382,840,279.13
	daily	pocpec_area	Developmental	$3,327.09	1.51470E-03	$2,196,530.92
	daily	pocpec_egu_negu	Developmental	$3,875.90	1.74260E-03	$2,224,210.43
	daily	sox_area	Developmental	$—	1.69830E-06	$—
	daily	sox_negu_pt	Developmental	$—	1.69830E-06	$—
MONTANA-IDAHO						
Missoula, MT Metropolitan Statistical Area	daily	nh3_area		$72.42	8.40414E-03	$8,617.69
	daily	nox_negu_area		$1,877.57	3.01562E-04	$6,226,157.66
	daily	POCPEC_area		$1,882.96	3.56803E-03	$527,730.41
	daily	POCPEC_egu_negu		$14,463.69	2.51111E-03	$5,759,878.37
	daily	sox_area		$2,205.23	5.39262E-04	$4,089,340.12
	daily	pocpec_area	Developmental	$3,448.95	3.56803E-03	$966,625.38
	daily	sox_area	Developmental	$—	5.39262E-04	$—

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
no_CBSA—Lincoln County, MT	daily	nh3_area		$72.42	–2.20314E-03	–$32,873.22
	daily	nox_negu_area		$1,877.57	3.41737E-04	$5,494,203.31
	daily	POCPEC_area		$1,882.96	5.67344E-03	$331,889.96
	daily	POCPEC_egu_negu		$14,463.69	1.72347E-03	$8,392,183.87
	daily	sox_area		$2,205.23	–2.93736E-03	–$750,750.92
	daily	pocpec_area	Developmental	$3,448.95	5.67344E-03	$607,911.25
	daily	sox_area	Developmental	$—	–2.93736E-03	–$0.00
no_CBSA—Shoshone County, ID	daily	nh3_area		$72.42	–1.10003E-04	–$658,384.25
	daily	nox_negu_area		$1,877.57	1.49074E-04	$12,594,902.91
	daily	POCPEC_area		$1,882.96	4.27748E-03	$440,202.92
	daily	POCPEC_egu_negu		$14,463.69		
	daily	sox_area		$2,205.23	–3.06755E-03	–$718,888.75
	daily	pocpec_area	Developmental	$3,448.95	4.27748E-03	$806,304.32
	daily	sox_area	Developmental	$—	–3.06755E-03	–$0.00
OREGON						
Eugene-Springfield, OR Metropolitan Statistical Area	daily	nox_negu_area		$2,537.11	1.46185E-04	$17,355,485.84
	daily	POCPEC_area		$1,841.08	4.72557E-04	$3,895,987.90
	daily	POCPEC_egu_negu		$6,841.69	6.76122E-05	$101,190,121.43
	daily	sox_area		$2,206.37	2.85787E-05	$77,203,193.51
	daily	sox_negu_pt		$28,179.53	–1.58689E-04	–$177,577,080.44
	daily	pocpec_area	Developmental	$3,132.66	4.72557E-04	$6,629,171.30
	daily	sox_area	Developmental	$—	2.85787E-05	$—
	daily	sox_negu_pt	Developmental	$—	–1.58689E-04	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Klamath Falls, OR Micropolitan Statistical Area	daily	nox_negu_area		$2,537.11	3.75495E-05	$67,567,123.33
	daily	POCPEC_area		$1,841.08	1.14385E-03	$1,609,542.11
	daily	POCPEC_egu_negu		$6,841.69	9.95506E-04	$6,872,572.07
	daily	sox_area		$2,206.37	–1.15393E-06	–$1,912,045,710.29
	daily	sox_negu_pt		$28,179.53	–1.19165E-04	–$236,474,882.04
	daily	pocpec_area	Developmental	$3,132.66	1.14385E-03	$2,738,697.00
	daily	sox_area	Developmental	$—	–1.15393E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	–1.19165E-04	–$0.00
Medford, OR Metropolitan Statistical Area	daily	nox_negu_area		$2,537.11	3.63606E-05	$69,776,398.01
	daily	POCPEC_area		$1,841.08	7.46085E-04	$2,467,649.60
	daily	POCPEC_egu_negu		$6,841.69	8.65888E-04	$7,901,352.98
	daily	sox_area		$2,206.37	1.56454E-05	$141,023,361.91
	daily	sox_negu_pt		$28,179.53	–3.06611E-05	–$919,064,525.34
	daily	pocpec_area	Developmental	$3,132.66	7.46085E-04	$4,198,799.47
	daily	sox_area	Developmental	$—	1.56454E-05	$—
	daily	sox_negu_pt	Developmental	$—	–3.06611E-05	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
PITTSBURGH						
Pittsburgh, PA Metropolitan Statistical Area	daily	nh3_area		$665.30	6.92841E-06	$96,024,480.32
	daily	nox_negu_area		$3,499.44	–4.28800E-06	–$816,100,829.18
	daily	POCPEC_area		$11,424.17	7.69671E-04	$14,842,922.10
	daily	POCPEC_egu_negu		$32,372.26	4.54322E-04	$71,254,002.11
	daily	sox_area		$2,205.38	1.34807E-05	$163,595,959.64
	daily	sox_negu_pt		$4,709.52	2.76302E-05	$170,448,453.43
	daily	nh3_area	Developmental	$6,410.21	6.92841E-06	$925,205,841.94
	daily	pocpec_area	Developmental	$3,335.52	7.69671E-04	$4,333,695.73
	daily	pocpec_egu_negu	Developmental	$5,776.61	4.54322E-04	$12,714,802.59
	daily	sox_area	Developmental	$—	1.34807E-05	$—
	daily	sox_negu_pt	Developmental	$—	2.76302E-05	$—
UTAH-IDAHO						
Logan, UT-ID Metropolitan Statistical Area	daily	nh3_area		$255.99	–3.49370E-06	–$73,270,623.39
	daily	nox_egu		$1,286.52	8.91658E-07	$1,442,837,652.41
	daily	nox_negu_area		$2,583.27	–1.44901E-06	–$1,782,781,216.04
	daily	POCPEC_area		$3,009.01	5.98476E-03	$502,778.44
	daily	POCPEC_egu_negu		$12,444.30	2.44403E-03	$5,091,706.83
	daily	sox_area		$2,206.77	–2.85386E-05	–$77,325,812.34
	daily	sox_negu_pt		$10,543.77	–2.17457E-05	–$484,867,081.49
	daily	pocpec_area	Developmental	$3,389.30	5.98476E-03	$566,321.62
	daily	pocpec_egu_negu	Developmental	$9,040.28	2.44403E-03	$3,698,917.55
	daily	sox_area	Developmental	$—	–2.85386E-05	–$0.00
	daily	sox_negu_pt	Developmental	$—	–2.17457E-05	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Salt Lake City, UT Metropolitan Statistical Area	daily	nh3_area		$255.99	3.20635E-04	$798,370.66
	daily	nox_egu		$1,286.52	3.69945E-05	$34,775,919.00
	daily	nox_negu_area		$2,583.27	8.82007E-05	$29,288,518.23
	daily	POCPEC_area		$3,009.01	4.00978E-03	$750,417.12
	daily	POCPEC_egu_negu		$12,444.30	8.21464E-04	$15,148,934.84
	daily	sox_area		$2,206.77	–2.94250E-05	–$74,996,446.15
	daily	sox_negu_pt		$10,543.77	1.83000E-04	$57,616,251.88
	daily	pocpec_area	Developmental	$3,389.30	4.00978E-03	$845,257.88
	daily	pocpec_egu_negu	Developmental	$9,040.28	8.21464E-04	$11,005,083.93
	daily	sox_area	Developmental	$—	–2.94250E-05	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.83000E-04	$—
WASHINGTON						
Seattle-Bellevue-Everett, WA Metropolitan Division	daily	nh3_area		$72.54	1.98544E-05	$3,653,708.54
	daily	nox_egu		$372.31	4.84570E-05	$7,683,364.75
	daily	nox_negu_area		$5,128.89	1.40820E-05	$364,215,866.14
	daily	POCPEC_area		$2,177.65	4.47865E-04	$4,862,300.62
	daily	POCPEC_egu_negu		$7,917.19	9.83956E-05	$80,462,835.93
	daily	sox_area		$2,204.80	2.97207E-04	$7,418,405.15
	daily	sox_egu		$1,702.25	1.14359E-04	$14,885,150.94
	daily	sox_negu_pt		$10,748.29	–8.69413E-06	–$1,236,269,499.23
	daily	pocpec_area	Developmental	$3,115.43	4.47865E-04	$6,956,189.34
	daily	pocpec_egu_negu	Developmental	$5,412.65	9.83956E-05	$55,009,059.51
	daily	sox_area	Developmental	$—	2.97207E-04	$—
	daily	sox_negu_pt	Developmental	$—	–8.69413E-06	–$0.00

(continued)

Table C-2: 15/35 Selected Standard—Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	ug/ton	$/ug
Tacoma, WA Metropolitan Division	daily	nh3_area		$72.54	7.04399E-05	$1,029,847.85
	daily	nox_egu		$372.31	–7.20081E-04	–$517,042.71
	daily	nox_negu_area		$5,128.89	1.60757E-05	$319,046,453.36
	daily	POCPEC_area		$2,177.65	5.47482E-04	$3,977,576.43
	daily	POCPEC_egu_negu		$7,917.19	1.64401E-04	$48,157,791.13
	daily	sox_area		$2,204.80	4.69105E-04	$4,700,021.48
	daily	sox_egu		$1,702.25	1.81761E-04	$9,365,284.62
	daily	sox_negu_pt		$10,748.29	–2.72905E-05	–$393,846,958.71
	daily	pocpec_area	Developmental	$3,115.43	5.47482E-04	$5,690,469.78
	daily	pocpec_egu_negu	Developmental	$5,412.65	1.64401E-04	$32,923,457.99
	daily	sox_area	Developmental	$—	4.69105E-04	$—
	daily	sox_negu_pt	Developmental	$—	–2.72905E-05	–$0.00

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
CALIFORNIA						
Bakersfield, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	2.13771E-05	$217,694,888.01
	annual	nox_negu_area		$1,657.82	1.57552E-05	$105,223,565.29
	annual	pocpec_area		$287.62	7.33446E-04	$392,149.10
	annual	POCPEC_area	Developmental	$3,404.58	7.33446E-04	$4,641,889.37
	annual	pocpec_egu_negu		$4,665.48	6.37028E-04	$7,323,823.23
	annual	POCPEC_egu_negu	Developmental	$2,299.07	6.37028E-04	$3,609,055.52
	annual	sox_area	Developmental	$—	5.06882E-05	$—
	annual	sox_negu_pt	Developmental	$—	1.04278E-05	$—
	daily	nh3_area	Developmental	$4,653.69	5.60983E-07	$8,295,590,758.47
	daily	nox_negu_area		$1,645.20	1.69326E-06	$971,615,294.27
	daily	pocpec_area		$413.87	7.73452E-06	$53,509,204.73
	daily	POCPEC_area	Developmental	$3,404.58	7.73452E-06	$440,179,246.82
	daily	pocpec_egu_negu		$4,665.48	4.44573E-06	$1,049,429,556.46
	daily	POCPEC_egu_negu	Developmental	$1,832.51	4.44573E-06	$412,195,464.38
	daily	sox_area	Developmental	$—	2.73613E-05	$—
	daily	sox_negu_pt	Developmental	$—	3.08962E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	3.49135E-05	$76,186,172.28
	daily_SJ	pocpec_area		$—	2.90120E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	8.93150E-04	$6,046,016.91
	daily_SJ	sox_area	Developmental	$—	1.69833E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–5.94129E-06	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Chico, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	1.53702E-06	$3,027,732,489.14
	daily	nox_negu_area		$1,645.20	6.00099E-07	$2,741,543,167.35
	daily	pocpec_area		$413.87	2.50250E-05	$16,538,182.38
	daily	POCPEC_area	Developmental	$3,404.58	2.50250E-05	$136,046,960.56
	daily	pocpec_egu_negu		$4,665.48	9.57012E-06	$487,504,907.15
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.57012E-06	$191,482,420.48
	daily	sox_area	Developmental	$—	5.15157E-06	$—
	daily	sox_negu_pt	Developmental	$—	6.10457E-07	$—
	daily_SJ	nox_negu_area		$2,659.93	9.30953E-07	$2,857,207,534.57
	daily_SJ	pocpec_area		$—	–9.80789E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	1.22646E-06	$4,402,915,708.62
	daily_SJ	sox_area	Developmental	$—	5.96512E-07	$—
	daily_SJ	sox_negu_pt	Developmental	$—	1.02869E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
El Centro, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	8.85951E-06	$525,275,708.30
	annual	nox_negu_area		$1,657.82	1.48277E-05	$111,805,493.49
	annual	pocpec_area		$287.62	6.30441E-03	$45,622.08
	annual	POCPEC_area	Developmental	$3,404.58	6.30441E-03	$540,030.91
	annual	pocpec_egu_negu		$4,665.48	1.22504E-03	$3,808,428.01
	annual	POCPEC_egu_negu	Developmental	$2,299.07	1.22504E-03	$1,876,728.55
	annual	sox_area	Developmental	$—	1.98722E-03	$—
	annual	sox_negu_pt	Developmental	$—	1.04830E-03	$—
	daily	nh3_area	Developmental	$4,653.69	3.38222E-07	$13,759,262,822.82
	daily	nox_negu_area		$1,645.20	1.40899E-07	$11,676,430,018.54
	daily	pocpec_area		$413.87	4.88931E-05	$8,464,752.98
	daily	POCPEC_area	Developmental	$3,404.58	4.88931E-05	$69,633,040.00
	daily	pocpec_egu_negu		$4,665.48	9.86730E-06	$472,822,399.44
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.86730E-06	$185,715,417.78
	daily	sox_area	Developmental	$—	–6.17899E-07	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.56682E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	3.12373E-08	$85,152,235,498.14
	daily_SJ	pocpec_area		$—	2.46101E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	6.10019E-06	$885,218,329.27
	daily_SJ	sox_area	Developmental	$—	4.03989E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–3.56935E-06	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Fresno, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	2.33721E-05	$199,112,847.82
	annual	nox_negu_area		$1,657.82	1.43636E-05	$115,418,023.05
	annual	pocpec_area		$287.62	5.88962E-04	$488,351.01
	annual	POCPEC_area	Developmental	$3,404.58	5.88962E-04	$5,780,636.42
	annual	pocpec_egu_negu		$4,665.48	2.94214E-04	$15,857,438.67
	annual	POCPEC_egu_negu	Developmental	$2,299.07	2.94214E-04	$7,814,276.08
	annual	sox_area	Developmental	$—	5.55483E-05	$—
	annual	sox_negu_pt	Developmental	$—	2.45551E-05	$—
	daily	nh3_area	Developmental	$4,653.69	1.89131E-06	$2,460,561,933.51
	daily	nox_negu_area		$1,645.20	1.67669E-06	$981,217,346.79
	daily	pocpec_area		$413.87	6.78513E-06	$60,996,327.88
	daily	POCPEC_area	Developmental	$3,404.58	6.78513E-06	$501,770,074.87
	daily	pocpec_egu_negu		$4,665.48	1.98551E-06	$2,349,764,273.17
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.98551E-06	$922,941,582.69
	daily	sox_area	Developmental	$—	2.38850E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.03621E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	5.50453E-05	$48,322,489.40
	daily_SJ	pocpec_area		$—	2.76451E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	2.73284E-04	$19,759,663.94
	daily_SJ	sox_area	Developmental	$—	3.69744E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.45742E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Hanford-Corcoran, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	1.42280E-05	$327,079,378.02
	annual	nox_negu_area		$1,657.82	1.63691E-05	$101,277,303.93
	annual	pocpec_area		$287.62	2.11666E-04	$1,358,839.81
	annual	POCPEC_area	Developmental	$3,404.58	2.11666E-04	$16,084,657.85
	annual	pocpec_egu_negu		$4,665.48	1.74456E-04	$26,743,020.95
	annual	POCPEC_egu_negu	Developmental	$2,299.07	1.74456E-04	$13,178,505.88
	annual	sox_area	Developmental	$—	2.54838E-05	$—
	annual	sox_negu_pt	Developmental	$—	4.31756E-06	$—
	daily	nh3_area	Developmental	$4,653.69	–1.45302E-07	–$32,027,676,084.71
	daily	nox_negu_area		$1,645.20	2.19162E-06	$750,676,355.02
	daily	pocpec_area		$413.87	6.49896E-06	$63,682,191.33
	daily	POCPEC_area	Developmental	$3,404.58	6.49896E-06	$523,864,616.51
	daily	pocpec_egu_negu		$4,665.48	9.16665E-06	$508,962,430.33
	daily	POCPEC_egu_negu	Developmental	$1,832.51	9.16665E-06	$199,910,517.13
	daily	sox_area	Developmental	$—	2.12439E-05	$—
	daily	sox_negu_pt	Developmental	$—	3.95878E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	5.71695E-05	$46,527,010.49
	daily_SJ	pocpec_area		$—	8.66795E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	3.94249E-04	$13,696,927.58
	daily_SJ	sox_area	Developmental	$—	1.70676E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	9.59128E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Los Angeles-Long Beach-Glendale, CA Metropolitan Division	annual	nh3_area	Developmental	$4,653.69	–1.42927E-05	–$325,598,759.54
	annual	nox_negu_area		$1,657.82	4.29512E-06	$385,977,182.44
	annual	pocpec_area		$287.62	2.24700E-04	$1,280,018.63
	annual	POCPEC_area	Developmental	$3,404.58	2.24700E-04	$15,151,647.48
	annual	pocpec_egu_negu		$4,665.48	3.08572E-04	$15,119,584.61
	annual	POCPEC_egu_negu	Developmental	$2,299.07	3.08572E-04	$7,450,674.14
	annual	sox_area	Developmental	$—	1.61722E-04	$—
	annual	sox_negu_pt	Developmental	$—	1.12259E-05	$—
	daily	nh3_area	Developmental	$4,653.69	–1.00213E-06	–$4,643,794,109.01
	daily	nox_negu_area		$1,645.20	–1.59398E-07	–$10,321,317,163.22
	daily	pocpec_area		$413.87	4.05735E-05	$10,200,451.38
	daily	POCPEC_area	Developmental	$3,404.58	4.05735E-05	$83,911,301.42
	daily	pocpec_egu_negu		$4,665.48	–4.95074E-06	–$942,380,424.35
	daily	POCPEC_egu_negu	Developmental	$1,832.51	–4.95074E-06	–$370,148,652.90
	daily	sox_area	Developmental	$—	9.98231E-06	$—
	daily	sox_negu_pt	Developmental	$—	8.83626E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	1.38352E-06	$1,922,578,586.45
	daily_SJ	pocpec_area		$—	–1.95929E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.72676E-05	–$198,037,231.00
	daily_SJ	sox_area	Developmental	$—	2.27002E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–1.74127E-05	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Merced, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	7.37090E-06	$631,359,181.44
	annual	nox_negu_area		$1,657.82	7.66415E-06	$216,308,177.14
	annual	pocpec_area		$287.62	2.10444E-04	$1,366,730.28
	annual	POCPEC_area	Developmental	$3,404.58	2.10444E-04	$16,178,057.76
	annual	pocpec_egu_negu		$4,665.48	1.88605E-04	$24,736,780.37
	annual	POCPEC_egu_negu	Developmental	$2,299.07	1.88605E-04	$12,189,864.65
	annual	sox_area	Developmental	$—	4.42085E-05	$—
	annual	sox_negu_pt	Developmental	$—	1.53218E-05	$—
	daily	nh3_area	Developmental	$4,653.69	3.41426E-06	$1,363,014,354.64
	daily	nox_negu_area		$1,645.20	9.68998E-07	$1,697,833,548.86
	daily	pocpec_area		$413.87	1.72796E-05	$23,951,249.69
	daily	POCPEC_area	Developmental	$3,404.58	1.72796E-05	$197,028,587.94
	daily	pocpec_egu_negu		$4,665.48	1.17795E-05	$396,067,784.03
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.17795E-05	$155,567,701.67
	daily	sox_area	Developmental	$—	4.30385E-06	$—
	daily	sox_negu_pt	Developmental	$—	1.96894E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	2.58471E-05	$102,910,033.46
	daily_SJ	pocpec_area		$—	6.18317E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	4.74982E-04	$11,368,851.87
	daily_SJ	sox_area	Developmental	$—	1.75756E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.85750E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Modesto, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	6.51515E-06	$714,286,760.93
	daily	nox_negu_area		$1,645.20	1.60408E-06	$1,025,632,956.70
	daily	pocpec_area		$413.87	2.47389E-05	$16,729,442.87
	daily	POCPEC_area	Developmental	$3,404.58	2.47389E-05	$137,620,314.08
	daily	pocpec_egu_negu		$4,665.48	1.57182E-05	$296,820,275.99
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.57182E-05	$116,585,215.98
	daily	sox_area	Developmental	$—	–7.73640E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	6.10820E-07	$—
	daily_SJ	nox_negu_area		$2,659.93	2.68842E-05	$98,940,118.21
	daily_SJ	pocpec_area		$—	2.12404E-04	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	5.66538E-06	$953,157,599.31
	daily_SJ	sox_area	Developmental	$—	2.47653E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	1.08366E-04	$—
Oakland-Fremont-Hayward, CA Metropolitan Division	daily	nh3_area	Developmental	$4,653.69	3.24150E-06	$1,435,657,994.90
	daily	nox_negu_area		$1,645.20	9.88374E-07	$1,664,549,364.09
	daily	pocpec_area		$413.87	2.32644E-05	$17,789,756.63
	daily	POCPEC_area	Developmental	$3,404.58	2.32644E-05	$146,342,703.36
	daily	pocpec_egu_negu		$4,665.48	1.55483E-05	$300,063,702.27
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.55483E-05	$117,859,170.57
	daily	sox_area	Developmental	$—	5.98392E-06	$—
	daily	sox_negu_pt	Developmental	$—	1.04277E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	8.14465E-07	$3,265,856,637.09
	daily_SJ	pocpec_area		$—	–5.15501E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–1.92864E-05	–$279,990,044.80
	daily_SJ	sox_area	Developmental	$—	1.51348E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.19907E-06	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Riverside-San Bernardino-Ontario, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	5.09196E-05	$91,392,811.23
	annual	nox_negu_area		$1,657.82	7.65189E-06	$216,654,750.11
	annual	pocpec_area		$287.62	1.19385E-04	$2,409,181.95
	annual	POCPEC_area	Developmental	$3,404.58	1.19385E-04	$28,517,612.67
	annual	pocpec_egu_negu		$4,665.48	–8.84176E-05	–$52,766,422.77
	annual	POCPEC_egu_negu	Developmental	$2,299.07	–8.84176E-05	–$26,002,395.70
	annual	sox_area	Developmental	$—	4.50740E-04	$—
	annual	sox_negu_pt	Developmental	$—	3.14236E-05	$—
	daily	nh3_area	Developmental	$4,653.69	3.62696E-06	$1,283,081,531.22
	daily	nox_negu_area		$1,645.20	9.74092E-07	$1,688,954,752.92
	daily	pocpec_area		$413.87	2.24467E-05	$18,437,811.09
	daily	POCPEC_area	Developmental	$3,404.58	2.24467E-05	$151,673,751.07
	daily	pocpec_egu_negu		$4,665.48	1.66080E-05	$280,917,657.88
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.66080E-05	$110,338,977.71
	daily	sox_area	Developmental	$—	–8.36330E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.36143E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	6.85715E-07	$3,879,054,601.29
	daily_SJ	pocpec_area		$—	3.43487E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–5.20033E-06	–$1,038,395,640.28
	daily_SJ	sox_area	Developmental	$—	7.02267E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	4.92793E-06	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Sacramento-Arden-Arcade-Roseville, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	5.35304E-06	$869,353,748.61
	daily	nox_negu_area		$1,645.20	5.42861E-07	$3,030,605,096.30
	daily	pocpec_area		$413.87	3.24297E-05	$12,762,005.64
	daily	POCPEC_area	Developmental	$3,404.58	3.24297E-05	$104,983,246.47
	daily	pocpec_egu_negu		$4,665.48	–2.29231E-06	–$2,035,274,662.69
	daily	POCPEC_egu_negu	Developmental	$1,832.51	–2.29231E-06	–$799,416,196.69
	daily	sox_area	Developmental	$—	2.78068E-05	$—
	daily	sox_negu_pt	Developmental	$—	1.77563E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	2.32163E-06	$1,145,714,832.22
	daily_SJ	pocpec_area		$—	–2.29473E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–3.29080E-06	–$1,640,938,373.65
	daily_SJ	sox_area	Developmental	$—	3.46552E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.05420E-05	$—
San Francisco-San Mateo-Redwood City, CA Metropolitan Division	daily	nh3_area	Developmental	$4,653.69	1.01066E-06	$4,604,600,350.72
	daily	nox_negu_area		$1,645.20	4.23282E-07	$3,886,764,174.20
	daily	pocpec_area		$413.87	2.49747E-05	$16,571,490.92
	daily	POCPEC_area	Developmental	$3,404.58	2.49747E-05	$136,320,964.34
	daily	pocpec_egu_negu		$4,665.48	1.12818E-06	$4,135,404,334.44
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.12818E-06	$1,624,306,176.18
	daily	sox_area	Developmental	$—	9.93926E-06	$—
	daily	sox_negu_pt	Developmental	$—	3.11963E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	1.65736E-07	$16,049,174,143.98
	daily_SJ	pocpec_area		$—	–4.13024E-07	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–4.16643E-06	–$1,296,073,616.98
	daily_SJ	sox_area	Developmental	$—	7.83322E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	3.39345E-06	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
San Jose-Sunnyvale-Santa Clara, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	6.06688E-07	$7,670,640,247.48
	daily	nox_negu_area		$1,645.20	5.15160E-07	$3,193,565,713.92
	daily	pocpec_area		$413.87	2.37302E-05	$17,440,561.57
	daily	POCPEC_area	Developmental	$3,404.58	2.37302E-05	$143,470,143.03
	daily	pocpec_egu_negu		$4,665.48	7.28727E-06	$640,223,356.90
	daily	POCPEC_egu_negu	Developmental	$1,832.51	7.28727E-06	$251,467,249.31
	daily	sox_area	Developmental	$—	1.26976E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.80488E-07	$—
	daily_SJ	nox_negu_area		$2,659.93	3.42777E-07	$7,759,931,167.86
	daily_SJ	pocpec_area		$—	–1.47085E-05	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.23324E-05	–$241,801,149.90
	daily_SJ	sox_area	Developmental	$—	–1.59014E-06	–$0.00
	daily_SJ	sox_negu_pt	Developmental	$—	1.05576E-05	$—
Santa Ana-Anaheim-Irvine, CA Metropolitan Division	annual	nh3_area	Developmental	$4,653.69	–7.86193E-06	–$591,926,586.79
	annual	nox_negu_area		$1,657.82	3.55914E-06	$465,791,824.94
	annual	pocpec_area		$287.62	1.98222E-04	$1,451,000.33
	annual	POCPEC_area	Developmental	$3,404.58	1.98222E-04	$17,175,566.73
	annual	pocpec_egu_negu		$4,665.48	7.54146E-05	$61,864,419.65
	annual	POCPEC_egu_negu	Developmental	$2,299.07	7.54146E-05	$30,485,733.82
	annual	sox_area	Developmental	$—	6.23109E-05	$—
	annual	sox_negu_pt	Developmental	$—	1.76892E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Santa Rosa-Petaluma, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	4.82269E-07	$9,649,563,605.50
	daily	nox_negu_area		$1,645.20	2.20831E-07	$7,450,028,814.71
	daily	pocpec_area		$413.87	4.48468E-05	$9,228,484.85
	daily	POCPEC_area	Developmental	$3,404.58	4.48468E-05	$75,915,677.11
	daily	pocpec_egu_negu		$4,665.48	4.18355E-05	$111,519,653.45
	daily	POCPEC_egu_negu	Developmental	$1,832.51	4.18355E-05	$43,802,745.08
	daily	sox_area	Developmental	$—	–3.28269E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.97442E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	2.77757E-07	$9,576,449,651.77
	daily_SJ	pocpec_area		$—	–2.98388E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–3.79326E-06	–$1,423,577,608.71
	daily_SJ	sox_area	Developmental	$—	–1.19397E-06	–$0.00
	daily_SJ	sox_negu_pt	Developmental	$—	2.29526E-06	$—
Stockton, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	5.72554E-06	$812,794,145.26
	daily	nox_negu_area		$1,645.20	1.16901E-06	$1,407,342,377.89
	daily	pocpec_area		$413.87	2.22923E-05	$18,565,514.29
	daily	POCPEC_area	Developmental	$3,404.58	2.22923E-05	$152,724,267.49
	daily	pocpec_egu_negu		$4,665.48	1.28722E-05	$362,446,237.79
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.28722E-05	$142,361,813.97
	daily	sox_area	Developmental	$—	–7.55842E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	–4.48950E-07	–$0.00
	daily_SJ	nox_negu_area		$2,659.93	1.05160E-05	$252,940,844.99
	daily_SJ	pocpec_area		$—	7.05877E-05	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–1.99618E-04	–$27,051,668.69
	daily_SJ	sox_area	Developmental	$—	1.95770E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.57364E-05	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Vallejo-Fairfield, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	3.38678E-06	$1,374,073,719.13
	daily	nox_negu_area		$1,645.20	9.16130E-07	$1,795,812,071.63
	daily	pocpec_area		$413.87	2.47283E-05	$16,736,614.09
	daily	POCPEC_area	Developmental	$3,404.58	2.47283E-05	$137,679,306.22
	daily	pocpec_egu_negu		$4,665.48	1.21109E-05	$385,229,872.43
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.21109E-05	$151,310,781.35
	daily	sox_area	Developmental	$—	5.19470E-07	$—
	daily	sox_negu_pt	Developmental	$—	6.25961E-07	$—
	daily_SJ	nox_negu_area		$2,659.93	4.42753E-07	$6,007,697,126.67
	daily_SJ	pocpec_area		$—	–2.06931E-06	–$0.00
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–2.25966E-05	–$238,974,004.94
	daily_SJ	sox_area	Developmental	$—	5.27118E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	5.27013E-06	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Visalia-Porterville, CA Metropolitan Statistical Area	annual	nh3_area	Developmental	$4,653.69	2.46450E-05	$188,828,784.36
	annual	nox_negu_area		$1,657.82	1.99979E-05	$82,899,620.25
	annual	pocpec_area		$287.62	7.22294E-04	$398,203.76
	annual	POCPEC_area	Developmental	$3,404.58	7.22294E-04	$4,713,558.73
	annual	pocpec_egu_negu		$4,665.48	4.06670E-04	$11,472,398.90
	annual	POCPEC_egu_negu	Developmental	$2,299.07	4.06670E-04	$5,653,403.06
	annual	sox_area	Developmental	$—	6.14453E-05	$—
	annual	sox_negu_pt	Developmental	$—	1.38684E-05	$—
	daily	nh3_area	Developmental	$4,653.69	–4.36443E-07	–$10,662,756,397.65
	daily	nox_negu_area		$1,645.20	2.12171E-06	$775,411,019.03
	daily	pocpec_area		$413.87	4.69665E-06	$88,119,833.11
	daily	POCPEC_area	Developmental	$3,404.58	4.69665E-06	$724,894,379.63
	daily	pocpec_egu_negu		$4,665.48	6.02814E-06	$773,950,250.33
	daily	POCPEC_egu_negu	Developmental	$1,832.51	6.02814E-06	$303,992,565.18
	daily	sox_area	Developmental	$—	2.72836E-05	$—
	daily	sox_negu_pt	Developmental	$—	5.24116E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	6.05240E-05	$43,948,283.75
	daily_SJ	pocpec_area		$—	3.01884E-03	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	7.36748E-04	$7,329,507.51
	daily_SJ	sox_area	Developmental	$—	3.07092E-04	$—
	daily_SJ	sox_negu_pt	Developmental	$—	8.68331E-06	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
Yuba City, CA Metropolitan Statistical Area	daily	nh3_area	Developmental	$4,653.69	5.33627E-07	$8,720,858,184.58
	daily	nox_negu_area		$1,645.20	1.97909E-07	$8,312,897,913.60
	daily	pocpec_area		$413.87	1.96091E-05	$21,105,915.83
	daily	POCPEC_area	Developmental	$3,404.58	1.96091E-05	$173,622,205.41
	daily	pocpec_egu_negu		$4,665.48	1.06391E-05	$438,522,098.86
	daily	POCPEC_egu_negu	Developmental	$1,832.51	1.06391E-05	$172,242,928.62
	daily	sox_area	Developmental	$—	–3.76941E-06	–$0.00
	daily	sox_negu_pt	Developmental	$—	1.33278E-06	$—
	daily_SJ	nox_negu_area		$2,659.93	1.14472E-07	$23,236,476,395.33
	daily_SJ	pocpec_area		$—	2.05451E-06	$—
	daily_SJ	POCPEC_egu_negu	Developmental	$5,400.00	–5.02853E-06	–$1,073,872,483.61
	daily_SJ	sox_area	Developmental	$—	5.36392E-06	$—
	daily_SJ	sox_negu_pt	Developmental	$—	–1.19726E-06	–$0.00
MONTANA-IDAHO						
Missoula, MT Metropolitan Statistical Area	daily	nh3_area		$72.42	8.40414E-03	$8,617.69
	daily	nox_negu_area		$1,877.57	3.01562E-04	$6,226,157.66
	daily	POCPEC_area		$1,882.96	3.56803E-03	$527,730.41
	daily	pocpec_area	Developmental	$3,448.95	3.56803E-03	$966,625.38
	daily	POCPEC_egu_negu		$14,463.69	2.51111E-03	$5,759,878.37
	daily	sox_area		$2,205.23	5.39262E-04	$4,089,340.12
	daily	sox_area	Developmental	$—	5.39262E-04	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
no_CBSA—Lincoln County, MT	annual	nh3_area		$72.42	–1.45128E-03	–$49,903.80
	annual	nox_negu_area		$1,877.57	9.77814E-04	$1,920,173.53
	annual	POCPEC_area		$1,882.96	1.80405E-02	$104,373.93
	annual	pocpec_area	Developmental	$3,448.95	1.80405E-02	$191,178.09
	annual	POCPEC_egu_negu		$14,463.69	4.95955E-03	$2,916,330.73
	annual	sox_area		$2,205.23	–8.23672E-05	–$26,773,105.48
	annual	sox_area	Developmental	$—	–8.23672E-05	–$0.00
	daily	nh3_area		$72.42	–2.20314E-03	–$32,873.22
	daily	nox_negu_area		$1,877.57	3.41737E-04	$5,494,203.31
	daily	POCPEC_area		$1,882.96	5.67344E-03	$331,889.96
	daily	pocpec_area	Developmental	$3,448.95	5.67344E-03	$607,911.25
	daily	POCPEC_egu_negu		$14,463.69	1.72347E-03	$8,392,183.87
	daily	sox_area		$2,205.23	–2.93736E-03	–$750,750.92
	daily	sox_area	Developmental	$—	–2.93736E-03	–$0.00
no_CBSA—Shoshone County, ID	daily	nh3_area		$72.42	–1.10003E-04	–$658,384.25
	daily	nox_negu_area		$1,877.57	1.49074E-04	$12,594,902.91
	daily	POCPEC_area		$1,882.96	4.27748E-03	$440,202.92
	daily	pocpec_area	Developmental	$3,448.95	4.27748E-03	$806,304.32
	daily	POCPEC_egu_negu		$14,463.69		
	daily	sox_area		$2,205.23	–3.06755E-03	–$718,888.75
	daily	sox_area	Developmental	$—	–3.06755E-03	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
OREGON						
Eugene-Springfield, OR Metropolitan Statistical Area	daily	nox_negu_area		$2,537.11	1.46185E-04	$17,355,485.84
	daily	POCPEC_area		$1,841.08	4.72557E-04	$3,895,987.90
	daily	pocpec_area	Developmental	$3,132.66	4.72557E-04	$6,629,171.30
	daily	POCPEC_egu_negu		$6,841.69	6.76122E-05	$101,190,121.43
	daily	sox_area		$2,206.37	2.85787E-05	$77,203,193.51
	daily	sox_area	Developmental	$—	2.85787E-05	$—
	daily	sox_negu_pt		$28,179.53	–1.58689E-04	–$177,577,080.44
	daily	sox_negu_pt	Developmental	$—	–1.58689E-04	–$0.00
Klamath Falls, OR Micropolitan Statistical Area	daily	nox_negu_area		$2,537.11	3.75495E-05	$67,567,123.33
	daily	POCPEC_area		$1,841.08	1.14385E-03	$1,609,542.11
	daily	pocpec_area	Developmental	$3,132.66	1.14385E-03	$2,738,697.00
	daily	POCPEC_egu_negu		$6,841.69	9.95506E-04	$6,872,572.07
	daily	sox_area		$2,206.37	–1.15393E-06	–$1,912,045,710.29
	daily	sox_area	Developmental	$—	–1.15393E-06	–$0.00
	daily	sox_negu_pt		$28,179.53	–1.19165E-04	–$236,474,882.04
	daily	sox_negu_pt	Developmental	$—	–1.19165E-04	–$0.00
Medford, OR Metropolitan Statistical Area	daily	nox_negu_area		$2,537.11	3.63606E-05	$69,776,398.01
	daily	POCPEC_area		$1,841.08	7.46085E-04	$2,467,649.60
	daily	pocpec_area	Developmental	$3,132.66	7.46085E-04	$4,198,799.47
	daily	POCPEC_egu_negu		$6,841.69	8.65888E-04	$7,901,352.98
	daily	sox_area		$2,206.37	1.56454E-05	$141,023,361.91
	daily	sox_area	Developmental	$—	1.56454E-05	$—
	daily	sox_negu_pt		$28,179.53	–3.06611E-05	–$919,064,525.34
	daily	sox_negu_pt	Developmental	$—	–3.06611E-05	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
UTAH-IDAHO						
Logan, UT-ID Metropolitan Statistical Area	daily	nh3_area		$255.99	–3.49370E-06	–$73,270,623.39
	daily	nox_egu		$1,286.52	8.91658E-07	$1,442,837,652.41
	daily	nox_negu_area		$2,583.27	–1.44901E-06	–$1,782,781,216.04
	daily	POCPEC_area		$3,009.01	5.98476E-03	$502,778.44
	daily	pocpec_area	Developmental	$3,389.30	5.98476E-03	$566,321.62
	daily	POCPEC_egu_negu		$12,444.30	2.44403E-03	$5,091,706.83
	daily	pocpec_egu_negu	Developmental	$9,040.28	2.44403E-03	$3,698,917.55
	daily	sox_area		$2,206.77	–2.85386E-05	–$77,325,812.34
	daily	sox_area	Developmental	$—	–2.85386E-05	–$0.00
	daily	sox_negu_pt		$10,543.77	–2.17457E-05	–$484,867,081.49
	daily	sox_negu_pt	Developmental	$—	–2.17457E-05	–$0.00
Salt Lake City, UT Metropolitan Statistical Area	daily	nh3_area		$255.99	3.20635E-04	$798,370.66
	daily	nox_egu		$1,286.52	3.69945E-05	$34,775,919.00
	daily	nox_negu_area		$2,583.27	8.82007E-05	$29,288,518.23
	daily	POCPEC_area		$3,009.01	4.00978E-03	$750,417.12
	daily	pocpec_area	Developmental	$3,389.30	4.00978E-03	$845,257.88
	daily	POCPEC_egu_negu		$12,444.30	8.21464E-04	$15,148,934.84
	daily	pocpec_egu_negu	Developmental	$9,040.28	8.21464E-04	$11,005,083.93
	daily	sox_area		$2,206.77	–2.94250E-05	–$74,996,446.15
	daily	sox_area	Developmental	$—	–2.94250E-05	–$0.00
	daily	sox_negu_pt		$10,543.77	1.83000E-04	$57,616,251.88
	daily	sox_negu_pt	Developmental	$—	1.83000E-04	$—

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
WASHINGTON						
Seattle-Bellevue-Everett, WA Metropolitan Division	daily	nh3_area		$72.54	1.98544E-05	$3,653,717.71
	daily	nox_egu		$359.28	4.84570E-05	$7,414,406.93
	daily	nox_negu_area		$4,739.66	1.40820E-05	$336,575,612.42
	daily	POCPEC_area		$2,177.65	4.47865E-04	$4,862,296.60
	daily	pocpec_area	Developmental	$3,115.43	4.47865E-04	$6,956,183.59
	daily	POCPEC_egu_negu		$7,917.19	9.83956E-05	$80,462,835.93
	daily	pocpec_egu_negu	Developmental	$5,412.65	9.83956E-05	$55,009,059.51
	daily	sox_area		$2,204.80	2.97207E-04	$7,418,402.85
	daily	sox_area	Developmental	$—	2.97207E-04	$—
	daily	sox_negu_pt		$10,683.89	–8.69413E-06	–$1,228,862,060.13
	daily	sox_negu_pt	Developmental	$—	–8.69413E-06	–$0.00
Tacoma, WA Metropolitan Division	daily	nh3_area		$72.54	7.04399E-05	$1,029,847.76
	daily	nox_egu		$359.28	–7.20081E-04	–$498,943.75
	daily	nox_negu_area		$4,739.66	1.60757E-05	$294,833,679.04
	daily	POCPEC_area		$2,177.65	5.47482E-04	$3,977,578.20
	daily	pocpec_area	Developmental	$3,115.43	5.47482E-04	$5,690,472.31
	daily	POCPEC_egu_negu		$7,917.19	1.64401E-04	$48,157,791.13
	daily	pocpec_egu_negu	Developmental	$5,412.65	1.64401E-04	$32,923,457.99
	daily	sox_area		$2,204.80	4.69105E-04	$4,700,016.53
	daily	sox_area	Developmental	$—	4.69105E-04	$—
	daily	sox_negu_pt		$10,683.89	–2.72905E-05	–$391,487,385.83
	daily	sox_negu_pt	Developmental	$—	–2.72905E-05	–$0.00

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
ATLANTA						
Atlanta-Sandy Springs-Marietta, GA Metropolitan Statistical Area	annual	nh3_area		$72.35	–2.93352E-06	–$24,664,205.86
	annual	nox_negu_area		$2,571.07	–3.68176E-06	–$698,326,829.17
	annual	POCPEC_area		$1,919.70	4.95456E-04	$3,874,612.48
	annual	POCPEC_area	Developmental	$3,465.64	4.95456E-04	$6,994,840.59
	annual	POCPEC_egu_negu		$73,504.82	2.47036E-04	$297,547,010.57
	annual	POCPEC_egu_negu	Developmental	$2,937.50	2.47036E-04	$11,890,979.45
	annual	sox_area	Developmental	$—	2.04124E-05	$—
	annual	sox_negu_pt		$9,000.50	1.18953E-05	$756,643,473.57
BIRMINGHAM						
Birmingham-Hoover, AL Metropolitan Statistical Area	annual	nox_negu_area		$4,049.74	6.14607E-07	$6,589,152,210.48
	annual	POCPEC_area		$1,919.65	5.49627E-04	$3,492,639.75
	annual	POCPEC_area	Developmental	$3,437.91	5.49627E-04	$6,254,986.73
	annual	POCPEC_egu_negu		$14,110.88	6.76329E-04	$20,863,924.19
	annual	POCPEC_egu_negu	Developmental	$7,507.28	6.76329E-04	$11,100,045.54
	annual	sox_area	Developmental	$—	2.07578E-05	$—
	annual	sox_negu_pt		$9,000.50	1.40440E-05	$640,878,746.17
CHICAGO						
Chicago-Naperville-Joliet, IL Metropolitan Division	annual	nh3_area	Developmental	$1,508.09	8.82829E-06	$170,824,487.52
	annual	nox_negu_area		$4,637.66	–4.46005E-07	–$10,398,220,143.08
	annual	POCPEC_area	Developmental	$2,734.43	6.59998E-05	$41,430,836.97
	annual	POCPEC_egu_negu		$42,114.67	8.26120E-05	$509,788,830.19
	annual	POCPEC_egu_negu	Developmental	$4,149.59	8.26120E-05	$50,229,809.62
	annual	sox_area		$2,203.44	6.28360E-06	$350,665,885.84
	annual	sox_area	Developmental	$—	6.28360E-06	$—
	annual	sox_negu_pt		$3,236.48	1.62830E-06	$1,987,643,873.12

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
CINCINNATI						
Cincinnati-Middletown, OH-KY-IN Metropolitan Statistical Area	annual	nh3_area		$545.02	6.96094E-06	$78,297,493.53
	annual	nh3_area	Developmental	$2,632.43	6.96094E-06	$378,171,021.84
	annual	nox_negu_area		$2,453.50	4.43931E-07	$5,526,761,876.04
	annual	POCPEC_area		$2,919.63	3.75360E-04	$7,778,220.02
	annual	POCPEC_area	Developmental	$3,435.37	3.75360E-04	$9,152,193.16
	annual	POCPEC_egu_negu		$10,442.73	5.34903E-04	$19,522,667.23
	annual	POCPEC_egu_negu	Developmental	$5,442.79	5.34903E-04	$10,175,282.97
	annual	sox_area		$2,205.53	4.55858E-06	$483,819,405.83
	annual	sox_area	Developmental	$—	4.55858E-06	$—
	annual	sox_negu_pt		$3,236.48	1.21161E-05	$267,122,301.62

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
CLEVELAND						
Cleveland-Elyria-Mentor, OH Metropolitan Statistical Area	annual	nh3_area		$525.49	8.44516E-06	$62,224,019.83
	annual	nh3_area	Developmental	$3,721.83	8.44516E-06	$440,705,750.12
	annual	nox_negu_area		$2,821.22	2.18731E-06	$1,289,810,780.59
	annual	POCPEC_area		$1,919.00	3.79601E-04	$5,055,308.07
	annual	POCPEC_area	Developmental	$3,321.45	3.79601E-04	$8,749,842.85
	annual	POCPEC_egu_negu		$31,871.17	5.48728E-04	$58,081,912.82
	annual	POCPEC_egu_negu	Developmental	$7,747.73	5.48728E-04	$14,119,429.03
	annual	sox_area		$2,204.32	6.84586E-06	$321,993,335.41
	annual	sox_area	Developmental	$—	6.84586E-06	$—
	annual	sox_negu_pt		$3,236.48	2.87017E-05	$112,762,676.73
	daily	nh3_area		$525.49	6.92841E-06	$75,845,944.93
	daily	nh3_area	Developmental	$3,721.83	6.92841E-06	$537,183,938.69
	daily	nox_negu_area		$2,821.22		
	daily	POCPEC_area		$1,919.00	1.51470E-03	$1,266,917.54
	daily	POCPEC_area	Developmental	$3,321.45	1.51470E-03	$2,192,809.86
	daily	POCPEC_egu_negu		$31,871.17	1.74260E-03	$18,289,467.88
	daily	POCPEC_egu_negu	Developmental	$7,747.73	1.74260E-03	$4,446,080.22
	daily	sox_area		$2,204.32	1.69830E-06	$1,297,957,542.92
	daily	sox_area	Developmental	$—	1.69830E-06	$—
	daily	sox_negu_pt		$3,236.48	1.69830E-06	$1,905,717,787.56

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
DETROIT						
Detroit-Livonia-Dearborn, MI Metropolitan Division&Warren-Troy-Farmington Hills, MI Metropolitan Division	annual	nh3_area		$552.14	3.18272E-05	$17,348,144.26
	annual	nh3_area	Developmental	$8,004.22	3.18272E-05	$251,489,985.19
	annual	nox_negu_area		$4,528.70	1.67161E-06	$2,709,181,714.16
	annual	POCPEC_area		$41,373.77	3.83747E-04	$107,815,236.56
	annual	POCPEC_area	Developmental	$3,345.26	3.83747E-04	$8,717,364.11
	annual	POCPEC_egu_negu		$24,822.06	3.40292E-04	$72,943,419.06
	annual	POCPEC_egu_negu	Developmental	$3,527.94	3.40292E-04	$10,367,402.31
	annual	sox_area		$2,205.74	4.65975E-06	$473,360,617.71
	annual	sox_area	Developmental	$—	4.65975E-06	$—
	annual	sox_negu_pt	Developmental	$—	1.47566E-05	$—
	annual	sox_negu_pt		$3,236.48	1.47566E-05	$219,324,269.72
GARY, IN						
Gary, IN Metropolitan Division	annual	nh3_area	Developmental	$1,888.11	1.50482E-06	$1,254,705,638.02
	annual	nox_negu_area		$5,477.25	5.26004E-07	$10,412,942,528.98
	annual	POCPEC_area	Developmental	$3,377.73	7.95697E-05	$42,449,985.88
	annual	POCPEC_egu_negu		$13,936.05	8.76926E-05	$158,919,318.24
	annual	POCPEC_egu_negu	Developmental	$2,129.69	8.76926E-05	$24,285,865.42
	annual	sox_area	Developmental	$—	5.50039E-06	$—
	annual	sox_negu_pt		$3,236.48	1.55855E-06	$2,076,597,169.55

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
PORTSMOUTH						
Portsmouth, OH Micropolitan Statistical Area	annual	nh3_area		$1,017.88	2.20417E-04	$4,617,968.61
	annual	nox_negu_area		$3,535.69	1.23438E-05	$286,434,280.42
	annual	POCPEC_area		$1,919.00	3.18900E-03	$601,755.47
	annual	POCPEC_area	Developmental	$3,483.33	3.18900E-03	$1,092,293.71
	annual	POCPEC_egu_negu	Developmental	$4,811.94	6.57168E-03	$732,223.43
	annual	sox_area		$2,209.14	1.71038E-04	$12,916,073.30
	annual	sox_area	Developmental	$—	1.71038E-04	$—
	annual	sox_negu_pt		$3,236.48	9.64993E-05	$33,538,901.51
ST. LOUIS						
St. Louis, MO-IL Metropolitan Statistical Area	annual	nh3_area		$383.09	4.24796E-06	$90,183,034.36
	annual	nh3_area	Developmental	$1,168.82	4.24796E-06	$275,149,134.13
	annual	nox_negu_area		$7,179.84	1.48918E-06	$4,821,334,933.95
	annual	POCPEC_area		$2,818.28	1.83903E-04	$15,324,796.23
	annual	POCPEC_area	Developmental	$3,381.42	1.83903E-04	$18,386,993.38
	annual	POCPEC_egu_negu		$12,875.82	3.56097E-04	$36,158,185.72
	annual	POCPEC_egu_negu	Developmental	$1,591.83	3.56097E-04	$4,470,203.53
	annual	sox_area		$2,207.05	5.39508E-06	$409,085,923.11
	annual	sox_area	Developmental	$—	5.39508E-06	$—
	annual	sox_negu_pt		$3,236.48	2.31531E-06	$1,397,860,553.71

(continued)

Table C-3: 14/35 Current Standard – Maximum Percent Reduction, Average Cost per Ton, and Resulting Cost per Microgram (continued)

CBSA and Division Titles and Components	*Standard*	*RSM Factor*	*Category*	*Avg.$/ton*	*ug/ton*	*$/ug*
PITTSBURGH						
Pittsburgh, PA Metropolitan Statistical Area	annual	nh3_area		$665.30	4.49345E-05	$14,805,927.96
	annual	nh3_area	Developmental	$6,410.21	4.49345E-05	$142,656,653.74
	annual	nox_negu_area		$3,138.46	2.26155E-06	$1,387,747,428.59
	annual	POCPEC_area		$11,424.17	2.96840E-04	$38,485,956.47
	annual	pocpec_area	Developmental	$3,335.52	2.96840E-04	$11,236,764.85
	annual	POCPEC_egu_negu		$24,907.39	5.70318E-04	$43,672,809.38
	annual	pocpec_egu_negu	Developmental	$5,776.61	5.70318E-04	$10,128,759.83
	annual	sox_area		$2,205.38	3.84901E-06	$572,973,687.06
	annual	sox_area	Developmental	$—	3.84901E-06	$—
	annual	sox_negu_pt	Developmental	$—	2.76302E-05	$—
	annual	sox_negu_pt		$3,236.48	2.76302E-05	$117,135,616.77
	annual	sox_negu_pt		$3,236.48	7.60584E-06	$425,525,716.90
	daily	nh3_area		$665.30	6.92841E-06	$96,024,480.32
	daily	nh3_area	Developmental	$6,410.21	6.92841E-06	$925,205,841.94
	daily	nox_negu_area		$3,138.46	–4.28800E-06	–$731,917,023.58
	daily	POCPEC_area		$11,424.17	7.69671E-04	$14,842,928.11
	daily	pocpec_area	Developmental	$3,335.52	7.69671E-04	$4,333,697.49
	daily	POCPEC_egu_negu		$24,907.39	4.54322E-04	$54,823,207.55
	daily	pocpec_egu_negu	Developmental	$5,776.61	4.54322E-04	$12,714,801.50
	daily	sox_area		$2,205.38	1.34807E-05	$163,595,469.91
	daily	sox_area	Developmental	$—	1.34807E-05	$—
	daily	sox_negu_pt	Developmental	$—	2.76302E-05	$—
	daily	sox_negu_pt		$3,236.48	2.76302E-05	$117,135,616.77
	daily	sox_negu_pt		$3,236.48	2.76302E-05	$117,135,616.77

Appendix D: Sensitivity of Emissions Inventory

Synopsis

As described in Section 2.3.3 of the RIA, the approach for future-year emissions projections for non-EGU stationary sources was modified for this analysis. Emission projection methods for all other source categories (including mobile sources and electric generating units) remain essentially unchanged from recent analyses. The methodology used in this RIA to forecast non-EGU stationary source categories recognizes the disconnection between prior projection estimates and the historical record. The methodology is called an 'interim' emissions projection approach to acknowledge that we will work to develop improved and consistent emissions forecasting model(s) for future analyses. Due to the potential significance of this analytical assumption, the EPA sought consultation and advice from the Advisory Council on Clean Air Compliance Analysis and Air Quality Modeling Subcommittee (Council) of the Science Advisory Board on this interim emissions projection approach and requested recommendations on long-term methodological improvements that could be made in emissions forecasting for the non-EGU stationary source sectors. This appendix includes information presented to the Council, the Council's advice to the EPA, a discussion of the implication of recommendations by the Council for three sectors in 2020, and a sensitivity analysis of the emissions and air quality impacts of this interim emissions projection approach. The sensitivity analysis included in this appendix presents the impact of this analysis change on emissions and air quality predictions in 2015.

D.1 Consultation with the Council

On August 31, 2006, the EPA consulted with the Council by teleconference. In this consultation, the EPA requested advice and comments from the Council on its interim forecasting approach for emissions from stationary non-EGU sources used in this RIA. Specifically, the EPA requested recommendations on caveats and sensitivities that could be provided in the RIA in the discussion of this approach and suggestions or data that could be provided to help with a longer term approach to emission forecasting for these source categories. A background document was prepared for the Council's consideration and is attached to this appendix as Attachment 1.

On September 15, 2006, the Council issued a letter to Stephen L. Johnson, Administrator of EPA with the findings of its consultation. The Council's letter is available at http://www.epa.gov/sab/pdf/council-con-06-007.pdf. In its response the Council recommends an alternative to the 'interim' method used by the EPA. This alternative would capture the underlying technological change that the Council contends is likely driving the decline in emissions, i.e., the efficiency gains in production processes and improvements in air pollution control technologies that can be expected over time. The Council suggests using the National Emissions Inventory in the 1990s to estimate a declining "emissions intensity" as it relates to the level of output by sector. The Council recommends the first step in this process be to factor out any decline in emissions that could be attributable to the Clean Air Act. As a default, the EPA could assume the residual historical rate of decline (i.e., after removing declines attributable to the Clean Air Act) would continue to be constant in future years. The Council did recognize the limitations of a court-ordered schedule for the PM NAAQS in the EPA's ability to implement its recommendations into this RIA. Detailed recommendations of longer term approaches were also discussed and included in the meeting minutes. These minutes are available at http://www.epa.gov/sab/06minute.htm.

In response to the Council's recommendation, the EPA did endeavor to conduct a limited analysis using the Council's recommended approach for three important non-EGU stationary source sectors including Pulp and Paper Manufacturing, Petroleum Refining, and Chemicals and Allied Products for SO_2 emissions only. The court-ordered schedule for the PM NAAQS review does not allow for further investigation of the merits of this method for all relevant non-EGU stationary source categories or relevant pollutants. We found that the Council's suggested approach resulted in essentially a downward trend in future year SO_2 emissions for these source categories. Using an approach similar to the Counsel's suggested approach, emissions would decline significant from 2002 to 2020 for these industries. This is because historical emissions reductions used in this analysis could not be directly attributed to Clean Air Act mandated controls and therefore the entire declining emission trend for these three sectors was assumed to continue into the future. We recognize the limitations of this analysis since some historical emission reductions may have been due to Clean Air Act mandated controls (e.g., SIPs, NSPS) that are applied to individual facilities (rather than mandated controls that would be applicable to the entire sector), but given the limited time and quality of the control information in the emission inventory an accurate attribution of these historical emission reductions to the Clean Air Act was not possible.

This comparison suggests the interim approach used for this RIA by EPA is conservative with respect to the emissions projections (i.e., results in emission projections that are lower than those used in previous analyses but higher than those resulting from the Council's recommended approach) relative to the alternative suggested. The EPA does recognize the need to develop a long-term more robust and consistent method for forecasting emissions for the non-EGU stationary sources sectors. The EPA feels the Council's advice will be helpful to formulate a new and improved emissions forecasting methodology for the stationary non-EGU sources for future analyses.

In addition to the analysis conducted in response to the Council's recommendation, ongoing emission inventory analysis has been conducted for the second 812 Prospective Benefits and Costs of the Clean Air Act analysis.[1] The results of a historical inventory analysis for the 812 study suggest the complexity involved in developing a new and improved emissions projections methodology that recognizes key components of historical emissions changes. This study found that sector-specific research needs to be done to improve emissions projections. The study showed that even within a specific source category the bias in projection methods and historical data may differ across pollutants demonstrating the challenges involved in developing a new method of emissions forecasting. The EPA recognizes that significant effort will be required to design an improved emission forecasting method for the stationary non-EGU sources, and the EPA is committed to designing an improved approach in the future.

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[1] Memorandum from Jim Neumann, IEc, Jim Wilson and Andy Bollman, EH Pechan and Associates to Jim DeMocker, EPA/OAR/OPAR. "Documentation of Analysis of 1990-2002 Emissions for Selected Non-EGU Stationary Point Sources," September 19, 2006.

D.2 Comparison of Sensitivity Analysis Emissions

For this sensitivity, we created two emissions cases for input to the CMAQ model. In Case 1 use the interim approach (i.e., removal of the economic growth term from the emissions projections equation) for projecting stationary non-EGU sources. Case 2 contains emission using our previous growth assumptions for these sources that was used for the Clean Air Interstate Rule (CAIR).

Both cases use *most* of our revised control assumptions that are described in Section 2.3.2 of the main body of the PM NAAQS RIA. Because the sensitivity was performed prior to the final version of the 2015 emissions used for the RIA modeling, there are some differences between the control assumptions in the 2015 inventories used for this sensitivity and those of the final 2015 emissions used for the RIA. These differences are relatively localized to a handful of plants affected by the changes, so we have concluded that the results of this sensitivity are sufficiently applicable for the purpose of characterizing the AQ modeling sensitivity to the revised growth approach.

In this section, we first describe the differences between Case 1 of the sensitivity and the final 2015 baseline emissions. Second, we describe how we created the Case 2 emissions and summarize the differences between Case 1 and Case 2.

D.1.1 Difference in 2015 Emissions Used in Sensitivity Comparison to Final Analysis 2015 Baseline Emissions

For both Case 1 and Case 2, there were two differences in the control assumptions used as compared to the final 2015 and 2020 emissions used for the PM NAAQS RIA. These were:

1. Included SO2 reductions in the non-EGU point sources for the "Industrial, Commercial, and Institutional Boilers and Process Heaters Rule". These were ultimately determined to be invalid and therefore removed from the final analysis used for the RIA.
2. Used original EGU emissions including CAIR, CAMR, and CAVR (used for the Clear Skies analyses). These were ultimately revised as described in Section 2.3.3 and Table 2-8 of the main body of the RIA.

These changes resulted in emissions differences in selected counties. We compare Case 1 with the final RIA emissions in Table 1(a) for EGUs and Table 1(b) for non-EGU point sources.

Table D-1(a): EGU Sector Comparison of Case 1 Emissions with Final RIA Baseline Emissions*

	2015 NOX				2015 SO2				2015 PM2.5			
State	Case 1	RIA Baseline	Diff	%Diff	Case 1	RIA Baseline	Diff	%Diff	Case 1	RIA Baseline	Diff	%Diff
Alabama	49,144	48,501	-643	-1.3%	260,267	247,538	-12,729	-4.9%	15,853	15,993	140	0.9%
Arizona	65,858	65,840	-18	0.0%	60,347	60,321	-26	0.0%	10,012	10,010	-2	0.0%
Arkansas	31,908	31,925	17	0.1%	22,801	22,795	-6	0.0%	4,731	4,735	4	0.1%
California	21,968	21,964	-4	0.0%	5,068	5,066	-1	0.0%	4,835	4,833	-2	-0.1%
Colorado	60,440	60,437	-3	0.0%	57,467	57,452	-15	0.0%	3,942	3,943	1	0.0%
Connecticut	6,936	6,901	-34	-0.5%	3,902	3,901	-1	0.0%	676	668	-8	-1.2%
Delaware	9,551	8,198	-1,352	-14.2%	27,646	22,992	-4,653	-16.8%	4,623	3,962	-661	-14.3%
District of Columbia	53	54	0	0.6%	0	0	0	0.0%	7	7	0	3.3%
Florida	61,483	60,411	-1,072	-1.7%	167,199	163,704	-3,495	-2.1%	19,847	19,771	-76	-0.4%
Georgia	66,780	66,773	-7	0.0%	240,913	220,749	-20,164	-8.4%	21,102	20,235	-866	-4.1%
Idaho	587	587	0	0.0%	0	0	0	0.0%	69	69	0	0.0%
Illinois	65,352	65,728	376	0.6%	245,328	230,488	-14,840	-6.0%	13,786	14,271	484	3.5%
Indiana	81,795	80,329	-1,467	-1.8%	376,779	362,960	-13,819	-3.7%	32,326	31,181	-1,144	-3.5%
Iowa	51,741	52,456	715	1.4%	163,493	162,891	-602	-0.4%	8,228	8,100	-128	-1.6%
Kansas	39,816	39,799	-17	0.0%	58,540	58,525	-15	0.0%	6,219	6,217	-2	0.0%
Kentucky	76,860	79,310	2,450	3.2%	264,152	262,778	-1,374	-0.5%	24,202	24,195	-7	0.0%
Louisiana	32,486	32,475	-11	0.0%	62,050	62,034	-17	0.0%	3,536	3,535	-1	0.0%
Maine	1,797	1,816	19	1.1%	5,335	4,801	-533	-10.0%	231	238	6	2.8%
Maryland	12,843	12,815	-27	-0.2%	42,787	34,267	-8,520	-19.9%	4,867	4,867	0	0.0%
Massachusetts	19,111	19,179	68	0.4%	17,400	17,741	341	2.0%	2,869	2,874	5	0.2%
Michigan	92,411	92,275	-136	-0.1%	393,060	369,805	-23,255	-5.9%	22,347	21,622	-725	-3.2%
Minnesota	40,086	40,156	71	0.2%	84,742	84,979	237	0.3%	14,481	14,485	4	0.0%
Mississippi	7,878	7,893	15	0.2%	85,649	57,919	-27,730	-32.4%	4,009	3,584	-425	-10.6%
Missouri	69,950	69,921	-29	0.0%	266,422	266,369	-53	0.0%	26,508	26,499	-8	0.0%
Montana	38,431	38,420	-10	0.0%	22,480	22,474	-6	0.0%	4,831	4,830	-1	0.0%
Nebraska	42,854	42,842	-12	0.0%	36,760	36,750	-10	0.0%	2,905	2,904	-1	0.0%
Nevada	30,589	30,596	8	0.0%	27,394	27,424	30	0.1%	4,123	4,126	3	0.1%
New Hampshire	2,932	2,968	36	1.2%	7,423	7,426	3	0.0%	928	940	12	1.3%
New Jersey	13,244	12,732	-512	-3.9%	32,490	29,426	-3,065	-9.4%	5,978	5,870	-108	-1.8%
New Mexico	71,538	71,517	-21	0.0%	52,899	52,884	-14	0.0%	7,916	7,915	-2	0.0%
New York	23,405	23,616	212	0.9%	48,835	48,544	-290	-	8,703	8,652	-50	-0.6%

								0.6%				
North Carolina	50,814	50,855	41	0.1%	124,591	124,637	46	0.0%	18,966	19,001	35	0.2%
North Dakota	39,857	39,862	6	0.0%	85,061	85,050	-11	0.0%	6,132	6,132	1	0.0%
Ohio	93,344	90,204	-3,140	-3.4%	271,778	266,292	-5,486	-2.0%	33,425	32,821	-604	-1.8%
Oklahoma	57,929	57,815	-115	-0.2%	46,670	45,755	-915	-2.0%	13,354	13,349	-5	0.0%
Oregon	10,607	10,604	-2	0.0%	10,037	10,034	-3	0.0%	807	807	0	0.0%
Pennsylvania	74,277	74,813	536	0.7%	141,443	136,360	-5,084	-3.6%	23,956	23,718	-238	-1.0%
Rhode Island	481	475	-5	-1.1%	0	0	0	0.0%	111	110	-2	-1.6%
South Carolina	36,391	36,380	-11	0.0%	105,427	104,914	-512	-0.5%	14,487	14,453	-34	-0.2%
South Dakota	1,749	1,748	0	0.0%	4,149	4,148	-1	0.0%	372	372	0	0.0%
Tennessee	27,310	27,191	-119	-0.4%	191,511	173,081	-18,431	-9.6%	14,363	13,690	-674	-4.7%
Texas	158,008	158,413	405	0.3%	373,127	363,943	-9,183	-2.5%	28,995	29,603	608	2.1%
Utah	53,408	53,393	-14	0.0%	53,123	53,109	-14	0.0%	4,361	4,360	-1	0.0%
Vermont	35	41	7	19.6%	0	0	0	0.0%	7	9	2	32.0%
Virginia	39,960	39,739	-221	-0.6%	94,576	87,365	-7,212	-7.6%	10,296	10,043	-254	-2.5%
Washington	14,996	14,995	-1	0.0%	11,077	11,074	-3	0.0%	2,641	2,641	0	0.0%
West Virginia	39,545	39,534	-11	0.0%	111,001	111,953	952	0.9%	17,690	17,687	-3	0.0%
Wisconsin	40,843	42,412	1,569	3.8%	150,657	148,032	-2,625	-1.7%	8,942	8,727	-215	-2.4%
Wyoming	53,079	53,065	-14	0.0%	74,265	73,846	-420	-0.6%	7,246	7,244	-2	0.0%
	1,982,455	1,979,977	-2,479	-0.1%	4,988,121	4,804,595	-183,526	-3.7%	490,841	485,895	-4,946	-1.0%

* Differences of 5% are more are shaded. Differences in other pollutants exist, but not shown.

Table D-1(b): Non-EGU Comparison of Case 1 Emissions with Final RIA Baseline Emissions*

		2015 SO2		
State	**County**	**Case 1**	**RIA Baseline**	**Diff**
Illinois	Macon Co	25,164	29,605	4,441
Illinois	Peoria Co	2,890	9,763	6,873
Iowa	Clinton Co	3,778	18,879	15,101
Iowa	Muscatine Co	4,042	16,115	12,073
Iowa	Story Co	2,267	11,336	9,069
Maryland	Allegany Co	4,423	19,227	14,804
Ohio	Ross Co	6,597	30,735	24,138
Pennsylvania	Erie Co	2,286	10,210	7,924
Pennsylvania	York Co	6,161	12,363	6,202
Tennessee	Davidson Co	2,746	8,554	5,808
Tennessee	Sullivan Co	14,600	32,539	17,939
West Virginia	Marshall Co	15,159	24,799	9,640
Wisconsin	Brown Co	6,200	20,959	14,759

* Only counties with differences are shown

D.1.2. Difference in 2015 Emissions Due to Revised Growth Assumptions

To create the Case 2 emissions, we applied the growth factors used for CAIR to the non-EGU point, other area and fugitive dust sectors. These CAIR growth factors were applied with our revised control assumptions used for PM NAAQS, with the exception of those two revisions listed in Section 2.1. The origin of the CAIR growth data is described more fully in Section 4.1 of the CAIR Emission Inventory Technical Support Document, available at http://www.epa.gov/air/interstateairquality/pdfs/finaltech01.pdf. The emissions were the same between Case 1 and Case 2 for emissions from EGUs, on-road mobile sources, nonroad mobile sources, agricultural livestock and fertilizer application, and fires (wildfires, prescribed burning, agricultural burning, and open burning).

Table 2(a) provides state-total differences for non-EGU point and stationary area sources between the Case 1 and Case 2 for VOC, NO_x, SO_2, NH_3, and $PM_{2.5}$. Table 2(b) provides state-total differences for the entire state between the two cases for the same pollutants.

Table D-2(a): Case 1 Compared to Case 2 Emissions by State, Sectors that Changed and Pollutant

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Alabama	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	18,826	20,050	6%
	Nonpoint	152,290	196,383	29%	10,612	13,175	24%	44,895	31,436	-30%	1,370	1,635	19%	11,015	13,791	25%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	447	255	-43%
	Non-EGU Point	47,520	63,838	34%	89,158	112,327	26%	113,811	128,959	13%	494	589	19%	24,063	30,556	27%
Alabama Total		**199,810**	**260,220**	**30%**	**99,770**	**125,502**	**26%**	**158,706**	**160,395**	**1%**	**1,863**	**2,225**	**19%**	**54,352**	**64,652**	**19%**
Arizona	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	23,394	28,891	23%
	Nonpoint	91,612	130,416	42%	53,957	67,996	26%	3,457	3,504	1%	2,699	3,159	17%	5,025	7,000	39%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	327	413	26%
	Non-EGU Point	5,706	9,204	61%	29,725	39,710	34%	32,568	48,431	49%	41	78	91%	2,145	2,933	37%
Arizona Total		**97,318**	**139,620**	**43%**	**83,682**	**107,706**	**29%**	**36,025**	**51,935**	**44%**	**2,740**	**3,237**	**18%**	**30,891**	**39,236**	**27%**
Arkansas	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	36,892	37,149	1%
	Nonpoint	92,027	112,573	22%	35,729	42,949	20%	19,998	30,680	53%	1,069	1,377	29%	7,003	8,713	24%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	35	42	18%
	Non-EGU Point	26,495	35,455	34%	54,281	69,560	28%	26,849	33,652	25%	1,235	1,454	18%	17,776	23,912	35%
Arkansas Total		**118,522**	**148,028**	**25%**	**90,010**	**112,509**	**25%**	**46,846**	**64,332**	**37%**	**2,305**	**2,832**	**23%**	**61,707**	**69,815**	**13%**
California	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	63,469	71,821	13%
	Nonpoint	415,895	506,517	22%	145,151	167,149	15%	10,453	12,196	17%	1,936	2,254	16%	67,190	82,513	23%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	32	42	32%
	Non-EGU Point	45,589	62,985	38%	101,665	120,422	18%	37,134	44,628	20%	13,902	13,699	-1%	21,630	29,367	36%
California Total		**461,484**	**569,502**	**23%**	**246,816**	**287,570**	**17%**	**47,586**	**56,824**	**19%**	**15,837**	**15,953**	**1%**	**152,321**	**183,744**	**21%**
Colorado	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	25,524	26,380	3%
	Nonpoint	84,216	105,390	25%	11,237	15,622	39%	1,991	2,361	19%	72	97	35%	12,596	16,245	29%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	45	61	36%

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
	Non-EGU Point	33,869	47,126	39%	38,415	48,359	26%	9,191	11,137	21%	242	295	22%	11,457	15,169	32%
Colorado Total		**118,085**	**152,516**	**29%**	**49,651**	**63,981**	**29%**	**11,183**	**13,498**	**21%**	**314**	**392**	**25%**	**49,622**	**57,855**	**17%**
Connecticut	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	1,649	1,963	19%
	Nonpoint	118,202	127,272	8%	13,721	14,873	8%	12,121	12,148	0%	2,285	2,766	21%	10,263	12,289	20%
	Non-EGU Point	5,615	7,596	35%	3,293	4,266	30%	2,946	4,097	39%	39	52	34%	1,749	2,506	43%
Connecticut Total		**123,817**	**134,868**	**9%**	**17,014**	**19,139**	**12%**	**15,066**	**16,244**	**8%**	**2,324**	**2,818**	**21%**	**13,661**	**16,757**	**23%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Delaware	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	1,664	1,820	9%
	Nonpoint	14,820	18,917	28%	3,857	5,247	36%	10,594	16,086	52%	379	466	23%	2,292	3,141	37%
	Non-EGU Point	3,641	4,610	27%	8,550	10,363	21%	20,096	22,457	12%	671	762	14%	765	996	30%
Delaware Total		**18,461**	**23,527**	**27%**	**12,407**	**15,610**	**26%**	**30,690**	**38,543**	**26%**	**1,050**	**1,228**	**17%**	**4,721**	**5,957**	**26%**
District of Columbia	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	262	367	40%
	Nonpoint	9,561	10,898	14%	2,326	3,061	32%	5,938	7,448	25%	982	1,133	15%	728	969	33%
	Non-EGU Point	4	5	24%	477	547	15%	792	924	17%	9	12	38%	29	35	18%
District of Columbia Total		**9,565**	**10,903**	**14%**	**2,803**	**3,608**	**29%**	**6,730**	**8,371**	**24%**	**990**	**1,145**	**16%**	**1,019**	**1,371**	**34%**
Florida	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	22,270	25,783	16%
	Nonpoint	269,923	359,803	33%	30,248	35,731	18%	39,817	62,248	56%	3,389	4,548	34%	14,722	19,891	35%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	19	26	43%
	Non-EGU Point	40,347	52,998	31%	59,586	76,949	29%	87,311	105,004	20%	569	737	29%	29,238	38,988	33%
Florida Total		**310,270**	**412,800**	**33%**	**89,834**	**112,680**	**25%**	**127,128**	**167,252**	**32%**	**3,958**	**5,284**	**34%**	**66,249**	**84,688**	**28%**
Georgia	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	32,708	35,300	8%
	Nonpoint	167,804	215,134	28%	26,056	32,418	24%	4,407	5,934	35%	2,452	3,180	30%	16,968	23,029	36%
	Non-EGU Point	30,264	40,575	34%	77,356	95,851	24%	84,486	115,947	37%	4,778	6,247	31%	50,009	66,558	33%
Georgia Total		**198,068**	**255,710**	**29%**	**103,412**	**128,269**	**24%**	**88,893**	**121,881**	**37%**	**7,230**	**9,427**	**30%**	**99,686**	**124,886**	**25%**
Idaho	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	26,653	27,428	3%
	Nonpoint	169,139	261,550	55%	36,323	50,800	40%	1,652	2,040	23%	562	740	32%	13,682	19,934	46%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	3	4	42%
	Non-EGU Point	3,942	5,592	42%	11,298	14,393	27%	18,109	23,392	29%	984	1,292	31%	5,828	8,215	41%
Idaho Total		**173,080**	**267,142**	**54%**	**47,620**	**65,192**	**37%**	**19,762**	**25,432**	**29%**	**1,546**	**2,032**	**31%**	**46,166**	**55,581**	**20%**
Illinois	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	92,621	91,260	-1%
	Nonpoint	272,712	341,249	25%	39,045	46,306	19%	41,299	56,996	38%	9,979	12,273	23%	17,107	22,139	29%
	Point fugitive	0	0	0%	0	0	0%	0	0	0%	0	0	0%	215	260	21%

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
	dust															
	Non-EGU Point	82,756	113,170	37%	100,177	127,465	27%	174,790	194,627	11%	9,215	13,490	46%	30,695	42,176	37%
Illinois Total		**355,468**	**454,419**	**28%**	**139,221**	**173,771**	**25%**	**216,089**	**251,622**	**16%**	**19,194**	**25,763**	**34%**	**140,638**	**155,835**	**11%**
Indiana	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	54,764	55,930	2%
	Nonpoint	190,403	236,149	24%	43,924	46,630	6%	8,922	9,015	1%	2,948	3,754	27%	13,691	16,896	23%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	576	744	29%
	Non-EGU Point	63,344	88,865	40%	89,582	112,702	26%	168,608	194,805	16%	3,460	4,802	39%	46,199	58,815	27%
Indiana Total		**253,747**	**325,014**	**28%**	**133,506**	**159,331**	**19%**	**177,530**	**203,820**	**15%**	**6,409**	**8,556**	**34%**	**115,229**	**132,386**	**15%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Iowa	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	70,799	69,864	-1%
	Nonpoint	123,428	132,131	7%	29,622	34,596	17%	23,947	24,405	2%	7,234	7,583	5%	9,552	9,707	2%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	Non-EGU Point	8,295	11,259	36%	28,043	32,049	14%	54,132	56,262	4%	4,145	5,382	30%	5,223	7,155	37%
Iowa Total		**131,723**	**143,389**	**9%**	**57,665**	**66,645**	**16%**	**78,079**	**80,667**	**3%**	**11,379**	**12,965**	**14%**	**85,574**	**86,725**	**1%**
Kansas	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	102,359	101,325	-1%
	Nonpoint	88,932	97,015	9%	14,362	16,382	14%	3,800	4,376	15%	1,637	1,895	16%	6,981	6,786	-3%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	213	286	34%
	Non-EGU Point	22,742	30,772	35%	85,488	108,635	27%	17,165	23,787	39%	858	1,116	30%	8,501	11,097	31%
Kansas Total		**111,674**	**127,787**	**14%**	**99,850**	**125,017**	**25%**	**20,965**	**28,163**	**34%**	**2,495**	**3,011**	**21%**	**118,053**	**119,493**	**1%**
Kentucky	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	18,216	20,012	10%
	Nonpoint	106,387	130,612	23%	73,937	84,608	14%	56,977	56,666	-1%	1,242	1,521	23%	14,301	19,028	33%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	298	325	9%
	Non-EGU Point	64,477	82,869	29%	35,240	41,784	19%	34,990	39,571	13%	575	664	15%	12,712	16,036	26%
Kentucky Total		**170,865**	**213,481**	**25%**	**109,177**	**126,392**	**16%**	**91,967**	**96,236**	**5%**	**1,817**	**2,185**	**20%**	**45,527**	**55,401**	**22%**
Louisiana	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	19,511	21,177	9%
	Nonpoint	93,605	110,099	18%	93,604	112,916	21%	90,933	135,352	49%	22,828	23,289	2%	9,262	11,070	20%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	3	4	20%
	Non-EGU Point	55,074	67,429	22%	234,799	282,924	20%	163,566	206,605	26%	8,507	10,777	27%	33,318	42,140	26%
Louisiana Total		**148,679**	**177,528**	**19%**	**328,402**	**395,840**	**21%**	**254,499**	**341,956**	**34%**	**31,334**	**34,067**	**9%**	**62,094**	**74,391**	**20%**
Maine	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	2,318	2,591	12%
	Nonpoint	90,770	115,111	27%	8,218	8,804	7%	15,722	16,897	7%	1,278	1,574	23%	14,317	17,429	22%
	Non-EGU Point	4,230	5,638	33%	18,897	25,403	34%	30,595	43,305	42%	123	170	39%	10,019	13,328	33%
Maine Total		**95,001**	**120,749**	**27%**	**27,115**	**34,208**	**26%**	**46,317**	**60,202**	**30%**	**1,401**	**1,744**	**24%**	**26,654**	**33,348**	**25%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Maryland	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	6,375	7,440	17%
	Nonpoint	80,866	113,550	40%	17,069	20,955	23%	41,581	54,861	32%	1,636	2,166	32%	15,145	20,191	33%
	Non-EGU Point	5,264	6,738	28%	18,529	23,637	28%	22,836	28,755	26%	372	511	37%	4,108	5,101	24%
Maryland Total		**86,130**	**120,287**	**40%**	**35,598**	**44,592**	**25%**	**64,416**	**83,615**	**30%**	**2,008**	**2,677**	**33%**	**25,628**	**32,732**	**28%**
Massachusetts	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	10,345	11,249	9%
	Nonpoint	146,756	178,720	22%	25,595	28,858	13%	68,235	85,836	26%	5,665	6,917	22%	18,086	21,941	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	Non-EGU Point	9,078	12,524	38%	17,675	22,121	25%	17,904	24,535	37%	64	87	35%	2,343	3,208	37%
Massachusetts Total		**155,835**	**191,244**	**23%**	**43,271**	**50,978**	**18%**	**86,140**	**110,371**	**28%**	**5,729**	**7,004**	**22%**	**30,774**	**36,398**	**18%**
Michigan	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	37,834	39,983	6%
	Nonpoint	249,950	283,840	14%	48,563	55,971	15%	34,238	38,797	13%	5,489	6,912	26%	18,175	22,991	26%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	35	44	28%
	Non-EGU Point	43,667	60,547	39%	90,725	114,013	26%	76,286	91,921	20%	393	492	25%	12,928	17,251	33%
Michigan Total		**293,617**	**344,387**	**17%**	**139,287**	**169,983**	**22%**	**110,524**	**130,718**	**18%**	**5,883**	**7,404**	**26%**	**68,971**	**80,269**	**16%**
Minnesota	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	89,116	87,386	-2%
	Nonpoint	162,881	171,010	5%	21,747	24,126	11%	5,662	6,122	8%	3,776	4,237	12%	16,131	15,382	-5%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	343	413	20%
	Non-EGU Point	23,284	30,693	32%	55,734	67,831	22%	21,466	25,656	20%	990	1,106	12%	13,987	17,744	27%
Minnesota Total		**186,165**	**201,703**	**8%**	**77,481**	**91,958**	**19%**	**27,129**	**31,778**	**17%**	**4,766**	**5,343**	**12%**	**119,577**	**120,924**	**1%**
Mississippi	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	25,401	26,098	3%
	Nonpoint	114,534	141,358	23%	4,154	5,243	26%	492	480	-2%	798	1,022	28%	8,714	11,816	36%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	1	1	33%
	Non-EGU Point	49,184	72,732	48%	103,232	134,960	31%	69,285	81,194	17%	1,146	1,703	49%	21,575	28,569	32%
Mississippi Total		**163,718**	**214,090**	**31%**	**107,387**	**140,203**	**31%**	**69,777**	**81,673**	**17%**	**1,944**	**2,725**	**40%**	**55,691**	**66,484**	**19%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Missouri	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	84,991	87,148	3%
	Nonpoint	141,792	157,892	11%	35,170	37,137	6%	34,207	37,589	10%	3,806	4,153	9%	16,723	16,995	2%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	77	101	31%
	Non-EGU Point	28,479	37,598	32%	31,422	40,255	28%	114,680	142,441	24%	3,968	4,917	24%	10,093	12,664	25%
Missouri Total		**170,271**	**195,491**	**15%**	**66,593**	**77,391**	**16%**	**148,887**	**180,029**	**21%**	**7,774**	**9,070**	**17%**	**111,884**	**116,907**	**4%**
Montana	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	30,128	31,183	3%
	Nonpoint	41,974	45,221	8%	10,310	13,082	27%	1,233	1,248	1%	269	344	28%	3,990	5,457	37%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	125	176	41%
	Non-EGU Point	3,365	4,480	33%	15,350	18,919	23%	19,805	24,536	24%	407	473	16%	5,469	7,143	31%
Montana Total		**45,339**	**49,700**	**10%**	**25,661**	**32,001**	**25%**	**21,038**	**25,784**	**23%**	**676**	**816**	**21%**	**39,712**	**43,958**	**11%**
Nebraska	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	73,693	74,178	1%
	Nonpoint	70,366	73,827	5%	13,784	16,517	20%	9,850	13,536	37%	598	783	31%	3,769	3,940	5%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	56	74	33%
	Non-EGU Point	6,702	10,179	52%	11,537	15,194	32%	7,097	9,426	33%	14	18	24%	2,519	3,699	47%
Nebraska Total		**77,068**	**84,007**	**9%**	**25,321**	**31,712**	**25%**	**16,948**	**22,962**	**35%**	**612**	**801**	**31%**	**80,037**	**81,891**	**2%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Nevada	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	15,666	19,866	27%
	Nonpoint	33,547	50,610	51%	7,220	8,992	25%	3,452	3,463	0%	915	1,302	42%	2,289	3,036	33%
	Non-EGU Point	840	1,378	64%	4,693	6,460	38%	656	867	32%	14	21	42%	1,281	1,645	28%
Nevada Total		**34,387**	**51,988**	**51%**	**11,912**	**15,452**	**30%**	**4,108**	**4,330**	**5%**	**929**	**1,323**	**42%**	**19,236**	**24,546**	**28%**
New Hampshire	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	821	964	17%
	Nonpoint	53,387	67,255	26%	5,385	5,947	10%	10,185	11,121	9%	945	1,179	25%	9,446	11,572	22%
	Non-EGU Point	2,229	3,098	39%	2,743	3,648	33%	5,250	7,610	45%	47	69	48%	1,587	2,223	40%
New Hampshire Total		**55,617**	**70,353**	**26%**	**8,128**	**9,595**	**18%**	**15,435**	**18,731**	**21%**	**992**	**1,248**	**26%**	**11,854**	**14,759**	**24%**
New Jersey	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	5,320	6,323	19%
	Nonpoint	145,975	168,922	16%	37,797	41,146	9%	47,838	52,714	10%	4,051	4,809	19%	15,819	18,695	18%
	Non-EGU Point	19,237	25,132	31%	17,022	20,304	19%	6,553	7,451	14%	186	226	22%	1,727	2,090	21%
New Jersey Total		**165,212**	**194,054**	**17%**	**54,819**	**61,449**	**12%**	**54,391**	**60,166**	**11%**	**4,237**	**5,035**	**19%**	**22,866**	**27,109**	**19%**
New Mexico	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	71,683	74,356	4%
	Nonpoint	44,554	57,577	29%	25,426	31,398	23%	8,451	5,939	-30%	389	487	25%	3,922	5,026	28%
	Non-EGU Point	12,101	15,477	28%	79,394	100,801	27%	74,580	102,463	37%	42	51	22%	2,345	3,441	47%
New Mexico Total		**56,656**	**73,054**	**29%**	**104,820**	**132,199**	**26%**	**83,031**	**108,402**	**31%**	**430**	**538**	**25%**	**77,950**	**82,824**	**6%**
New York	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	24,246	26,938	11%
	Nonpoint	598,612	715,327	19%	65,289	67,254	3%	159,191	159,552	0%	13,437	16,040	19%	71,427	84,611	18%
	Non-EGU Point	5,465	7,385	35%	37,583	46,857	25%	71,006	79,401	12%	972	1,095	13%	3,855	4,679	21%
New York Total		**604,077**	**722,712**	**20%**	**102,873**	**114,111**	**11%**	**230,197**	**238,953**	**4%**	**14,409**	**17,135**	**19%**	**99,529**	**116,228**	**17%**
North Carolina	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	16,121	18,028	12%
	Nonpoint	207,535	260,171	25%	14,412	17,774	23%	31,822	33,669	6%	2,122	2,657	25%	23,618	31,877	35%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	50%
	Non-EGU Point	68,168	93,710	37%	46,995	58,432	24%	66,220	84,852	28%	1,876	2,468	32%	14,571	19,606	35%
North Carolina Total		**275,703**	**353,881**	**28%**	**61,407**	**76,206**	**24%**	**98,042**	**118,520**	**21%**	**3,998**	**5,125**	**28%**	**54,311**	**69,510**	**28%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
North Dakota	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	60,541	59,874	-1%
	Nonpoint	60,442	52,882	-13%	18,442	19,719	7%	56,231	52,831	-6%	202	243	21%	2,834	2,771	-2%
	Non-EGU Point	661	754	14%	10,627	11,688	10%	21,629	24,007	11%	12	14	16%	3,482	4,058	17%
North Dakota Total		**61,103**	**53,636**	**-12%**	**29,069**	**31,407**	**8%**	**77,860**	**76,838**	**-1%**	**214**	**258**	**20%**	**66,856**	**66,703**	**0%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Ohio	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	45,273	47,795	6%
	Nonpoint	259,823	319,076	23%	60,160	67,867	13%	67,415	75,340	12%	7,196	8,996	25%	22,232	26,832	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	695	909	31%
	Non-EGU Point	33,261	45,189	36%	69,407	80,740	16%	79,844	83,247	4%	2,505	3,070	23%	14,723	18,657	27%
Ohio Total		**293,084**	**364,265**	**24%**	**129,567**	**148,607**	**15%**	**147,259**	**158,587**	**8%**	**9,701**	**12,065**	**24%**	**82,922**	**94,192**	**14%**
Oklahoma	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	76,349	78,323	3%
	Nonpoint	122,510	150,164	23%	30,256	35,282	17%	5,277	6,735	28%	7,736	8,029	4%	6,711	8,114	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	13	19	45%
	Non-EGU Point	19,900	24,599	24%	98,984	116,193	17%	27,498	31,773	16%	3,490	4,268	22%	5,898	7,538	28%
Oklahoma Total		**142,410**	**174,764**	**23%**	**129,241**	**151,475**	**17%**	**32,774**	**38,508**	**17%**	**11,226**	**12,297**	**10%**	**88,971**	**93,994**	**6%**
Oregon	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	9,487	10,136	7%
	Nonpoint	252,174	305,486	21%	17,460	20,325	16%	22,142	24,124	9%	292	349	20%	40,518	48,832	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	4	6	37%
	Non-EGU Point	11,890	16,225	36%	15,988	19,685	23%	8,932	11,003	23%	67	75	12%	8,149	10,938	34%
Oregon Total		**264,064**	**321,710**	**22%**	**33,448**	**40,010**	**20%**	**31,074**	**35,126**	**13%**	**359**	**424**	**18%**	**58,158**	**69,911**	**20%**
Pennsylvania	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	21,181	23,574	11%
	Nonpoint	233,160	277,662	19%	53,241	60,281	13%	94,191	105,063	12%	6,050	7,261	20%	30,781	35,079	14%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	97	115	19%
	Non-EGU Point	38,255	51,239	34%	89,806	105,159	17%	82,718	91,483	11%	1,277	1,518	19%	15,182	18,379	21%
Pennsylvania Total		**271,415**	**328,901**	**21%**	**143,047**	**165,440**	**16%**	**176,909**	**196,546**	**11%**	**7,328**	**8,779**	**20%**	**67,241**	**77,148**	**15%**
Rhode Island	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	528	663	25%
	Nonpoint	30,425	44,695	47%	4,901	5,981	22%	5,263	5,711	9%	97	107	10%	1,232	1,387	13%
	Non-EGU Point	1,566	2,221	42%	1,650	2,212	34%	2,505	3,493	39%	3	4	47%	127	174	36%
Rhode Island Total		**31,991**	**46,916**	**47%**	**6,551**	**8,193**	**25%**	**7,768**	**9,204**	**18%**	**100**	**111**	**11%**	**1,888**	**2,224**	**18%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
South Carolina	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	13,723	14,553	6%
	Nonpoint	167,921	217,715	30%	18,945	22,279	18%	14,763	15,286	4%	1,005	1,268	26%	11,062	14,711	33%
	Non-EGU Point	25,434	36,526	44%	35,917	42,427	18%	52,420	61,982	18%	1,111	1,470	32%	7,580	9,405	24%
South Carolina Total		**193,355**	**254,241**	**31%**	**54,862**	**64,706**	**18%**	**67,183**	**77,268**	**15%**	**2,116**	**2,737**	**29%**	**32,365**	**38,669**	**19%**
South Dakota	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	45,372	46,022	1%
	Nonpoint	40,987	38,866	-5%	6,292	6,657	6%	20,387	20,634	1%	309	386	25%	3,266	3,266	0%
	Non-EGU Point	1,256	1,893	51%	4,503	5,965	32%	1,363	1,867	37%	1	1	54%	400	495	24%
South Dakota Total		**42,243**	**40,758**	**-4%**	**10,795**	**12,622**	**17%**	**21,750**	**22,502**	**3%**	**310**	**387**	**25%**	**49,038**	**49,783**	**2%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Tennessee	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	18,271	20,494	12%
	Nonpoint	178,994	233,527	30%	23,997	29,385	22%	41,818	46,434	11%	3,377	4,946	46%	15,068	20,307	35%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	2	3	55%
	Non-EGU Point	81,141	116,387	43%	62,850	75,238	20%	75,252	88,682	18%	2,246	2,950	31%	27,675	40,280	46%
Tennessee Total		**260,134**	**349,914**	**35%**	**86,846**	**104,623**	**20%**	**117,069**	**135,116**	**15%**	**5,624**	**7,897**	**40%**	**61,016**	**81,085**	**33%**
Texas	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	231,843	243,614	5%
	Nonpoint	528,746	636,524	20%	43,589	49,983	15%	7,113	8,982	26%	6,917	8,777	27%	27,008	32,678	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	88	115	32%
	Non-EGU Point	118,284	149,692	27%	423,216	495,841	17%	204,910	238,233	16%	0	0	0%	21,869	27,424	25%
Texas Total		**647,031**	**786,216**	**22%**	**466,804**	**545,824**	**17%**	**212,022**	**247,215**	**17%**	**6,917**	**8,777**	**27%**	**280,808**	**303,832**	**8%**
Utah	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	13,334	15,654	17%
	Nonpoint	47,699	64,544	35%	18,576	23,020	24%	10,560	9,720	-8%	632	871	38%	4,199	5,599	33%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	274	381	39%
	Non-EGU Point	6,751	9,163	36%	24,839	30,025	21%	9,391	11,641	24%	785	932	19%	3,873	5,040	30%
Utah Total		**54,450**	**73,707**	**35%**	**43,415**	**53,045**	**22%**	**19,951**	**21,361**	**7%**	**1,417**	**1,803**	**27%**	**21,680**	**26,674**	**23%**
Vermont	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	2,578	2,822	9%
	Nonpoint	22,491	25,441	13%	3,999	4,658	16%	6,988	8,426	21%	272	339	25%	5,200	5,763	11%
	Non-EGU Point	1,767	2,442	38%	877	1,432	63%	1,294	1,904	47%	1	1	53%	425	600	41%
Vermont Total		**24,257**	**27,883**	**15%**	**4,876**	**6,091**	**25%**	**8,283**	**10,331**	**25%**	**272**	**340**	**25%**	**8,204**	**9,185**	**12%**
Virginia	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	8,739	9,812	12%
	Nonpoint	168,516	216,083	28%	43,689	50,568	16%	15,237	18,193	19%	685	809	18%	18,707	25,165	35%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	3	4	21%
	Non-EGU Point	43,536	58,742	35%	68,155	80,635	18%	73,384	87,033	19%	727	788	8%	11,739	15,031	28%
Virginia Total		**212,052**	**274,825**	**30%**	**111,844**	**131,203**	**17%**	**88,622**	**105,226**	**19%**	**1,413**	**1,597**	**13%**	**39,187**	**50,012**	**28%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Washington	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	14,379	14,265	-1%
	Nonpoint	156,929	201,834	29%	17,915	21,626	21%	3,086	3,291	7%	3,715	4,650	25%	23,540	30,568	30%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	1	2	23%
	Non-EGU Point	12,290	16,945	38%	31,619	39,609	25%	36,290	44,551	23%	4,206	5,514	31%	10,184	13,445	32%
Washington Total		**169,219**	**218,779**	**29%**	**49,533**	**61,235**	**24%**	**39,376**	**47,843**	**22%**	**7,921**	**10,164**	**28%**	**48,105**	**58,280**	**21%**

		VOC			NO_X			SO_2			NH_3			$PM_{2.5}$		
State	**Sector**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
West Virginia	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	2,543	2,760	9%
	Nonpoint	47,466	55,715	17%	12,988	15,476	19%	13,003	14,599	12%	441	522	18%	7,114	8,621	21%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	108	127	18%
	Non-EGU Point	16,531	20,608	25%	44,318	52,440	18%	51,470	59,383	15%	514	587	14%	10,766	13,483	25%
West Virginia Total		**63,997**	**76,323**	**19%**	**57,306**	**67,916**	**19%**	**64,473**	**73,983**	**15%**	**955**	**1,109**	**16%**	**20,531**	**24,991**	**22%**
Wisconsin	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	23,550	25,417	8%
	Nonpoint	211,413	257,205	22%	29,434	32,713	11%	43,831	57,219	31%	2,596	3,325	28%	29,331	37,898	29%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	2	2	38%
	Non-EGU Point	31,347	44,210	41%	41,740	49,030	17%	56,804	58,937	4%	846	1,045	24%	7,383	9,989	35%
Wisconsin Total		**242,760**	**301,416**	**24%**	**71,175**	**81,743**	**15%**	**100,634**	**116,156**	**15%**	**3,442**	**4,370**	**27%**	**60,266**	**73,307**	**22%**
Wyoming	Nonpoint fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	34,434	35,814	4%
	Nonpoint	17,354	20,439	18%	60,241	74,895	24%	14,903	14,276	-4%	292	353	21%	2,524	3,211	27%
	Point fugitive dust	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	Non-EGU Point	11,418	14,085	23%	36,495	42,874	17%	38,120	39,916	5%	654	752	15%	15,621	19,575	25%
Wyoming Total		**28,772**	**34,524**	**20%**	**96,735**	**117,769**	**22%**	**53,023**	**54,192**	**2%**	**946**	**1,105**	**17%**	**52,579**	**58,600**	**11%**
Grand Total		**8,467,766**	**10,532,928**	**24%**	**4,127,627**	**4,962,706**	**20%**	**3,770,157**	**4,429,407**	**17%**	**228,834**	**275,325**	**20%**	**3,031,998**	**3,455,245**	**14%**

Table D-2(b): Case 1 Compared to Case 2 Emissions by State and Pollutant (all anthropogenic emission sectors included)

	VOC			NOX			SO2			NH3			PM2.5		
State	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
Alabama	286,037	346,447	21%	255,044	280,775	10%	424,702	426,391	0%	85,199	85,561	0%	94,151	104,451	11%
Arizona	193,129	235,431	22%	263,284	287,307	9%	100,500	116,410	16%	45,348	45,845	1%	84,187	92,532	10%
Arkansas	170,115	199,621	17%	203,948	226,447	11%	74,130	91,616	24%	146,535	147,062	0%	83,121	91,229	10%
California	849,540	957,558	13%	825,242	865,997	5%	70,243	79,480	13%	324,066	324,181	0%	291,590	323,013	11%
Colorado	191,953	226,383	18%	205,042	219,372	7%	71,260	73,575	3%	78,299	78,377	0%	81,557	89,790	10%
Connecticut	160,769	171,820	7%	81,643	83,768	3%	20,352	21,529	6%	9,806	10,299	5%	18,290	21,386	17%
Delaware	30,215	35,281	17%	43,139	46,342	7%	59,755	67,608	13%	17,752	17,930	1%	10,769	12,005	11%
District of Columbia	12,939	14,277	10%	9,331	10,136	9%	6,780	8,422	24%	1,509	1,664	10%	1,241	1,592	28%
Florida	609,012	711,543	17%	432,336	455,182	5%	310,958	351,082	13%	73,489	74,815	2%	210,806	229,245	9%
Georgia	355,854	413,495	16%	350,655	375,512	7%	335,024	368,012	10%	124,332	126,529	2%	173,021	198,222	15%
Idaho	274,187	368,248	34%	98,419	115,991	18%	23,876	29,546	24%	81,136	81,621	1%	167,056	176,471	6%
Illinois	486,738	585,689	20%	444,125	478,674	8%	471,599	507,132	8%	111,111	117,680	6%	167,400	182,597	9%
Indiana	344,207	415,474	21%	371,901	397,726	7%	561,507	587,797	5%	100,650	102,797	2%	157,479	174,636	11%
Iowa	177,629	189,295	7%	201,599	210,579	4%	243,118	245,707	1%	241,350	242,935	1%	99,948	101,099	1%
Kansas	154,747	170,860	10%	227,556	252,723	11%	80,132	87,330	9%	151,498	152,014	0%	136,048	137,488	1%
Kentucky	234,191	276,806	18%	310,692	327,907	6%	368,433	372,702	1%	61,098	61,467	1%	83,664	93,537	12%
Louisiana	234,179	263,028	12%	613,661	681,099	11%	358,309	445,767	24%	66,430	69,162	4%	121,437	133,733	10%
Maine	126,724	152,472	20%	54,420	61,513	13%	52,086	65,971	27%	9,075	9,418	4%	32,013	38,706	21%
Maryland	152,199	186,357	22%	157,258	166,252	6%	110,597	129,796	17%	35,107	35,776	2%	41,051	48,155	17%
Massachusetts	220,112	255,522	16%	175,130	182,838	4%	105,995	130,226	23%	14,659	15,934	9%	40,897	46,522	14%
Michigan	473,221	523,990	11%	423,462	454,158	7%	513,080	533,273	4%	71,642	73,163	2%	107,199	118,497	11%
Minnesota	306,630	322,167	5%	270,278	284,755	5%	119,636	124,286	4%	163,719	164,297	0%	153,339	154,686	1%
Mississippi	222,793	273,165	23%	210,436	243,252	16%	165,720	177,617	7%	76,176	76,956	1%	89,271	100,064	12%
Missouri	259,237	284,456	10%	295,736	306,535	4%	422,967	454,109	7%	121,992	123,288	1%	151,542	156,566	3%
Montana	73,469	77,830	6%	127,553	133,893	5%	45,202	49,948	11%	47,456	47,596	0%	65,054	69,300	7%
Nebraska	104,123	111,061	7%	152,303	158,693	4%	54,225	60,239	11%	142,849	143,038	0%	88,400	90,254	2%
Nevada	76,173	93,774	23%	91,068	94,607	4%	33,406	33,628	1%	11,802	12,195	3%	44,741	50,051	12%
New Hampshire	80,159	94,895	18%	38,997	40,464	4%	23,356	26,652	14%	3,926	4,182	7%	16,545	19,449	18%
New Jersey	249,603	278,446	12%	197,426	204,056	3%	90,234	96,008	6%	18,307	19,105	4%	35,882	40,125	12%
New Mexico	116,160	132,559	14%	246,040	273,418	11%	139,821	165,191	18%	52,614	52,722	0%	137,636	142,510	4%
New York	787,657	906,292	15%	427,458	438,696	3%	290,825	299,581	3%	75,399	78,125	4%	128,333	145,032	13%

	VOC			NOX			SO2			NH3			PM2.5		
State	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**	**Case 1**	**Case 2**	**% Diff**
North Carolina	471,046	549,225	17%	267,441	282,240	6%	225,881	246,359	9%	198,260	199,387	1%	105,593	120,793	14%
North Dakota	76,760	69,292	-10%	117,103	119,441	2%	163,147	162,126	-1%	57,449	57,492	0%	76,935	76,782	0%
Ohio	436,266	507,447	16%	451,373	470,413	4%	431,072	442,399	3%	86,803	89,168	3%	132,126	143,396	9%
Oklahoma	201,035	233,388	16%	272,262	294,496	8%	80,694	86,427	7%	123,609	124,680	1%	113,620	118,643	4%
Oregon	365,104	422,750	16%	153,020	159,582	4%	50,840	54,892	8%	49,658	49,724	0%	134,968	146,721	9%
Pennsylvania	414,605	472,091	14%	462,695	485,087	5%	328,200	347,837	6%	92,757	94,208	2%	108,787	118,694	9%
Rhode Island	41,240	56,165	36%	23,122	24,764	7%	8,431	9,866	17%	1,705	1,716	1%	2,788	3,124	12%
South Carolina	261,951	322,836	23%	174,160	184,004	6%	175,256	185,341	6%	37,309	37,930	2%	64,706	71,009	10%
South Dakota	60,161	58,676	-2%	46,961	48,788	4%	26,552	27,303	3%	83,011	83,088	0%	58,785	59,530	1%
Tennessee	349,379	439,159	26%	250,355	268,131	7%	316,869	334,915	6%	54,005	56,278	4%	90,329	110,399	22%
Texas	951,427	1,090,613	15%	1,145,445	1,224,465	7%	620,673	655,866	6%	319,202	321,061	1%	377,140	400,164	6%
Utah	112,574	131,831	17%	153,361	162,991	6%	75,448	76,858	2%	31,154	31,540	1%	63,633	68,627	8%
Vermont	38,222	41,848	9%	20,185	21,399	6%	8,436	10,484	24%	9,867	9,935	1%	10,422	11,403	9%
Virginia	310,041	372,814	20%	319,590	338,950	6%	188,262	204,866	9%	59,252	59,436	0%	66,319	77,143	16%
Washington	252,421	301,981	20%	190,411	202,112	6%	57,377	65,843	15%	62,892	65,134	4%	65,546	75,720	16%
West Virginia	91,769	104,095	13%	160,080	170,690	7%	183,911	193,420	5%	14,041	14,195	1%	47,537	51,997	9%
Wisconsin	346,558	405,213	17%	223,676	234,244	5%	254,576	270,098	6%	86,221	87,150	1%	81,110	94,150	16%
Wyoming	51,472	57,223	11%	184,094	205,128	11%	128,540	129,709	1%	17,725	17,884	1%	77,144	83,165	8%
Grand Total	**12,845,731**	**14,910,893**	**16%**	**12,420,516**	**13,255,595**	**7%**	**9,071,990**	**9,731,241**	**7%**	**3,949,250**	**3,995,741**	**1%**	**4,791,155**	**5,214,402**	**9%**

D.3 Impact of Emissions Changes on Air Quality Model Prediction

The results of the growth sensitivity model runs (i.e., 2015 Case 1 and Case 2) are provided in Table 3. This table contains the county PM2.5 concentrations for those counties that are projected to be nonattainment of the current PM2.5 annual NAAQS in either of the two cases. The data in Table 3 indicate that all of these counties have higher PM2.5 in Case 2 compared to Case 1. The average increase between the two cases is 1.3 $\mu g/m^3$. In over 50 percent of the counties, the increase in PM2.5 is less than 1 $\mu g/m^3$. The largest differences, which are 3 $\mu g/m^3$ or more, are predicted for several counties in California. Between Case 1 and Case 2, the number of nonattainment counties increases from 20 to 29. Of the additional nonattainment counties, 3 are in the West and 6 are in the East.

Table D-3: Comparison of Projected Annual Average $PM_{2.5}$ Concentrations for 2015 Case 1 and Case 2.

State	County	2015 Case 1	2015 Case 2	Difference in PM2.5 (Case 2 - Case 1)
Alabama	Jefferson Co	16.1	17.4	1.2
California	Fresno Co	20.3	21.1	0.8
California	Imperial Co	14.8	15.2	0.4
California	Kern Co	21.6	22.6	0.9
California	Kings Co	17.4	18.0	0.6
California	Los Angeles Co	23.7	27.7	3.9
California	Merced Co	15.8	16.4	0.6
California	Orange Co	20.0	23.0	3.0
California	Riverside Co	27.8	30.8	3.0
California	San Bernardino Co	24.6	27.9	3.3
California	San Diego Co	15.8	16.5	0.7
California	San Joaquin Co	15.3	16.2	0.8
California	Stanislaus Co	16.5	17.3	0.8
California	Tulare Co	21.4	22.3	0.9
California	Ventura Co	14.1	15.3	1.2
Georgia	Bibb Co	13.9	15.1	1.2
Georgia	Clayton Co	14.2	15.3	1.1
Georgia	Floyd Co	14.4	16.2	1.8
Georgia	Fulton Co	15.9	16.7	0.8
Georgia	Wilkinson Co	13.8	15.2	1.4
Illinois	Cook Co	15.5	16.9	1.4
Illinois	Madison Co	15.3	16.6	1.3
Illinois	St. Clair Co	14.7	15.9	1.2
Michigan	Wayne Co	17.6	18.5	0.9
Montana	Lincoln Co	15.0	15.4	0.4
Ohio	Cuyahoga Co	15.6	16.4	0.8
Ohio	Hamilton Co	14.4	15.2	0.8
Ohio	Scioto Co	15.6	16.3	0.6
Pennsylvania	Allegheny Co	16.5	17.1	0.6

Maps of the increase in emissions associated with the comparison of sensitivity Case 2 that incorporates growth for the non-EGU stationary sources to the estimates for Case 1 are shown in Figure 2 for the eastern US and Figure 3 for the western states. Figures 4 and 5 present the distribution of increases for individual grid cells of this comparison for the east and west, respectively. This analysis shows that geographically the largest increases in $PM_{2.5}$ associated with the growth sensitivity case are predicted in the Southeast from Arkansas and Louisiana to Georgia and Tennessee, and western Kentucky northward into Illinois, Indiana and Ohio. Figure 2 and 4 indicate $PM_{2.5}$ is higher by more than a ug/m3 in Birmingham, St. Louis, Chicago and Atlanta, with Detroit at 0.9 ug/me higher in Case 2. The impact of the growth sensitivity scenario emissions is less in Cleveland and Pittsburgh, compared with other cities. In most of the gird cells in the East (over 70 percent) $PM_{2.5}$ is higher in Case 2 by 0.5 ug/m3 or less. Fewer than 5 percent of the grid cells are predicted to have increases in $PM_{2.5}$ at or above 0.75 ug/m3. The granularity of the patterns shown on the map suggests that many of the areas with the largest increases in PM may be affected by differential growth assumptions at non-EGU point sources. As shown on Figures 3 and 5 in the west, the largest increases are in the South Coast/LA and Central Valley of California. $PM_{2.5}$ is higher in the South Coast by over 3 ug/m3 in Case 2 compared to Case 1. In the Central Valley, $PM_{2.5}$ is higher by less than 1.5 ug/m3. Other areas with notably higher $PM_{2.5}$ in Case 2 include Salt Lake City, southwest Idaho, northern Idaho, and an isolated grid cell in western Oregon. Outside of the above areas the impacts of the Case 2 growth assumptions are on the order of 0.5 ug/m3 in urban areas and 0.25 ug/m3 or less in rural areas.

D.4 Discussion and Implication of results

The air quality modeling above illustrates the implications that assumptions regarding the projection of the emissions inventory can have for the “down-stream” emission control cost and monetized human health benefit analyses. To the extent that we over-estimate growth in future emissions, then we apply emission controls to reduce emissions beyond a level necessary to meet attainment. This “over-control” would then bias control costs high; it would also bias estimated benefits high, as we would monetize the human health benefits of achieving a larger increment of air quality change than necessary to reach attainment.

Conversely, if we under-estimate future emissions growth, then we fail to apply enough emission controls to attain fully. This “under-control” would then bias both estimated control cost low; it would also bias estimated benefits low, as we would monetize the human health benefits of achieving a smaller increment of air quality change than necessary to reach attainment.

As indicated in Chapter 2, EPA used the interim approach instead of the approach used in the past since it is in better alignment with historical data.

Figure D-2. Increase in PM2.5 Predicted for the Case 2 Growth Scenario vs Case 1 - East

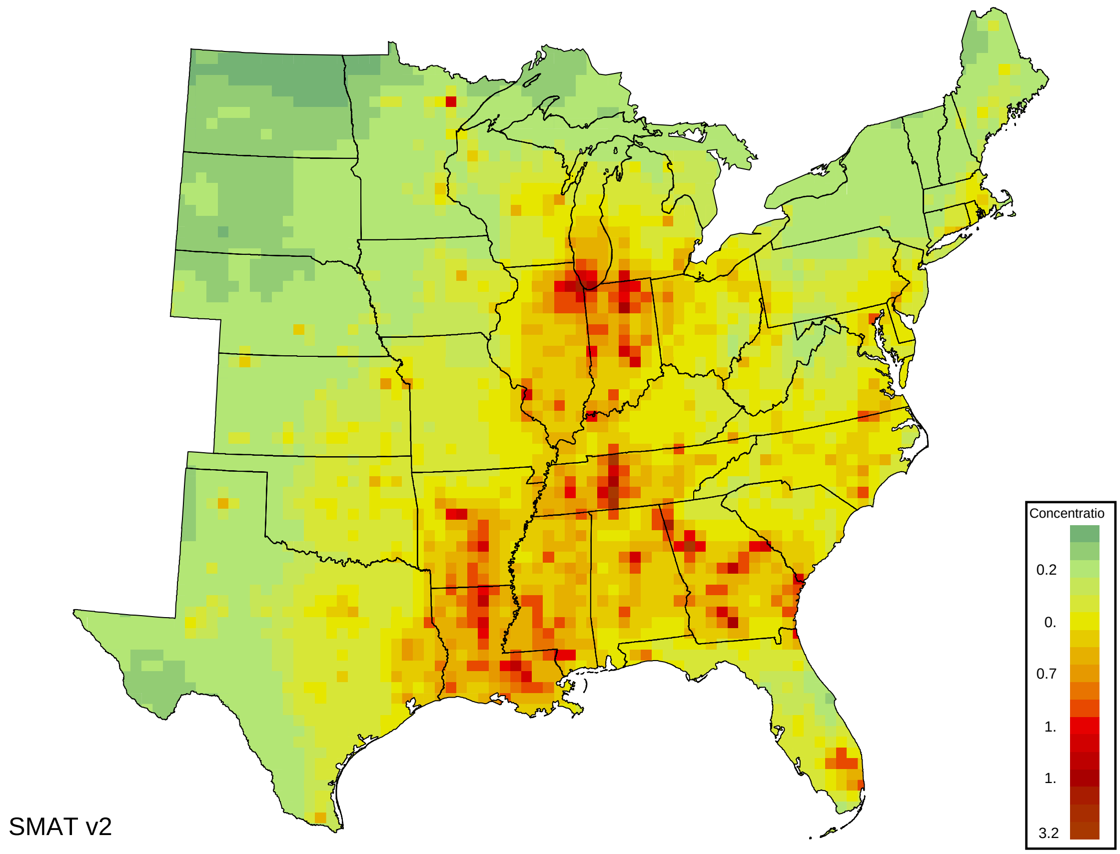


Figure D-3. Increase in PM2.5 Predicted for the Case 2 Growth Scenario vs Case 1 – West

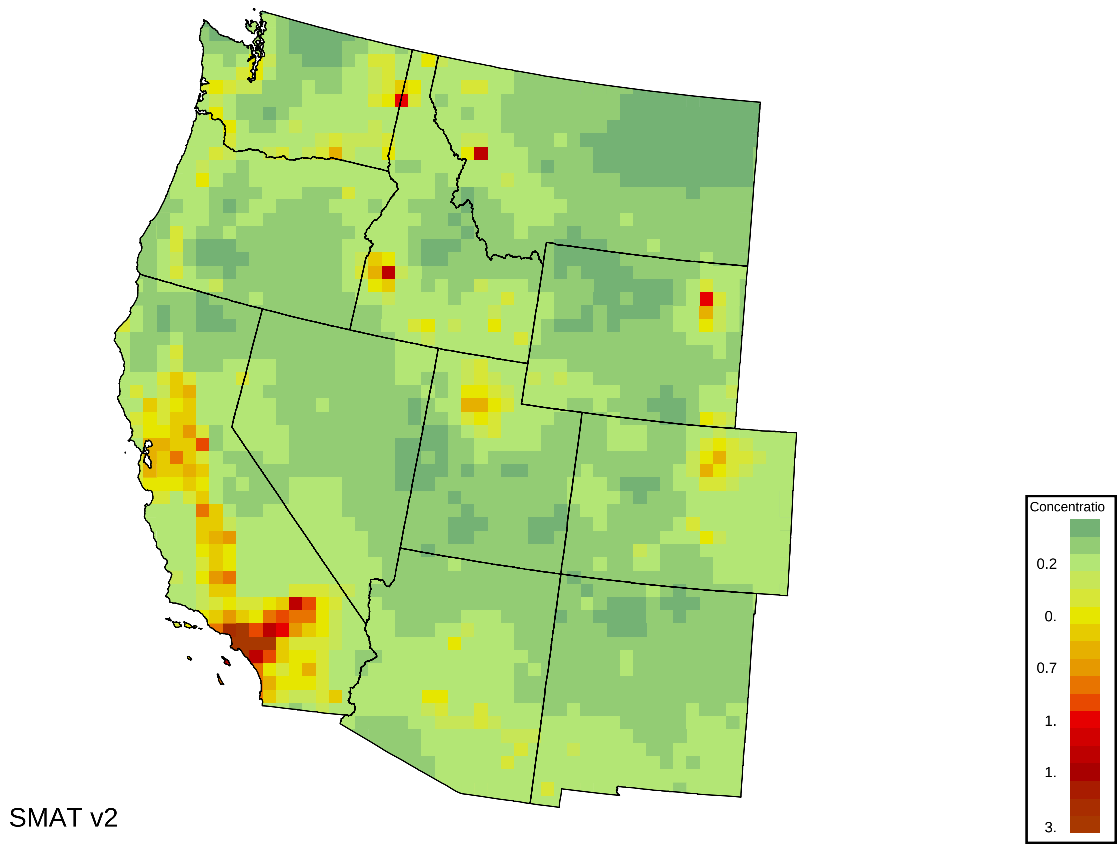


Figure D-4. Percent of Model Grids in the East with Higher PM2.5 in the Growth Sensitivity Case vs the Base Case

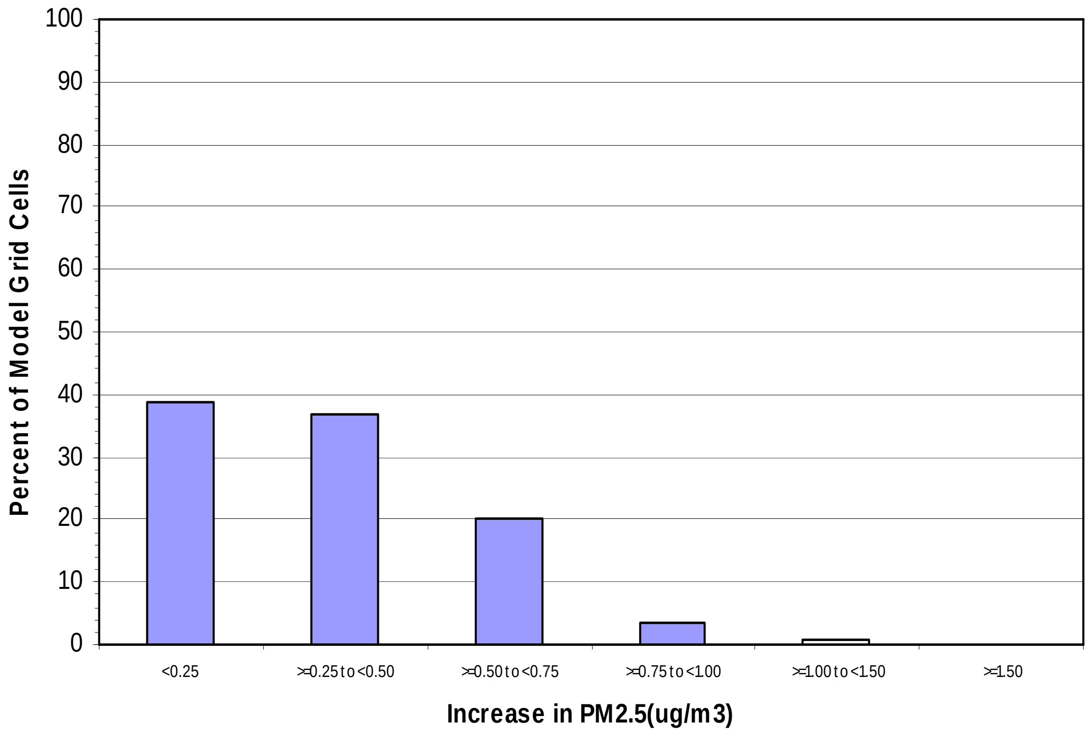
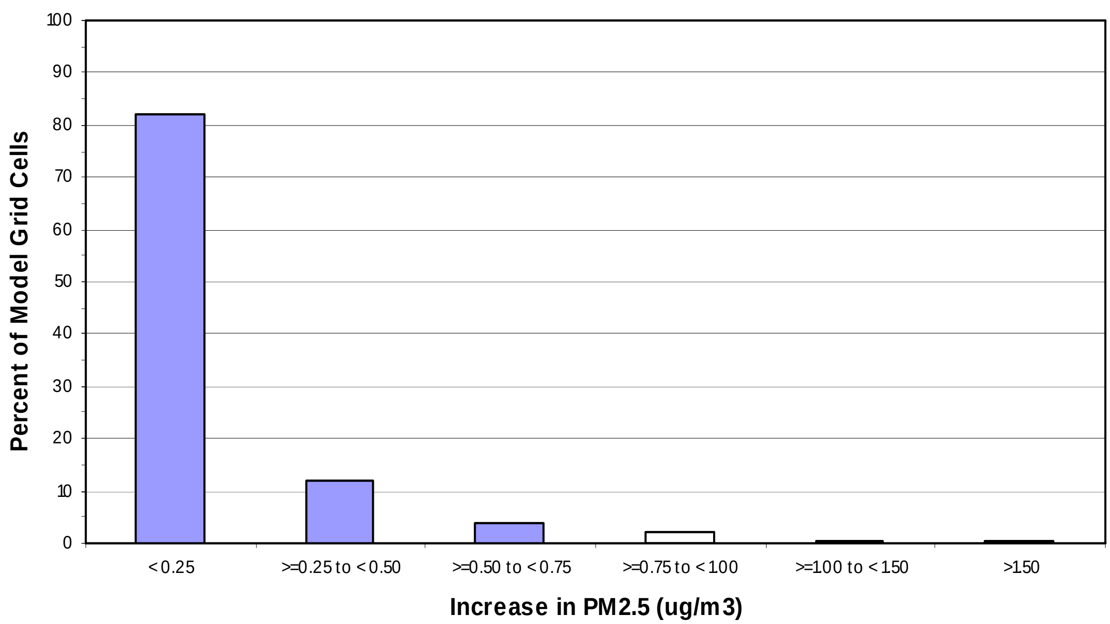


Figure D-5. Percent of Model Grids in the West with Higher PM2.5 in the Growth Sensitivity Case vs the Base Case



Attachment 1. Background Document Provided to the Council

Improving EPA Emissions Forecasting For Regulatory Impact Analyses

Summary of the Issue

The EPA conducts Regulatory Impact Analyses (RIAs) to assess the benefits and costs of air regulations. These RIAs require emissions forecasts for all relevant source categories. We continually improve these forecasts over time and significant advances have been made for major source categories including mobile sources and Electric Generating Units (EGUs). However, we have observed a disconnect between our emissions forecasts for certain stationary non-EGU source categories and the historical record. (For this document, stationary non-EGU or non-utility sources include large industrial combustion and process point sources (e.g., industrial boilers, petroleum refineries, chemical manufactures, etc.), as well as, small stationary commercial, institutional, and residential non-point sources.) This discrepancy appears to have led to significant over-prediction of emissions projections in longer-forecast periods required for the NAAQS and other programs. We have developed an interim approach for addressing this issue and intend to use it to develop a range of forecasts that will provide some understanding of the potential uncertainties implied by the past methodology and the historical record. This interim application will first be used for the RIA for the review of the PM NAAQS. We seek a consultation with the Council to provide advice on how to portray the interim approach and the uncertainties involved. We will continue to work to develop long-term improved approaches for addressing this issue.

Background

Overview of Emission Inventory Forecasts in RIAs

EPA has established a tradition of improving the emissions inventory and modeling platform for Regulatory Impact Analyses. As new and improved data, methods, and models become available, we incorporate this information into the emissions estimates and modeling platform at appropriate times. The drivers to the updates are the ever-evolving “state of knowledge” and comments received on previous analyses. We have placed highest priority on improving data/methods/and models for pollutants or sectors impacted by the policy (e.g., EGUs for the Clean Air Interstate Rule (CAIR); mobile sources for the Heavy Duty Diesel Engine and Fuel Rule and the Spark Ignition Nonroad Engine Rule).

For most Regulatory Impact Analyses, we use emissions from a historical year, or base year, (e.g., 2001) as the starting point for forecasting potential future-year emissions. In evaluating the potential impact of the subject regulation, we develop multiple future-year emission estimates based on a range of regulatory options. In general, EPA estimates the future-year emissions by forecasting changes in the various activities that generate emissions and using this forecasted activity to increase (or decrease) emissions.

We then reduce forecasted future-year emissions for the impact of mandated Clean Air Act (CAA) emission controls.

Methods Used to Forecast Emissions Inventories

Emissions in the future will differ from current emissions inventories due the following factors:

- Changes (typically growth) in economic activity that influence emissions,
- Changes in the mix of production activities both within and between economic sectors,
- Changes in vintages of capital equipment,
- Changes in population, energy use, land use, or motor vehicle miles traveled,
- Technological innovation or changes altering:
    - Production processes for emission sources,
    - Control technologies available,
    - Substitution of inputs to production (e.g., fuel switching), and
- Emission controls implemented to satisfy CAA regulations, voluntary programs and other initiatives expected to reduce air emissions.

For many source categories, EPA uses emission factors to relate air pollution to emission-generating activities (e.g., production activities of an industry). In previous analyses, the method used to project stationary non-utility emissions involves forecasting current emissions into the future by considering the following two factors:

- Changes in economic activity (generally we have assumed a linear relationship between economic activity changes and emission changes because, as stated above, many of the other factors that may influence changes in emissions are difficult to quantify) and
- Application of emission controls mandated by various parts of the CAA.

The typical formula for estimating projected inventories follows:

Projected Future Emissions = Current Emissions * Emission Growth Adjustment * Emission Control Adjustment

The emissions growth adjustment increases or decreases (typically increases) emissions in the future from current base year levels due to forecasted changes in economic or other activities that impact emission levels (e.g., population). The emission control adjustment decreases future-year emissions for expected emissions controls resulting from mandated CAA regulations. In the past, the economic growth adjustment for stationary non-EGU sources has been based upon the results of the Policy Insight® Model for Regional Economic Model, Inc (REMI) by state and Standard Industrial Classification (SIC) codes or fuel consumption forecasts by fuel type and energy sector (e.g., industrial, commercial, residential) from the US Department of Energy.

For non-EGU stationary source categories, many factors that influence future emissions (technology innovations, changes in vintages of capital equipment, energy use, etc.) listed above are difficult to quantify and are not adequately captured in current models. Our past forecasting approaches for these source categories do appear to model economic growth and the impacts of CAA emission controls relatively well, but do not address the many other factors affecting emissions (shown above) sufficiently. Forecasting emissions for these source categories is further complicated by the multitude of non-EGU stationary source categories involved (over 800 industry categories). In 2002, emissions from non-EGU stationary sources represented approximately 62 percent of total direct $PM_{2.5}$ emissions (excluding emissions from dust and fires) and approximately 18 percent and 25 percent of important PM precursors, NO_X and SO_2, respectively. While emissions from these sources are relatively small when compared to total emissions from all sources of SO_2 and NO_X, these sources represent the major contributors to direct $PM_{2.5}$ emissions and are major source categories considered in the current PM NAAQS RIA. Emission projections for the stationary non-EGU sources will be used to estimate the benefits and costs of the PM NAAQS in the RIA and EPA recognizes the immediate need for better future year emissions estimates for these categories.

Emissions projection methods are less of an issue for mobile sources and EGUs, and these sources are not subject to our interim approach. For these sources, EPA has developed improved models specific to mobile sources (MOBILE and NONROAD models) and EGUs (Integrated Planning Model). These models address many of the deficiencies in our current approach for stationary non-EGU sources previously discussed. The Integrated Planning Model is a market model of the electric utility industry that captures the impact of capital turnover and economically-motivated fuel switching on emissions. For EGUs, we also have better emissions source testing due to the installation of continuous emissions monitoring for these units. For mobile sources, our models directly address equipment turnover and the issue of fuel switching. More details may be obtained about these models at www.epa.gov/airmarkets/epa-ipm and http://www.epa.gov/OMSWWW/models.htm. In addition to EGUs and mobile sources, inventory projections for agricultural ammonia emissions are based on projected animal populations provided by US Department of Agriculture, and these sources are also not covered by our interim approach.

Problems with Past Projection Approaches

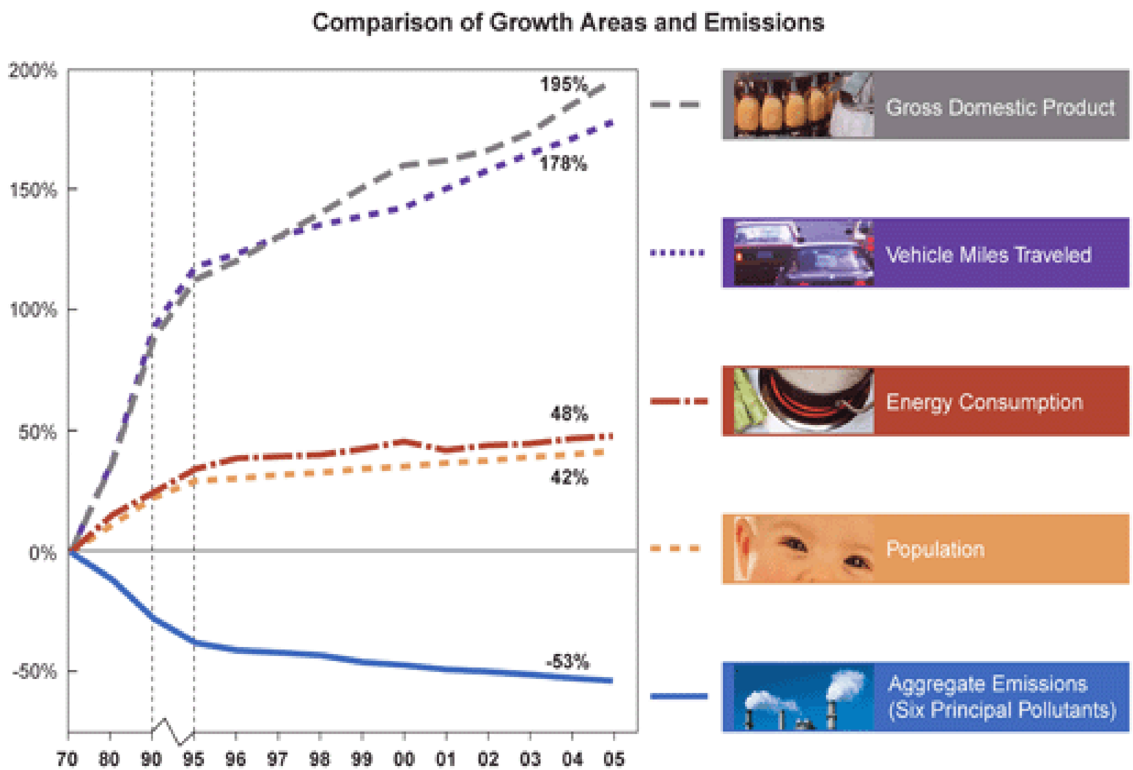
Using the approaches described above for stationary non-EGU sources, we logically forecast continuing emission increases relating to economic, population, and other sources of growth for any given analytical starting point. Such forecasts, however, are inconsistent with the relationships we see historically. Figure 1 compares activity variables that impact emissions (GDP, energy consumption, population, vehicle miles traveled) with historical air emissions from all sources (pollutants include SO_2, NO_x, VOC, PM_{10}, CO, and Pb). Since 1970, air emissions have been steadily declining while GDP, population, energy consumption, and vehicle miles traveled all have grown. The emissions shown in Figure 1 are dominated by mobile sources emissions. But the trend also exists when focusing on PM-related emissions from EGU or non-EGU stationary point and area sources, collectively as well as for key industry. The newly developed 2002 National Emissions Inventory provides more historical emissions data to corroborate the historical decline in emissions we are observing. Figure 2 shows decreasing trends in $PM_{2.5}$ and the primary PM precursors SO_2 and NO_x for non-EGU stationary source emissions from 1990 through 2002. The data source for the historical year emissions inventory is the National Emissions Inventory (NEI). The NEI provides historical emission estimates for 1990, 1996, 1999, and 2002 that represent measurements and estimates of actual emissions for the particular year. The primary data source for the NEI emissions are State emission inventories. These data are supplemented by emissions estimates developed by EPA to fill gaps in the data provided by the States. Both the State and EPA developed emissions are based on actual activity or actual activity surrogate data for the given year. Thus emissions estimates in the NEI for 1990, 1996, 1999, 2002 do not rely upon the application of growth factors to actual emissions from an older emissions inventory.

Historical emissions trends for key industrial sectors (chemical and allied products, petroleum refining and allied products, paper and allied products, and primary metals manufacturing) important to the PM NAAQS analysis are shown in Figure 3. We also see similar general downward trends in historical emissions across different regions of the country. Figure 4 compares historical trends for the stationary non-EGU source categories with the CAA baseline (includes control programs that would be implemented by 2010) emissions forecast made in the 1997 NAAQS RIA. This figure indicates the inconsistency between the forecasts and the trends thus far.

Our projection methods used to estimate growth for stationary non-EGU sources until now have focused on estimates of economic growth and emission reductions resulting from CAA mandates. We've assumed logically that the "growth" part of emission trends correlates linearly with economic or other emission generating activities. Our methods have attempted to forecast growth in the general economy and to match this growth to those industry sectors that generate air emissions. This approach assumes that the emission rate per unit of activity is the same in the base year and future years for the stationary non-EGU sources unless emission controls are applied (i.e., emission controls are the only factor that reduces emission rates.) Based upon historical data, we recognize this assumption is likely incomplete. It is now apparent that the focus exclusively on economic growth forecasts and consideration of CAA emission controls overlooks important factors that influence emission trends.

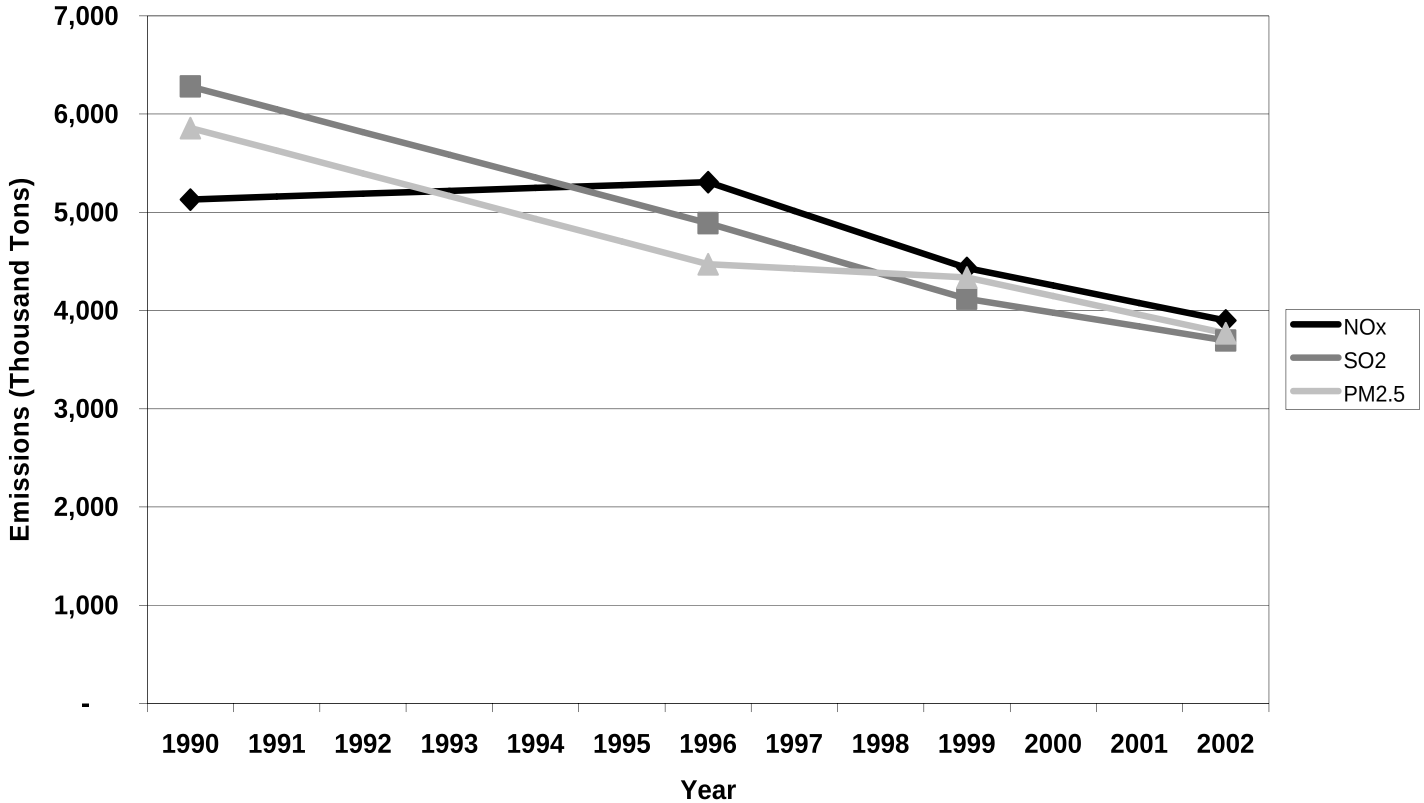
While information needed for a full understanding is lacking, we have several plausible explanations for the differences we observe in economic growth projections and emission trends and reasons to believe these trends may continue in the future. These explanations involve the replacement of older vintages of capital equipment and emission

Figure 1



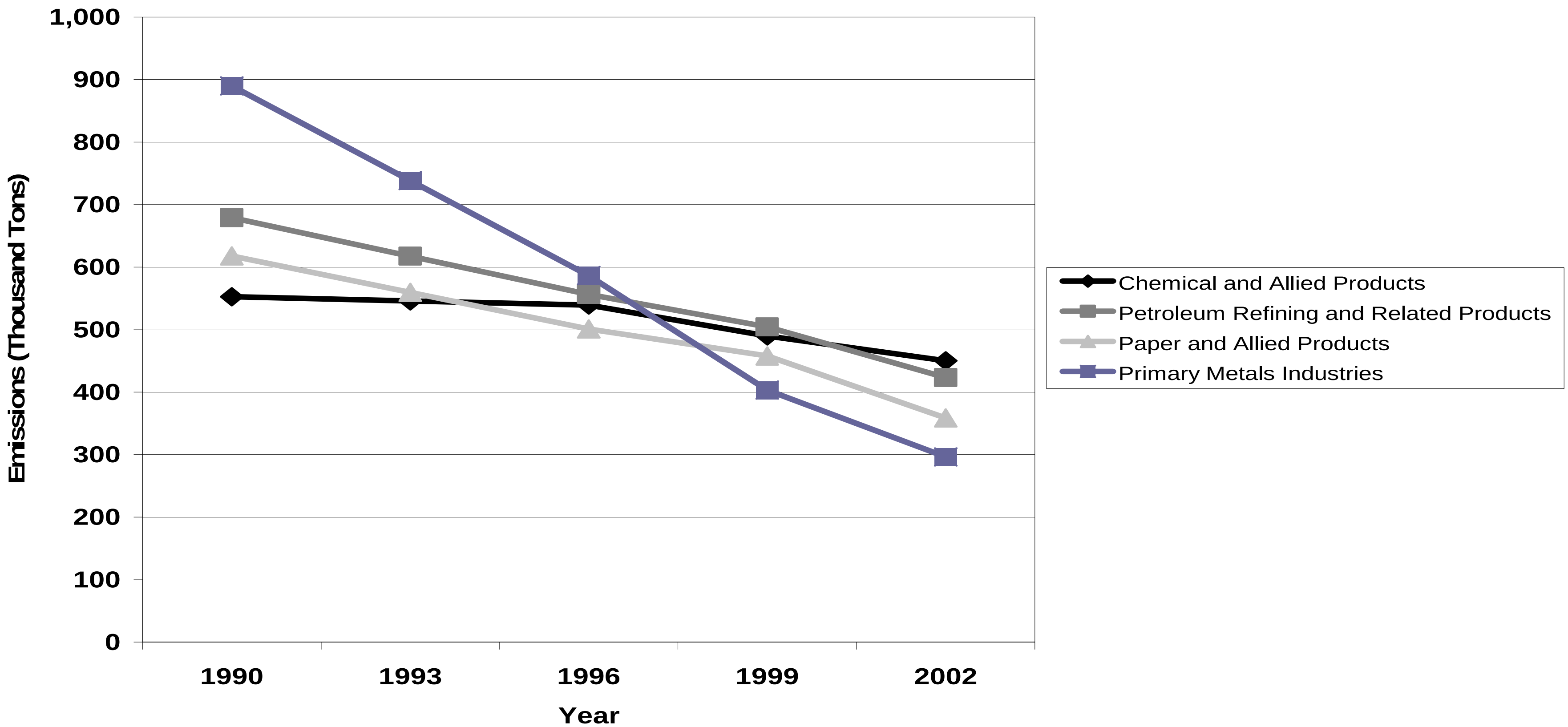
Data Sources: US Department of Commerce, Bureau of Economic Analysis, US Dept. of Transportation, Federal Highway Administration, US Census Bureau, and US Department of Energy.

Figure 2
1990 -2002 Emission Inventories
Non-EGU Stationary Sources Only[1]



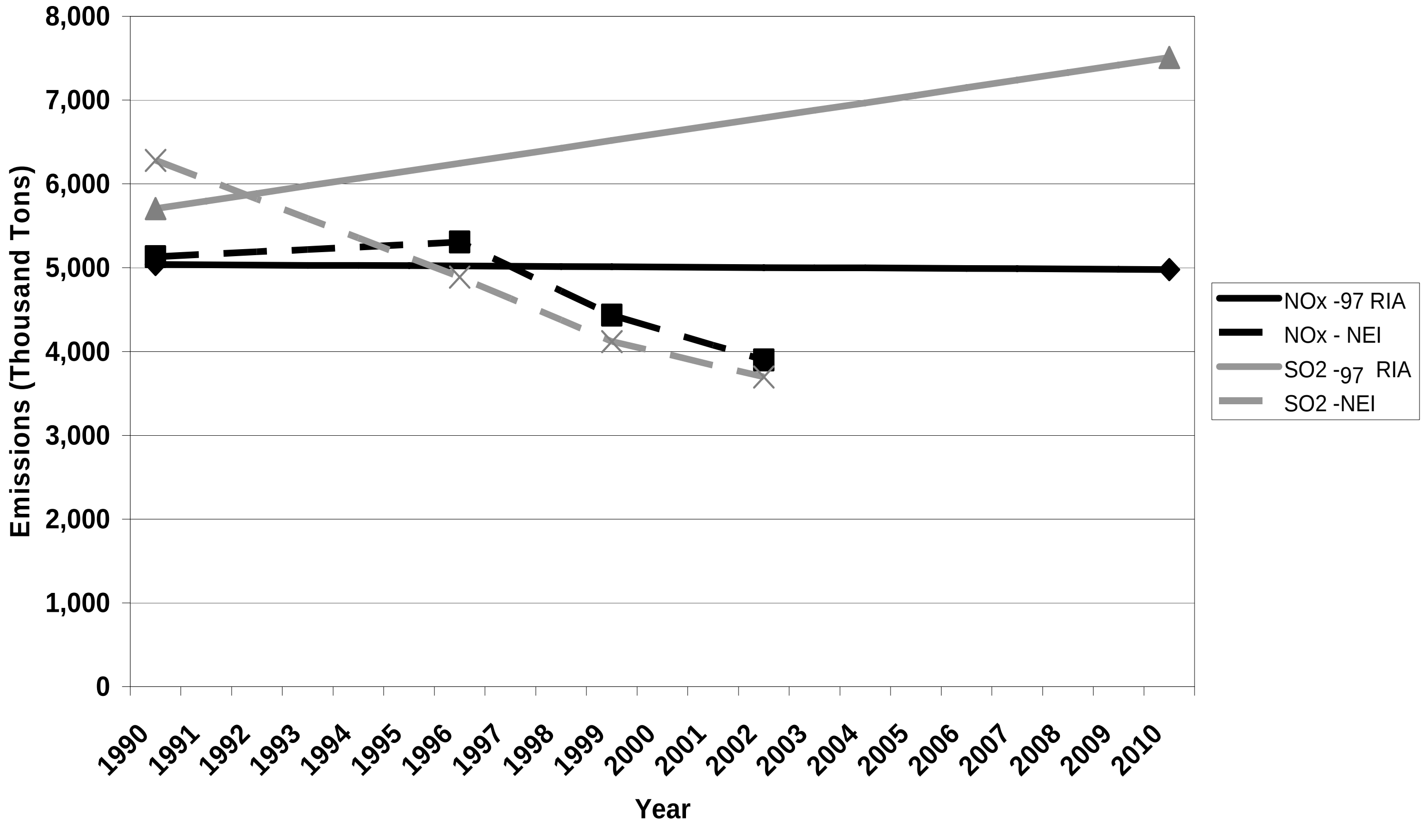
[1] Emissions shown reflect non-utility stationary point and non-point sources only, excluding fires. Source: National Emissions Inventory

Figure 3
Historical SO2 Emission Trends for Large Industrial Categories



[1] Emissions shown reflect 2 digit-SIC source categories. Source: National Emissions Inventory

Figure 4
Comparison of 1997 PM NAAQS RIA Forescasts and NEI Actual Emissions
Non-EGU Stationary Sources Only[1]



[1] Sources: National Emissions Inventory and Regulatory Impact Analysis for the Ozone and PM NAAQS, 1997.

rates. Firms replace emission generating equipment for multiple reasons including regulatory requirements, enhanced productivity, retirement of obsolete equipment, energy efficiency (e.g., fuel switching) and other reasons. Profit seeking firms will attempt to maximize profits for the firm with each capital investment. Thus, installation of new more efficient equipment may result in an increase in production of goods and services without the corollary per unit increase in emissions or in maintenance of current levels of production with lower levels of emissions. These outcomes are reasonably likely regardless of the rationale for the equipment replacement (i.e., enhanced productivity, regulatory requirements, obsolescence of existing equipment, or energy efficiency measures such as fuel switching) for firms seeking to maximize profits. Our current growth projection methods do not explicitly capture such a phenomenon, and there is a lag in our ability to recognize newly installed emission control equipment in our current emission inventory process. We have particular difficulty in accounting for potential emission reductions from regulatory actions such as CAA New Source Review and New Source Performance Standards. In addition, emission rates may not reflect current conditions. The emission rates are determined through source testing. Although we suspect that average emission rates are declining, we have not been able to verify this fact through updated sources testing due to budget constraints.

While it is not clear that all of the factors that have served to produce this historical decline will continue to operate in the future, it appears unreasonable to assume that we currently have arrived at an 'inflection point' past which the trend will stop or reverse itself. Indeed, because the available data show that a number of large sources in the sectors of interest have no or limited pollution controls, it is reasonable to expect emissions rates will be steady or decline. Continuing to ignore this factor in future-year emission projections may increasingly skew the predicted emissions increase, and the farther into the future the forecast the more dramatic the impact. The preceding and other explanations suggested that we need to reevaluate our emission forecasting approaches for stationary non-EGU sources to incorporate factors not adequately considered in past methodologies.

Interim Approach to Address this Issue

We are currently reviewing the PM NAAQS and completing an RIA that estimates the benefits and costs of the standard. The stationary non-EGU sectors are important sectors for this analysis and emission projections are more important for this analysis than they have been in some previous analyses. Over-predicting future emissions for these sectors will lead to an over-prediction of the benefits and costs of the PM NAAQS. We also believe that potential prediction errors will be greater in distant future years (e.g., 2020) due to compounding of growth. As recent and upcoming analyses are examining policies that will be implemented in 2020 or later, these over-prediction errors have become magnified. As a result, we explored alternative methods of addressing this problem. Due to a court-ordered schedule for this analysis, the time needed to complete a comprehensive revamp of our forecasting model for these source categories was not possible.

As we develop a more comprehensive approach, we are making an interim change in our analysis to better align our forecasts of future growth in the stationary non-EGU sectors with the historical record. As an interim approach, we will not apply economic growth to emissions for many stationary non-EGU sources. Table 1 shows the emission forecasting techniques planned for the PM NAAQS RIA. As shown, the interim approach affects stationary non-EGU point and non-point sources only. We recognize that this solution is a short term one at best, and needs to be improved for the future. Our RIA for the PM NAAQS will show a sensitivity analysis of the implications of the interim approach relative to our traditional approach. Figure 5 shows the forecasted emission trends for the non-utility stationary sources using the old methodology and the new interim approach. As depicted in Figure 5, the new interim approach will result in lower future-year emission projections for these sources that more closely match the observed historical trends. It is worthwhile to recognize that the emissions from these stationary non-EGU sectors are a subset of total emissions and the interim approach adjustment is minimal when looking at emissions from all source categories (see Figure 6).

In the long term, we recognize the need to improve our forecasting methods and models for these important source categories. The technical work needed for a more sophisticated and improved approach will take time to develop. In the interim, our approach has been implemented in the short time frame needed for our ongoing regulatory work. The interim approach minimizes the over-prediction error in future year emission estimates for stationary non-utility sources. This approach does not have an *a priori* bias in either direction, as it simply holds non-utility stationary source emissions to be consistent with the observed levels in 2001, accounting for known control programs to be implemented in future years. The interim approach does not apply the observed downward trend in emissions, and as such may still overstate future emissions levels if historical trends continue.

To develop an improved approach to emission projections, we are focusing first on sectors that are the largest contributors to precursors of ozone, PM, regional haze, and high risk toxics. Developing the appropriate emissions projection technique is a complex process that requires more analysis to first identify and understand the sources of change in historical emissions. As previously discussed, our past methods do appropriately reflect the impact of economic growth and emission control impacts on future-year emissions, but do not adequately reflect the impact of other factors such as technological innovation, capital turnover, fuel switching, and other activities that may have significant impacts on emissions. After gaining the necessary understanding of these trends, we will develop models that better reflect historical and anticipated future trends for key stationary non-EGU sectors. This focus on important sectors will provide the most benefit for the effort expended to improve emissions projections.

After gaining an understanding of historical trends, EPA will evaluate currently available forecasting models capable of estimating local, regional, and national economic trends. Key considerations will be the efficacy of these models to forecast growth for key stationary non-EGU industry sectors. In addition, EPA will consider techniques to model technological innovation and adoption for both productive processes and control equipment and models that consider new facility location decision-making. EPA's goal is to implement these improvements as a part of the new 2002 emissions based modeling platform. These changes may not be available for the initial version 2002 platform, but could be incorporated into the modeling platform along with other updates. When an improved approach is formulated, the EPA will consult with the Council to obtain feedback on the new methodology prior to its implementation.

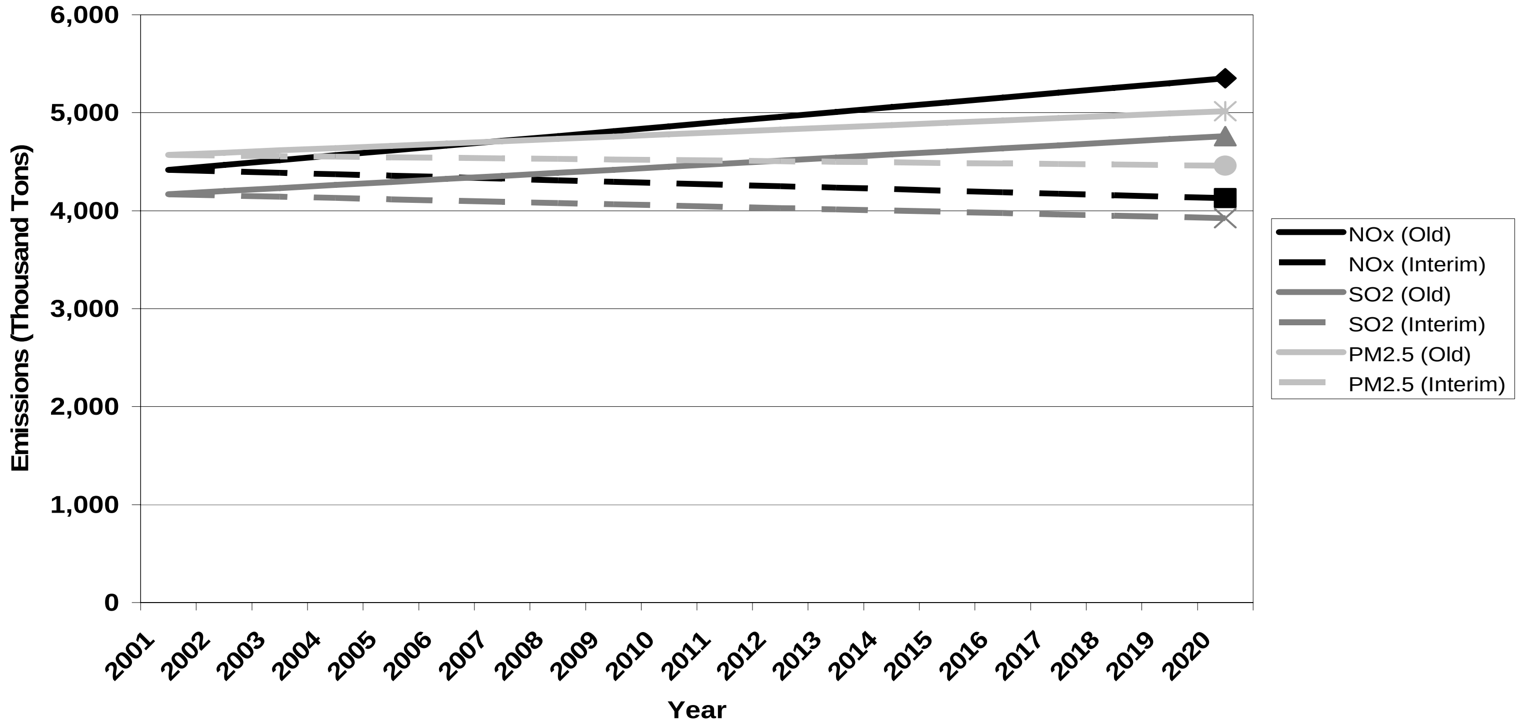
Question for the Council

Please provide your advice and comments on EPA's discussion and underlying development of the interim forecasting approach for stationary non-EGU sources described above. Are there caveats and sensitivities that should be provided in the discussion of this interim approach in our analyses? Are there additional suggestions or data you could provide to help with the development of a longer term approach?

Table 1. Emissions Sources and Basis for Current and Future-Year Inventories

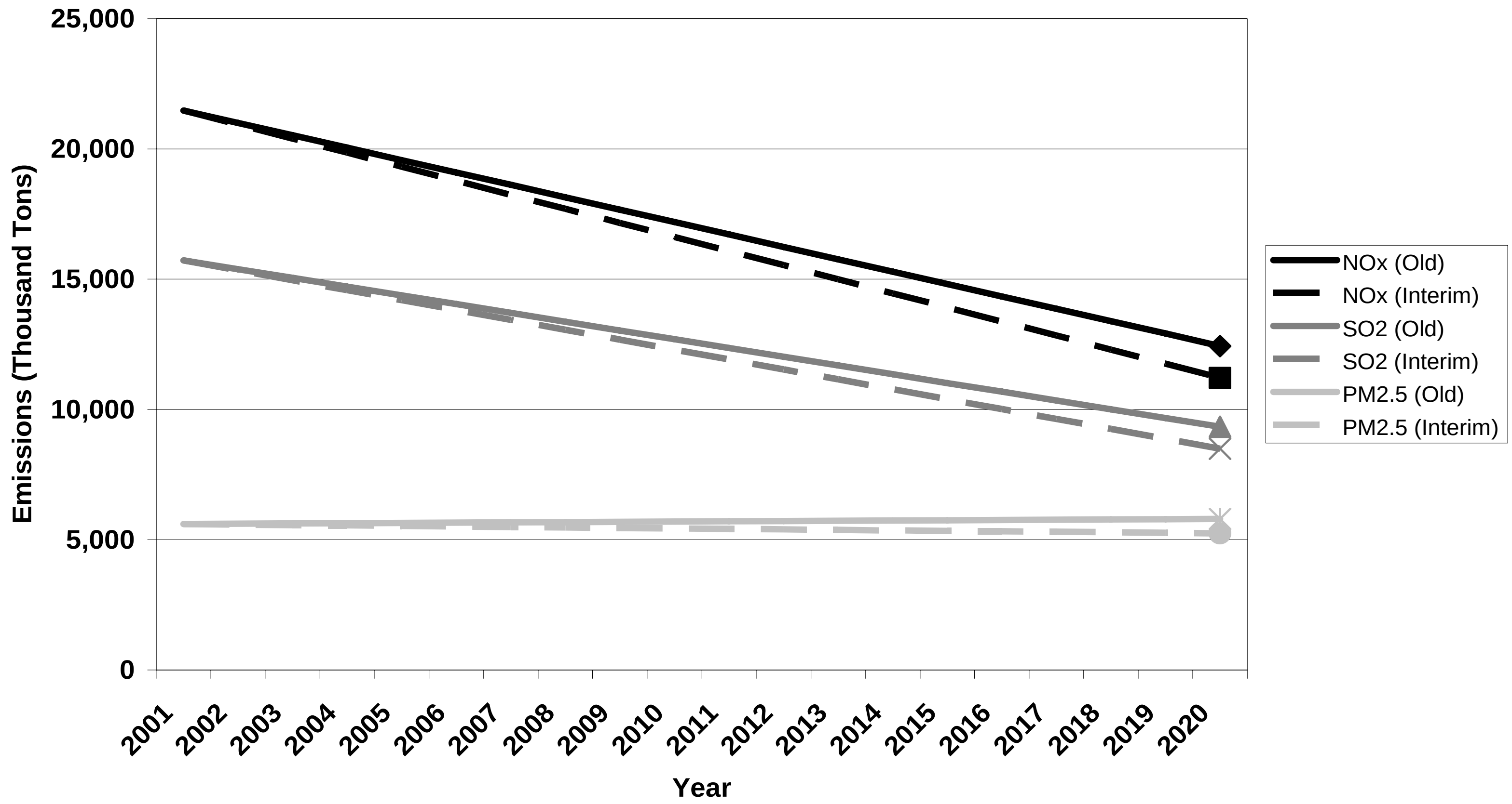
Sector	Interim Projection Method Applied	Future-Year Base Case Projections
EGU	No	Integrated Planning Model (IPM)
Non-EGU Point Sources	Yes	Apply CAA mandated controls to base year emissions to project future emissions. Projected changes in economic activity not applied to emission projection.
Other Stationary Non-point	Yes	Apply CAA mandated controls to base year emissions to project future emissions. Projected changes in economic activity not applied to emission projection.
Fires	No	Average fires from 1996 through 2002 (based on state-total acres burned), with the same emissions rates and county distributions of emissions as in the 2001 NEI
Ag -NH3	No	Livestock – USDA projections of future animal population Fertilizer – Held constant at 2001 level
On-road	No	Projected vehicle miles traveled (VMT) DOE Energy Outlook VMT projections, future-year emissions rates from MOBILE6.2 model via National Mobile Inventory Model (NMIM)
Nonroad	No	NONROAD 2004 model via NMIM

Figure 5
2020 Emission Forecasts - Old and Interim Methods
Non-EGU Stationary Sources Only[1]



Source: Analysis completed for the PM NAAQS RIA (forthcoming).

Figure 6
2020 Emission Forecasts - Old and Interim Methods
All Sources



Source: Analysis completed for the PM NAAQS RIA (forthcoming).

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Appendix E: Non-EGU Point and Area Source Control Measure Summary

The data in this table of non-EGU point and area source control measures for direct PM and PM precursor emissions comes from Appendix B of the AirControlNET 4.1 control measures documentation report prepared in May 2006. The detailed information found in AirControlNET for each of these control measures can be found in this same report. This detailed information also includes any assumptions, caveats, and limitations associated with the information and is presented in a "at-a-glance" table that is available for each control measure in AirControlNET. All of this information represents the best and most complete data that EPA has for each of these control measures at this time and will be revised and updated by EPA as appropriate.

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Cattle Feedlots	Chemical Additives to Waste								√							228	
Hog Operations	Chemical Additives to Waste								√*				50%			73	
Poultry Operations	Chemical Additives to Waste								√*				75%			1,014	
Agricultural Burning	Seasonal Ban (Ozone Season Daily)					√*							100%			N/A	
Ammonia—Natural Gas—Fired Reformers—Small Sources	Oxygen Trim + Water Injection					√*							65%			680	
Ammonia—Natural Gas—Fired Reformers—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		2,900	3,870	3,870
Ammonia—Natural Gas—Fired Reformers—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%		2,230	2,230	2,860
Ammonia—Natural Gas—Fired Reformers—Small Sources	Low NOx Burner					√*		X					50%			820	
Ammonia—Natural Gas—Fired Reformers—Small Sources	Low NOx Burner (LNB) + Flue Gas Recirculation (FGR)					√*							60%		2,470	2,560	2,560
Ammonia Products; Feedstock Desulfurization—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		2,470	2,560	2,560
Asphaltic Cone; Rotary Dryer; Conv Plant—Small Sources	Low NOx Burner					√*							50%			2,200	
By-Product Coke Manufacturing; Oven Underfiring	Selective Non-Catalytic Reduction (SNCR)					√*							60%			1,640	
Cement Kilns	Biosolid Injection					√*		X					23%			310	
Cement Manufacturing—Dry	Mid-Kiln Firing					√*							25%		-460	55	730
Cement Manufacturing—Dry	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*							50%				

X 770

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Cement Manufacturing—Dry	Selective Catalytic Reduction (SCR)					√*							80%			3,370	
Cement Manufacturing—Dry	Selective Non-Catalytic Reduction (SNCR) Ammonia Based					√*		X					50%				
Cement Manufacturing—Dry	Low NOx Burner					√*		X					25%		300 850	440	620
Cement Manufacturing—Wet	Mid-Kiln Firing					√*							25%		-460	55	730
Cement Manufacturing—Wet	Low NOx Burner					√*							25%		300	440	620
Cement Manufacturing—Wet—Large Sources	Selective Catalytic Reduction (SCR)					√*							80%			2,880	
Cement Manufacturing—Wet—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%			2,880	
Ceramic Clay Manufacturing; Drying—Small Sources	Low NOx Burner					√*		X					50%			2,200	
Coal Cleaning-Thrml Dryer; Fluidized Bed—Small Sources	Low NOx Burner					√*							50%			1,460	
Combustion Turbines—Jet Fuel—Small Sources	Selective Catalytic Reduction (SCR) + Water Injection					√*							90%			2,300	
Combustion Turbines—Jet Fuel—Small Sources	Water Injection					√*							68%			1,290	
Combustion Turbines—Natural Gas—Large Sources	Dry Low NOx Combustors					√*							50%		100	100	140
Combustion Turbines—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR) + Water Injection					√*							95%			2,730	
Combustion Turbines—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR) + Steam Injection					√*							95%		2,010	2,010	8,960
Combustion Turbines—Natural Gas—Small Sources	Steam Injection					√*		X					80%			1,040	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

Source Category	Control Measure Name	*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
		$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Combustion Turbines—Natural Gas—Small Sources	Water Injection					√*							76%			1,510	
Combustion Turbines—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR) + Low NOx Burner (LNB)					√*							94%		2,570	2,570	19,120
Combustion Turbines—Natural Gas—Small Sources	Dry Low NOx Combustors					√*		X					84%		490	490	540
Combustion Turbines—Oil—Small Sources	Selective Catalytic Reduction (SCR) + Water Injection					√*							90%			2,300	
Combustion Turbines—Oil—Small Sources	Water Injection					√*							68%			1,290	
Commercial/Institutional—Natural Gas	Water Heater Replacement					√*							7%			N/A	
Commercial/Institutional—Natural Gas	Water Heaters + LNB Space Heaters					√*							7%			1,230	
Commercial/Institutional Incinerators	Selective Non-Catalytic Reduction (SNCR)					√*							45%			1,130	
Conv Coating of Prod; Acid Cleaning Bath—Small Sources	Low NOx Burner					√*		X					50%			2,200	
Fiberglass Manufacture; Textile-Type; Recuperative Furnaces	Low NOx Burner					√*							40%			1,690	
Fluid Catalytic Cracking Units—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
Fuel Fired Equipment—Process Heaters	Low NOx Burner + Flue Gas Recirculation					√*							50%			570	
Fuel Fired Equipment; Furnaces; Natural Gas	Low NOx Burner					√*							50%			570	
Glass Manufacturing—Containers	OXY-Firing					√*							85%			4,590	
Glass Manufacturing—Containers	Electric Boost					√*							10%			7,150	
Glass Manufacturing—Containers	Gullet Preheat					√*							25%			940	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Glass Manufacturing—Containers	Low NOx Burner					√*							40%			1,690	
Glass Manufacturing—Containers	Selective Non-Catalytic Reduction (SNCR)					√*							40%			1,770	
Glass Manufacturing—Containers	Selective Catalytic Reduction (SCR)					√*		X					75%			2,200	
Glass Manufacturing—Flat	OXY-Firing					√*		X					85%			1,900	
Glass Manufacturing—Flat	Low NOx Burner					√*							40%			700	
Glass Manufacturing—Flat	Electric Boost					√*							10%			2,320	
Glass Manufacturing—Flat—Large Sources	Selective Catalytic Reduction (SCR)					√*							75%				
Glass Manufacturing—Flat—Large Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					40%			710	
Glass Manufacturing—Flat—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					75%			740	
Glass Manufacturing—Flat—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					40%			710	
Glass Manufacturing—Pressed	Gullet Preheat					√*		X					25%			810 740	
Glass Manufacturing—Pressed	Low NOx Burner					√*							40%			1,500	
Glass Manufacturing—Pressed	Selective Non-Catalytic Reduction (SNCR)					√*							40%			1,640	
Glass Manufacturing—Pressed	Selective Catalytic Reduction (SCR)					√*		X					75%			2,530	
Glass Manufacturing—Pressed	OXY-Firing					√*		X					85%			3,900	
Glass Manufacturing—Pressed	Electric Boost					√*							10%			8,760	
1C Engines—Gas	L-E (Low Speed)					√*							87%			176	
1C Engines—Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*							90%			2,769	
1C Engines—Gas, Diesel, LPG—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%			2,340	
1C Engines—Gas, Diesel, LPG—Small Sources	Ignition Retard					√*							25%			770	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

Source Category	Control Measure Name	Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
		$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
ICI Boilers—Coal/Cyclone—Large Sources	Coal Reburn					√*							50%			300	
ICI Boilers—Coal/Cyclone—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%			820	
ICI Boilers—Coal/Cyclone—Small Sources	Natural Gas Reburn (NGR)					√*							55%			1,570	
ICI Boilers—Coal/Cyclone—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							35%				
ICI Boilers—Coal/Cyclone—Small Sources	Coal Reburn					√*		X					50%		840	1,570	
ICI Boilers—Coal/FBC—Large Sources	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*							40%				
ICI Boilers—Coal/FBC—Small Sources	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*		X					75%		670		
ICI Boilers—Coal/Stoker—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					40%		873 900	1,015	1,015
ICI Boilers—Coal/Stoker—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					40%				
ICI Boilers—Coal/Wall—Large Sources	Low NOx Burner					√*		X					50%		817	1,090	
ICI Boilers—Coal/Wall—Large Sources	Selective Catalytic Reduction (SCR)					√*							70%			1,070	
ICI Boilers—Coal/Wall—Large Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					40%				
ICI Boilers—Coal/Wall—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					70%		840	1,260	
ICI Boilers—Coal/Wall—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							40%		400	1,040	1,040
ICI Boilers—Coal/Wall—Small Sources	Low NOx Burner					√*		X					50%			1,460	
ICI Boilers—Coke—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							40%		400	1,040	1,040
ICI Boilers—Coke—Small Sources	Low NOx Burner					√*		X					50%			1,460	
ICI Boilers—Coke—Small Sources	Selective Catalytic Reduction (SCR)					√*							70%			1,260	

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

Source Category	Control Measure Name	Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
		$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
ICI Boilers—Distillate Oil—Large Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%			1,890	
ICI Boilers—Distillate Oil—Small Sources	Low NOx Burner					√*		X					50%			1,180	
ICI Boilers—Distillate Oil—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		1,090	2,490	2,490
ICI Boilers—Distillate Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%		2,780	2,780	3,570
ICI Boilers—Distillate Oil—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					50%		3,470	4,640	4,640
ICI Boilers—Liquid Waste	Selective Catalytic Reduction (SCR)					√*		X					80%		1,480	1,480	1,910
ICI Boilers—Liquid Waste—Small Sources	Low NOx Burner					√*		X					50%			400	
ICI Boilers—Liquid Waste—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		1,120	1,120	1,080
ICI Boilers—Liquid Waste—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		1,940	2,580	2,580
ICI Boilers—LPG—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%		2,780	2,780	3,570
ICI Boilers—LPG—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		1,090	2,490	2,490
ICI Boilers—LPG—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		3,470	4,640	4,640
ICI Boilers—LPG—Small Sources	Low NOx Burner					√*		X					50%			1,180	
ICI Boilers—MSW/Stoker—Small Sources	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*							55%			1,690	
ICI Boilers—Natural Gas—Large Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					50%			1,570	
ICI Boilers—Natural Gas—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		2,470	2,560	2,560
ICI Boilers—Natural Gas—Small Sources	Oxygen Trim + Water Injection					√*							65%			680	
ICI Boilers—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%		2,230	2,230	2,860

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
ICI Boilers—Natural Gas—Small Sources	Low NOx Burner					√*							50%			820	
ICI Boilers—Natural Gas—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		2,900	3,870	3,870
ICI Boilers—Process Gas—Small Sources	Oxygen Trim + Water Injection					√*		X					65%			680	
ICI Boilers—Process Gas—Small Sources	Low NOx Burner					√*							50%			820	
ICI Boilers—Process Gas—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		2,470	2,560	2,560
ICI Boilers—Process Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%		2,230	2,230	2,860
ICI Boilers—Residual Oil—Large Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					50%			1,050	
ICI Boilers—Residual Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%		1,480	1,480	1,910
ICI Boilers—Residual Oil—Small Sources	Low NOx Burner					√*		X					50%			400	
ICI Boilers—Residual Oil—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		1,940	2,580	2,580
ICI Boilers—Residual Oil—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		1,120	1,120	1,080
ICI Boilers—Wood/Bark/Stoker—Large Sources	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*							55%			1,190	
ICI Boilers—Wood/Bark/Stoker—Small Sources	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*		X					55%			1,440	
Industrial Coal Combustion	RACT to 25 tpy (LNB)					√*		X					21%			1,350	
Industrial Coal Combustion	RACT to 50 tpy (LNB)					√*							21%			1,350	
Industrial Incinerators	Selective Non-Catalytic Reduction (SNCR)					√*							45%			1,130	
Industrial Natural Gas Combustion	RACT to 50 tpy (LNB)					√*		X					31%			770	
Industrial Natural Gas Combustion	RACT to 25 tpy (LNB)					√*							31%			770	
Industrial Oil Combustion	RACT to 50 tpy (LNB)					√*							36%			1,180	
Industrial Oil Combustion	RACT to 25 tpy (LNB)					√*							36%			1,180	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
In-Proc; Process Gas; Coke Oven/Blast Ovens	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
In-Process Fuel Use—Bituminous Coal—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							40%			1,260	
In-Process Fuel Use; Natural Gas—Small Sources	Low NOx Burner					√*		X					50%			2,200	
In-Process Fuel Use; Residual Oil—Small Sources	Low NOx Burner					√*							37%			2,520	
In-Process; Bituminous Coal; Cement Kilns	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*							50%				
In-Process; Bituminous Coal; Lime Kilns	Selective Non-Catalytic Reduction (SNCR) Urea Based					√*		X					50%		770		
In-Process; Process Gas; Coke Oven Gas	Low NOx Burner					√*		X					50%		770	2,200	
Internal Combustion Engines—Gas	L-E (Medium Speed)					√*							87%			380	
Internal Combustion Engines—Gas—Large Sources	Ignition Retard					√*							20%			550	
Internal Combustion Engines—Gas—Large Sources	Air/Fuel + Ignition Retard					√*							30%		150	460	460
Internal Combustion Engines—Gas—Large Sources	Air/Fuel Ratio Adjustment					√*							20%			380	
Internal Combustion Engines—Gas—Small Sources	Air/Fuel + Ignition Retard					√*							30%		270	1,440	1,440
Internal Combustion Engines—Gas—Small Sources	Air/Fuel Ratio Adjustment					√*							20%			1,570	
Internal Combustion Engines—Gas—Small Sources	Ignition Retard					√*							20%			1,020	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Internal Combustion Engines—Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%			2,340	
Internal Combustion Engines—Oil—Small Sources	Ignition Retard					√*		X					25%			770	
Iron & Steel Mills—Annealing	Low NOx Burner (LNB) + SCR					√*							80%		1,320	1,720	1,720
Iron & Steel Mills—Annealing	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		250	750	750
Iron & Steel Mills—Annealing	Selective Non-Catalytic Reduction (SNCR)					√*							60%			1,640	
Iron & Steel Mills—Annealing	Low NOx Burner					√*		X					50%			570	
Iron & Steel Mills—Annealing—Small Sources	Selective Catalytic Reduction (SCR)					√*							85%			3,830	
Iron & Steel Mills—Annealing—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*		X					90%		3,720	4,080	4,080
Iron & Steel Mills—Galvanizing	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		190	580	580
Iron & Steel Mills—Galvanizing	Low NOx Burner					√*							50%			490	
Iron & Steel Mills—Reheating	Low NOx Burner + Flue Gas Recirculation					√*							77%		150	380	380
Iron & Steel Mills—Reheating	Low NOx Burner					√*							66%			300	
Iron & Steel Mills—Reheating	Low Excess Air (LEA)					√*							13%			1,320	
Iron Production; Blast Furnaces; Blast Heating Stoves	Low NOx Burner + Flue Gas Recirculation					√*							77%			380	
Lime Kilns	Low NOx Burner					√*							30%			560	
Lime Kilns	Mid-Kiln Firing					√*							30%			460	
Medical Waste Incinerators	Selective Non-Catalytic Reduction (SNCR)					√*							45%			4,510	
Municipal Waste Combustors	Selective Non-Catalytic Reduction (SNCR)					√*		X					45%			1,130	

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

Source Category	Control Measure Name	Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
		$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Natural Gas Production; Compressors—Small Sources	Selective Catalytic Reduction (SCR)					√*							20%			1,651	
Nitric Acid Manufacturing—Small Sources	Extended Absorption					√*		X					95%			480	
Nitric Acid Manufacturing—Small Sources	Non-Selective Catalytic Reduction (NSCR)					√*							98%		510	550	710
Nitric Acid Manufacturing—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					97%				
Open Burning	Episodic Ban (Daily Only)					√*		X					100%		590	N/A	
Plastics Prod-Specific; (ABS)—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
Process Heaters—Distillate Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*							75%			9,230	
Process Heaters—Distillate Oil—Small Sources	Low NOx Burner - Selective Non-Catalytic Reduction (SNCR)					√*		X					78%		3,620	3,620	3,830
Process Heaters—Distillate Oil—Small Sources	Ultra Low NOx Burner					√*		X					74%			2,140	
Process Heaters—Distillate Oil—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							60%			3,180	
Process Heaters—Distillate Oil—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*		X					48%		4,250	4,250	19,540
Process Heaters—Distillate Oil—Small Sources	Low NOx Burner					√*							45%			3,470	
Process Heaters—Distillate Oil—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*							92%		9,120	9,120	15,350
Process Heaters—LPG—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*		X					60%			3,180	
Process Heaters—LPG—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*		X					92%		9,120	9,120	15,350
Process Heaters—LPG—Small Sources	Low NOx Burner (LNB) + SNCR					√*		X					78%		3,620	3,620	3,830
Process Heaters—LPG—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					75%			9,230	

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	$S0_2$	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Process Heaters—LPG—Small Sources	Ultra Low NOx Burner					√*							74%			2,140	
Process Heaters—LPG—Small Sources	Low NOx Burner					√*							45%			3,470	
Process Heaters—LPG—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							48%		4,250	4,250	19,540
Process Heaters—Natural Gas—Small Sources	Ultra Low NOx Burner					√*							75%			1,500	
Process Heaters—Natural Gas—Small Sources	Low NOx Burner					√*							50%			2,200	
Process Heaters—Natural Gas—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		3,190	3,190	15,580
Process Heaters—Natural Gas—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							60%			2,850	
Process Heaters—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					75%			12,040	
Process Heaters—Natural Gas—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*		X					88%		11,560	11,560	27,910
Process Heaters—Natural Gas—Small Sources	Low NOx Burner (LNB) + SNCR					√*		X					80%		3,520	3,520	6,600
Process Heaters—Other Fuel—Small Sources	Low NOx Burner (LNB) + SNCR					√*		X					75%		2,230	2,300	2,860
Process Heaters—Other Fuel—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					75%			5,350	
Process Heaters—Other Fuel—Small Sources	Ultra Low NOx Burner					√*		X					73%			1,290	
Process Heaters—Other Fuel—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							60%			1,930	
Process Heaters—Other Fuel—Small Sources	Low NOx Burner					√*		X					37%			2,520	
Process Heaters—Other Fuel—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							34%			3,490	
Process Heaters—Other Fuel—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*							91%		5,420	5,420	7,680
Process Heaters—Process Gas—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*		X					88%		11,560	11,560	27,910

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Process Heaters—Process Gas—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
Process Heaters—Process Gas—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							60%			2,850	
Process Heaters—Process Gas—Small Sources	Ultra Low NOx Burner					√*		X					75%			1,500	
Process Heaters—Process Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*							75%			12,040	
Process Heaters—Process Gas—Small Sources	Low NOx Burner (LNB) +Selective Reduction SNCR					√*		X					80%		3,520	3,520	6,600
Process Heaters—Process Gas—Small Sources	Low NOx Burner					√*		X					50%			2,200	
Process Heaters—Residual Oil—Small Sources	Low NOx Burner (LNB) + Selective Catalytic Reduction (SCR)					√*							91%		5,420	5,420	7,680
Process Heaters—Residual Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					75%			5,350	
Process Heaters—Residual Oil—Small Sources	Low NOx Burner (LNB) + SCR					√*		X					75%		2,230	2,300	2,860
Process Heaters—Residual Oil—Small Sources	Ultra Low NOx Burner					√*		X					73%			1,290	
Process Heaters—Residual Oil—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							60%			1,930	
Process Heaters—Residual Oil—Small Sources	Low NOx Burner					√*		X					37%			2,520	
Process Heaters—Residual Oil—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							34%			3,490	
Residential Natural Gas	Water Heater Replacement					√*							7%			N/A	
Residential Natural Gas	Water Heater + LNB Space Heaters					√*							7%			1,230	
Rich-Burn Stationary Reciprocating Internal Combustion Engines	Non-selective catalytic reduction					√*							90%			342	
Rich-Burn Stationary Reciprocating Internal Combustion Engines	Non-selective catalytic reduction					√*							90%			342	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	$S0_2$	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Rich-Burn Stationary Reciprocating Internal Combustion Engines (RICE)	Non-selective catalytic reduction (NSCR)					√*	√			√			90%			342	
Sand/Gravel; Dryer—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
Secondary Aluminum Production; Smelting Furnaces	Low NOx Burner					√*							50%			570	
Solid Waste Disposal; Government; Other	Selective Non-Catalytic Reduction (SNCR)					√*							45%			1,130	
Space Heaters—Distillate Oil—Small Sources	Low NOx Burner					√*		X					50%			1,180	
Space Heaters—Distillate Oil—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		3,470	4,640	4,640
Space Heaters—Distillate Oil—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%		2,780	2,780	3,570
Space Heaters—Distillate Oil—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*		X					60%		1,090	2,490	2,490
Space Heaters—Natural Gas—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		2,900	3,870	3,870
Space Heaters—Natural Gas—Small Sources	Selective Catalytic Reduction (SCR)					√*		X					80%		2,230	2,230	2,860
Space Heaters—Natural Gas—Small Sources	Oxygen Trim + Water Injection					√*		X					65%			680	
Space Heaters—Natural Gas—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		2,470	2,560	2,560
Space Heaters—Natural Gas—Small Sources	Low NOx Burner					√*							50%			820	
Starch Manufacturing; Combined Operation—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							55%		1,430	3,190	3,190
Steel Foundries; Heat Treating	Low NOx Burner					√*							50%			570	
Steel Production; Soaking Pits	Low NOx Burner + Flue Gas Recirculation					√*							60%		250	750	750
Sulfate Pulping—Recovery Furnaces—Small Sources	Low NOx Burner + Flue Gas Recirculation					√*							60%		2,470	2,560	2,560
Sulfate Pulping—Recovery Furnaces—Small Sources	Selective Catalytic Reduction (SCR)					√*							80%		2,230	2,230	2,860

X

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Sulfate Pulping—Recovery Furnaces—Small Sources	Low NOx Burner					√*							50%			820	
Sulfate Pulping—Recovery Furnaces—Small Sources	Selective Non-Catalytic Reduction (SNCR)					√*							50%		2,900	3,870	3,870
Sulfate Pulping—Recovery Furnaces—Small Sources	Oxygen Trim + Water Injection					√*		X					65%			680	
Surface Coat Oper; Coating Oven Htr; Nat Gas—Small Sources	Low NOx Burner					√*							50%			2,200	
Agricultural Burning	Bale Stack/Propane Burning	√	√*	√	√			X				49%	63%	63%		2,591	
Agricultural Tilling	Soil Conservation Plans	√	√	√	√								11.7%			138	
Asphalt Manufacture	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Asphalt Manufacture	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Asphalt Manufacture	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	147	256
Asphalt Manufacture	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Asphalt Manufacture	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Asphalt Manufacture	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Beef Cattle Feedlots	Watering	√	√*	√	√								50%			307	
Chemical Manufacture	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Chemical Manufacture	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Chemical Manufacture	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Commercial Institutional Boilers—Coal	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Commercial Institutional Boilers—Coal	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Commercial Institutional Boilers—Coal	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Commercial Institutional Boilers—Coal	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Commercial Institutional Boilers—Coal	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Commercial Institutional Boilers—Natural Gas	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Commercial Institutional Boilers—Oil	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Commercial Institutional Boilers—Oil	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Commercial Institutional Boilers—Oil	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Commercial Institutional Boilers—Solid Waste	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Commercial Institutional Boilers—Solid Waste	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Commercial Institutional Boilers—Wood	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Commercial Institutional Boilers—Wood	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Commercial Institutional Boilers—Wood/Bark	Dry ESP-Wire Plate Type	√	√*	√	√								90%		40	110	250
Commercial Institutional Boilers—Wood/Bark	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								80%		53	148	337
Commercial Institutional Boilers—Wood/Bark	Fabric Filter (Pulse Jet Type)	√	√*	√	√								80%		42	117	266
Construction Activities	Dust Control Plan	√	√*	√	√								62.5%			3,600	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Conveyorized Charbroilers	Catalytic Oxidizer	√*	√*	√	√		√					80%	83%	90%		2,966	
Conveyorized Charbroilers	ESP for Commercial Cooking	√*	√*	√	√							99%	99%	99%		7,000	
Fabricated Metal Products—Abrasive Blasting	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Fabricated Metal Products—Welding	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Ferrous Metals Processing—Coke	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Coke	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Coke	Venturi Scrubber	√	√*	√	√								93%		75	751	2,100
Ferrous Metals Processing—Coke	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Ferrous Metals Processing—Coke	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Ferrous Metals Processing—Ferroalloy Production	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Ferroalloy Production	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Ferroalloy Production	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Ferrous Metals Processing—Ferroalloy Production	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Ferrous Metals Processing—Ferroalloy Production	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Ferrous Metals Processing—Gray Iron Foundries	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Ferrous Metals Processing—Gray Iron Foundries	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Gray Iron Foundries	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Gray Iron Foundries	Impingement-Plate Scrubber	√	√*	√	√								64%		46	431	1,200
Ferrous Metals Processing—Gray Iron Foundries	Venturi Scrubber	√	√*	√	√								94%		76	751	2,100
Ferrous Metals Processing—Gray Iron Foundries	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Ferrous Metals Processing—Iron & Steel Production	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Iron & Steel Production	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Iron and Steel Production	Sinter Cooler	√*	√	√	√								99%			5,000	
Ferrous Metals Processing—Iron and Steel Production	Capture Hood Vented to a Baghouse	√*	√	√	√								85%			N/A	
Ferrous Metals Processing—Iron and Steel Production	Secondary Capture and Control System	√*	√	√	√								85%			N/A	
Ferrous Metals Processing—Iron and Steel Production	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Ferrous Metals Processing—Iron and Steel Production	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Ferrous Metals Processing—Iron and Steel Production	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

Source Category	Control Measure Name	Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
		$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Ferrous Metals Processing—Iron and Steel Production	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Ferrous Metals Processing—Iron and Steel Production	Venturi Scrubber	√	√*	√	√								73%		76	751	2,100
Ferrous Metals Processing—Iron and Steel Production	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Ferrous Metals Processing—Other	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Other	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Steel Foundries	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Ferrous Metals Processing—Steel Foundries	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Ferrous Metals Processing—Steel Foundries	Venturi Scrubber	√	√*	√	√								73%		76	751	2,100
Ferrous Metals Processing—Steel Foundries	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Ferrous Metals Processing—Steel Foundries	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Ferrous Metals Processing—Steel Foundries	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Grain Milling	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Grain Milling	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Grain Milling	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	$S0_2$	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Industrial Boilers—Coal	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Industrial Boilers—Coal	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Industrial Boilers—Coal	Venturi Scrubber	√	√*	√	√								82%		76	751	2,100
Industrial Boilers—Coal	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Industrial Boilers—Coal	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Industrial Boilers—Coal	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Industrial Boilers—Coke	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Industrial Boilers—Coke	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Industrial Boilers—Liquid Waste	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Industrial Boilers—Oil	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Industrial Boilers—Oil	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Industrial Boilers—Oil	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Industrial Boilers—Oil	Venturi Scrubber	√	√*	√	√								92%		76	751	2,100
Industrial Boilers—Solid Waste	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Industrial Boilers—Solid Waste	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Industrial Boilers—Wood	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Industrial Boilers—Wood	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Industrial Boilers—Wood	Venturi Scrubber	√	√*	√	√								93%		76	751	2,100
Industrial Boilers—Wood	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Industrial Boilers—Wood	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Industrial Boilers—Wood	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Mineral Products—Cement Manufacture	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Mineral Products—Cement Manufacture	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Mineral Products—Cement Manufacture	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Mineral Products—Cement Manufacture	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Mineral Products—Cement Manufacture	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Mineral Products—Cement Manufacture	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Mineral Products—Cement Manufacture	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Mineral Products—Coal Cleaning	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Mineral Products—Coal Cleaning	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Mineral Products—Coal Cleaning	Venturi Scrubber	√	√*	√	√								99%		76	751	2,100
Mineral Products—Coal Cleaning	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Mineral Products—Coal Cleaning	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Mineral Products—Coal Cleaning	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Mineral Products—Coal Cleaning	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Mineral Products—Other	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Mineral Products—Other	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Mineral Products—Other	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266
Mineral Products—Other	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Mineral Products—Other	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	145	256
Mineral Products—Other	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Mineral Products—Other	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Mineral Products—Other	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Mineral Products—Stone Quarrying & Processing	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Mineral Products—Stone Quarrying & Processing	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Mineral Products—Stone Quarrying and Processing	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Mineral Products—Stone Quarrying and Processing	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Mineral Products—Stone Quarrying and Processing	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Mineral Products—Stone Quarrying and Processing	Paper/Nonwoven Filters - Cartridge Collector Type	√	√*	√	√								99%		85	142	256
Mineral Products—Stone Quarrying and Processing	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Mineral Products—Stone Quarrying and Processing	Venturi Scrubber	√	√*	√	√								95%		76	751	2,100
Mineral Products—Stone Quarrying and Processing	Fabric Filter (Pulse Jet Type)	√	√*	√	√								99%		42	117	266

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Municipal Waste Incineration	Dry ESP-Wire Plate Type	√	√*	√									98%		40	110	250
Non-Ferrous Metals Processing—Aluminum	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Non-Ferrous Metals Processing—Aluminum	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Non-Ferrous Metals Processing—Aluminum	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Non-Ferrous Metals Processing—Aluminum	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Non-Ferrous Metals Processing—Aluminum	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Non-Ferrous Metals Processing—Aluminum	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Non-Ferrous Metals Processing—Copper	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Non-Ferrous Metals Processing—Copper	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Non-Ferrous Metals Processing—Copper	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Non-Ferrous Metals Processing—Copper	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Non-Ferrous Metals Processing—Copper	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Non-Ferrous Metals Processing—Copper	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Non-Ferrous Metals Processing—Lead	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Non-Ferrous Metals Processing—Lead	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Non-Ferrous Metals Processing—Lead	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Non-Ferrous Metals Processing—Lead	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Non-Ferrous Metals Processing—Lead	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Non-Ferrous Metals Processing—Lead	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Non-Ferrous Metals Processing—Other	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Non-Ferrous Metals Processing—Other	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Non-Ferrous Metals Processing—Other	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	1,260	303
Non-Ferrous Metals Processing—Other	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Non-Ferrous Metals Processing—Other	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Non-Ferrous Metals Processing—Other	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Non-Ferrous Metals Processing—Zinc	CEM Upgrade and Increased Monitoring Frequency of PM Controls	√*	√*										7.7%			5,200	
Non-Ferrous Metals Processing—Zinc	Increased Monitoring Frequency (IMF) of PM Controls	√*	√*	√	√								6.5%			620	
Non-Ferrous Metals Processing—Zinc	Fabric Filter (Mech. Shaker Type)	√	√*	√	√								99%		37	126	303
Non-Ferrous Metals Processing—Zinc	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Non-Ferrous Metals Processing—Zinc	Fabric Filter (Reverse-Air Cleaned Type)	√	√*	√	√								99%		53	148	337
Non-Ferrous Metals Processing—Zinc	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Paved Roads	Vacuum Sweeping	√	√*	√	√								50.5%			485	
Prescribed Burning	Increase Fuel Moisture	√	√*	√	√								50%			2,617	
Residential Home Heating	Switch to Low Sulfur Fuel	√*	√*			√		√					75%			2,350	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Residential Wood Combustion	Education and Advisory Program	√	√*	√	√								50%			1,320	
Residential Wood Stoves	NSPS compliant Wood Stoves	√*	√*										98%			2,000	
Unpaved Roads	Hot Asphalt Paving	√	√*	√	√								67.5%			537	
Unpaved Roads	Chemical Stabilization	√	√*	√									37.5%			2,753	
Wood Pulp & Paper	Wet ESP - Wire Plate Type	√	√*	√	√								99%		55	220	550
Wood Pulp & Paper	Dry ESP-Wire Plate Type	√	√*	√	√								98%		40	110	250
Bituminous/Subbituminous Coal	Flue Gas Desulfurization							√*					90%			N/A	
Bituminous/Subbituminous Coal	Flue Gas Desulfurization							√*					90%			N/A	
Bituminous/Subbituminous Coal (Industrial Boilers)	Spray Dryer Absorber							√*					90%		804	1,341	1,973
Bituminous/Subbituminous Coal (Industrial Boilers)	In-duct Dry Sorbent Injection							√*					40%		1,111	1,526	2,107
Bituminous/Subbituminous Coal (Industrial Boilers)	Wet Flue Gas Desulfurization							√*					90%		1,027	1,536	1,980
By-Product Coke Manufacturing	Vacuum Carbonate Plus Sulfur Recovery Plant							√*					90%			N/A	
Inorganic Chemical Manufacture Operations	Flue Gas Desulfurization							√*					90%			N/A	
In-process Fuel Use—Bituminous Coal	Flue Gas Desulfurization							√*					90%			N/A	
Lignite (Industrial Boiler)	In-duct Dry Sorbent Injection							√*					40%		1,111	1,526	2,107
Lignite (Industrial Boiler)	Spray Dryer Absorber							√*					90%		804	1,341	1,973
Lignite (Industrial Boiler)	Wet Flue Gas Desulfurization							√*					90%		1,027	1,536	1,980
Lignite (Industrial Boilers)	Flue Gas Desulfurization							√*					90%			N/A	
Mineral Products Industry	Flue Gas Desulfurization							√*					90%			N/A	
Petroleum Industry	Flue Gas Desulfurization (FGD)							√*					90%			N/A	
Primary Lead Smelters—Sintering	Dual Absorption							√*					99%			N/A	
Primary Metals Industry	Flue Gas Desulfurization							√*					90%			N/A	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Primary Zinc Smelters—Sintering	Dual Absorption							√*					99%			N/A	
Process Heaters (Oil and Gas Production)	Flue Gas Desulfurization							√*					90%			N/A	
Pulp and Paper Industry (Sulfate Pulping)	Flue Gas Desulfurization							√*					90%			N/A	
Residual Oil (Commercial/Institutional Boilers)	Wet Flue Gas Desulfurization							√*					90%		2,295	3,489	4,524
Residual Oil (Commercial/Institutional Boilers)	Flue Gas Desulfurization							√*					90%			N/A	
Residual Oil (Industrial Boilers	Flue Gas Desulfurization							√*					90%			N/A	
Secondary Metal Production	Flue Gas Desulfurization							√*					90%			N/A	
Steam Generating Unit-Coal/Oil	Flue Gas Desulfurization							√*					90%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing + Flue Gas Desulfurization							√*					99.8%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing + Flue Gas Desulfurization							√*					99.7%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing							√*					98.4%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing							√*					97.8%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing + Flue Gas Desulfurization							√*					99.8%			N/A	
Sulfur Recovery Plants—Elemental Sulfur	Amine Scrubbing							√*					97.1%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%) + Flue Gas Desulfurization							√*					75%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%)							√*					95%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%) + Flue Gas Desulfurization							√*					90%			N/A	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%)							√*					90%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%)							√*					85%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%) + Flue Gas Desulfurization							√*					95%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%)							√*					75%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Flue Gas Desulfurization							√*					90%			N/A	
Sulfuric Acid Plants—Contact Absorbers	Increase Absorption Efficiency from Existing to NSPS Level (99.7%) + Flue Gas Desulfurization							√*					85%			N/A	
Adhesives—Industrial	SCAQMDRule1168						√*						73%			2,202	
Aircraft Surface Coating	MACT Standard						√*						60%			165	
Architectural Coatings	OTC AIM Coating Rule						√*						55%			6,628	
Architectural Coatings	AIM Coating Federal Rule						√*						20%			228	
Architectural Coatings	South Coast Phase 1						√*						34%		3,300	1,443	4,600
Architectural Coatings	South Coast Phase III						√*						73%			10,059	
Architectural Coatings	South Coast Phase II						√*						47%			4,017	
AREA	OTC Mobile Equipment Repair and Refinishing Rule						√*						61%			2,534	
AREA	OTC Mobile Equipment Repair and Refinishing Rule						√*						61%			2,534	
AREA	OTC Solvent Cleaning Rule						√*						66%			1,400	
AREA	OTC Consumer Products Rule						√*						39.2%			1,032	
AREA	OTC Mobile Equipment Repair and Refinishing Rule						√*						61%			2,534	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant										Control Efficiency (% reduction)			Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
AREA	OTC Mobile Equipment Repair and Refinishing Rule						√*						61%			2,534	
AREA	OTC Consumer Products Rule						√*						39.2%			1,032	
Automobile Refinishing	California FIP Rule (VOC content & TE)						√*						89%			7,200	
Automobile Refinishing	CARB BARCT Limits						√*						47%			750	
Automobile Refinishing	Federal Rule						√*						37%			118	
Bakery Products	Incineration >1 00,000 lbs bread						√*						39.9%			1,470	
Commercial Adhesives	Federal Consumer Solvents Rule						√*						25%			232	
Commercial Adhesives	CARB Long-Term Limits						√*						85%			2,880	
Commercial Adhesives	CARB Mid-Term Limits						√*						55%			2,192	
Consumer Solvents	CARB Mid-Term Limits						√*						55%			2,192	
Consumer Solvents	Federal Consumer Solvents Rule						√*						25%			232	
Consumer Solvents	CARB Long-Term Limits						√*						85%			2,880	
Cutback Asphalt	Switch to Emulsified Asphalts						√*						100%			15	
Electrical/Electronic Coating	SCAQMD Rule						√*						70%			5,976	
Electrical/Electronic Coating	MACT Standard						√*						36%			5,000	
Fabric Printing, Coating and Dyeing	Permanent Total Enclosure (PTE)						√*						97%			N/A	
Flexographic Printing	Permanent Total Enclosure (PTE)						√*						95			9,947	
Graphic Arts	Use of Low or No VOC Materials						√*						65%		3,500	4,150	4,800
Industrial Maintenance Coating	South Coast Phase III						√*						73%			10,059	
Industrial Maintenance Coating	AIM Coating Federal Rule						√*						20%			228	
Industrial Maintenance Coating	South Coast Phase 1						√*						34%		3,300	1,443	4,600

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	SO_2	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Industrial Maintenance Coating	South Coast Phase II						√*						47%			4,017	
Machinery, Equipment, and Railroad Coating	SCAQMD Limits						√*						55.2%			2,027	
Marine Surface Coating (Shipbuilding)	Add-On Controls						√*						90%			8,937	
Marine Surface Coating (Shipbuilding)	MACT Standard						√*						24%			2,090	
Metal Can Surface Coating Operations	Permanent Total Enclosure (PTE)						√*						95			8,469	
Metal Coil & Can Coating	MACT Standard						√*						36%			1,000	
Metal Coil & Can Coating	Incineration						√*						90%			8,937	
Metal Coil & Can Coating	BAAQMD Rule 1 1 Amended						√*						42%			2,007	
Metal Furniture Surface Coating Operations	Permanent Total Enclosure (PTE)						√*						95			19,321	
Metal Furniture, Appliances, Parts	SCAQMD Limits						√*						55.2%			2,027	
Metal Furniture, Appliances, Parts	MACT Standard						√*						36%			1,000	
Miscellaneous Metal Products Coatings	MACT Standard						√*						36%			1,000	
Motor Vehicle Coating	Incineration						√*						90%			8,937	
Motor Vehicle Coating	MACT Standard						√*						36%			118	
Municipal Solid Waste Landfill	Gas Collection (SCAQMD/BAAQMD)						√*						70%			700	
Oil and Natural Gas Production	Equipment and Maintenance						√*						37%			317	
Oil and Natural Gas Production—Fugitive Emissions	SCAQMD Proposed Rule 1148.1 -Fugitive Emissions						√*						14%			2,483	
Open Top Degreasing	SCAQMD 1 122 (VOC content limit)						√*						76%			1,248	
Open Top Degreasing	Title III MACT Standard						√*						31%			-69	
Open Top Degreasing	Airtight Degreasing System						√*						98%			9,789	
Paper and other Web Coating Operations	Permanent Total Enclosure (PTE)						√*						95			1,503	

(continued)

Table E-1: Non-EGU Point and Area Control Measure Summary List by Source Category—Sorted alphabetically by Pollutant and Source Category (continued)

		*Pollutant(s) Affected √=pollutant reduction, X= pollutant increase, *=major pollutant*										*Control Efficiency (% reduction)*			*Average Annual Cost Effectiveness ($/ton primary pollutant in 1999 dollars)*		
Source Category	*Control Measure Name*	$PM_{2.5}$	PM_{10}	EC	OC	NO_x	VOC	$S0_2$	NH_3	CO	Hg	Low	Typical	High	Low	Typical	High
Paper Surface Coating	Incineration						√*						78%			4,776	
Pesticide Application	Reformulation - FIP Rule						√*						20%			9,300	
Portable Gasoline Containers	OTC Portable Gas Container Rule						√*						33%			581	
Product and Packaging Rotogravure and Screen Printing	Permanent Total Enclosure (PTE)						√*						95			12,770	
Publication Rotogravure Printing	Permanent Total Enclosure (PTE)						√*						95			2,422	
Rubber and Plastics Manufacturing	SCAQMD - Low VOC						√*						60%			1,020	
Stage II Service Stations	Low Pressure/Vacuum Relief Valve						√*						91.6%		930	1,080	1,230
Stage II Service Stations—Underground Tanks	Low Pressure/Vacuum Relief Valve						√*						73%		930	1,080	1,230
Traffic Markings	South Coast Phase III						√*						73%			1,059	
Traffic Markings	AIM Coating Federal Rule						√*						20%			228	
Traffic Markings	South Coast Phase 1						√*						34%		8,600	1,443	12,800
Traffic Markings	South Coast Phase II						√*						47%			4,017	
Wood Furniture Surface Coating	New CTG						√*						47%		462	967	22,100
Wood Furniture Surface Coating	Add-On Controls						√*					67%	75%	98%	468	20,000	22,100
Wood Furniture Surface Coating	MACT Standard						√*						30%			446	
Wood Product Surface Coating	Incineration						√*						86%			4,202	
Wood Product Surface Coating	SCAQMDRule1104						√*						53%			881	
Wood Product Surface Coating	MACT Standard						√*						30%			446	

Appendix F: Additional Regional Detail for Economic Cost Estimates

This appendix presents figures with additional regional economic impacts related to the illustrative control strategies developed for the 15/35 and 14/35 standards. Rather than showing an East-West separation for the country, findings are given for all five regions in the EMPAX-CGE model. Figures F-1a, F-1b, F-2a and F-2b have additional detail on changes in energy markets, and Figures F-3a, F-3b, F-4a and F-4b give disaggregated regional results for the energy-intensive industries shown in Figures 7-4 and 7-5 of the RIA.

Under the 15/35 alternative, effects on energy production are quite limited. On average across all energy types, output, as measured in quantity (or unit) terms in Figures F-1a and F-1a, declines by approximately three one-hundredths of one percent (0.03%). Impacts on electricity generation are slightly higher at one-tenth of one percent, driven largely by modestly higher costs in the Northeast. For 14/35, the illustrative controls assume additional measures are taken by electric utilities. As shown in Figure F-2a, this leads to additional adjustments in electricity output, which in turn has spillover effects on coal consumption (90% of coal is used for electricity generation). Figures F-1b and F-2b, which show the changes in terms of industrial gross revenues (these combine any declines in output with any changes in production costs or prices), generally go the same direction as the quantity changes – with the exception of electricity, which has lower output quantities, but higher gross revenues because of changes in production costs and hence prices.

Figures F-3a and F-4a (output quantities) give the regional detail behind Figures 7-4a and 7-5a in the main text, and Figures F-3b and F-4b (revenues) have the same detail for Figures 7-4b and 7-5b. These show that, although the illustrative controls for these alternative standards may tend to redistribute production around the nation (and across states within model regions), the majority of the impacts are less than one tenth of one percent. The disaggregated regional results do indicate, however, that an industry such as cement could experience relatively larger effects than other industries, especially within specific regions. However, as mentioned in Chapter 7, States' SIP strategies may be designed to mitigate such outcomes.

As with the main findings in Chapter 7, it is important to note when examining such findings that these impacts and redistributions are directly related to the specific control options assumed in the illustrative 15/35 and 14/35 analyses, and that attainment could be met through alternative approaches. Thus, while EPA provides this analysis as guidance for States, it is expected that States will evaluate the best strategies for achieving compliance and may choose options that could significantly alter these regional effects. Therefore, SIPs will most likely be different than the strategies developed in this RIA and could be designed to alleviate any disproportionate impacts on sensitive industries.

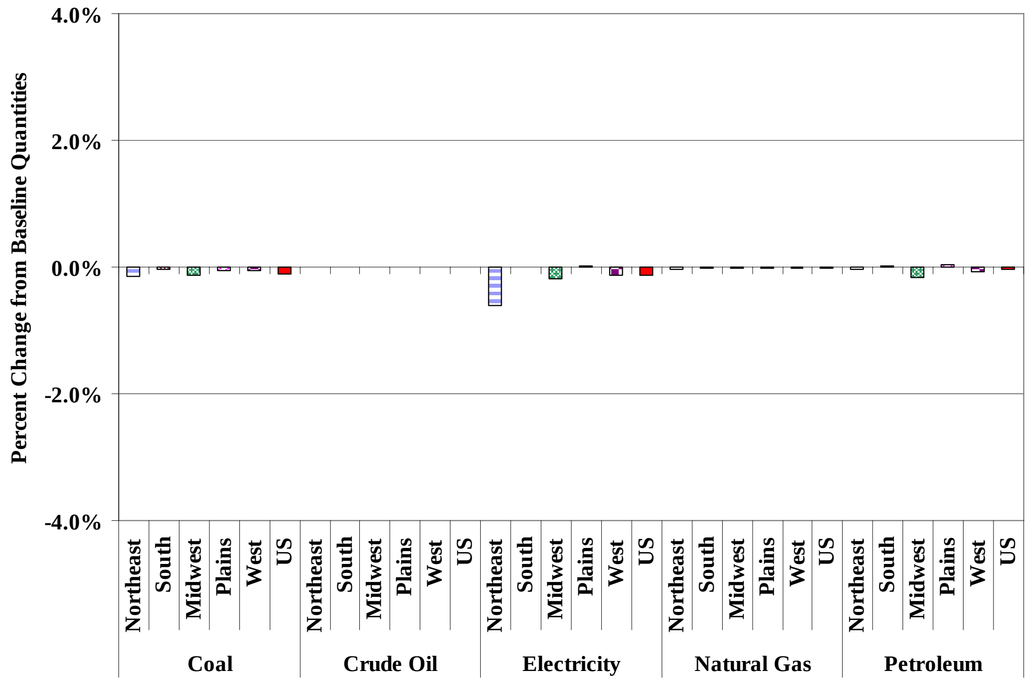

Figure F-1a. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy Output Quantities, 2020

Source: EMPAX-CGE

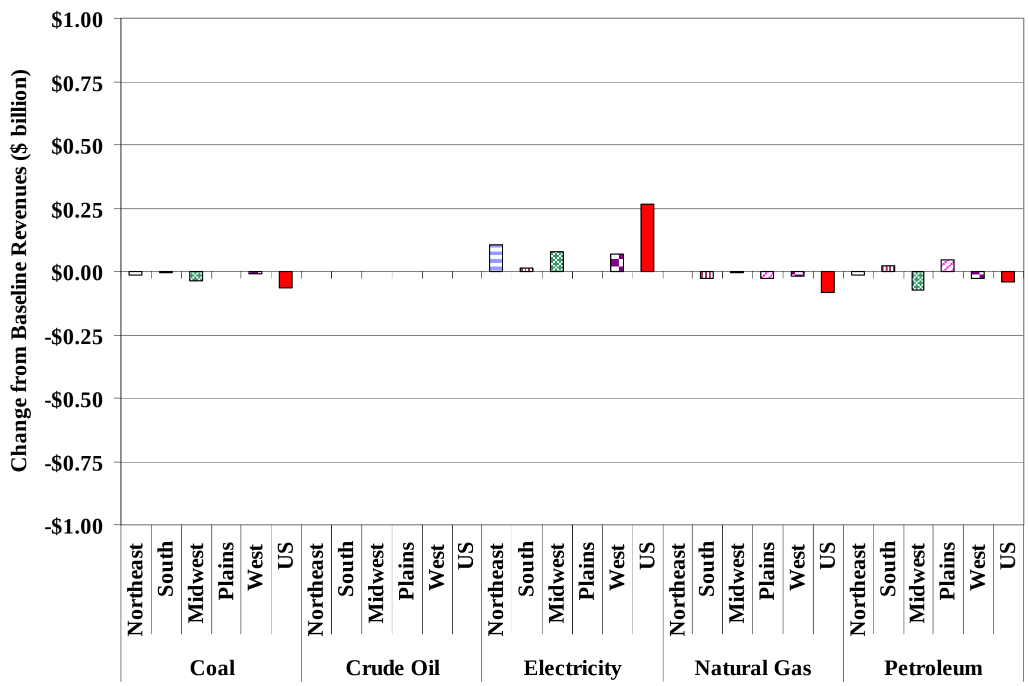

Figure F-1b. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy Output Revenues, 2020

Source: EMPAX-CGE

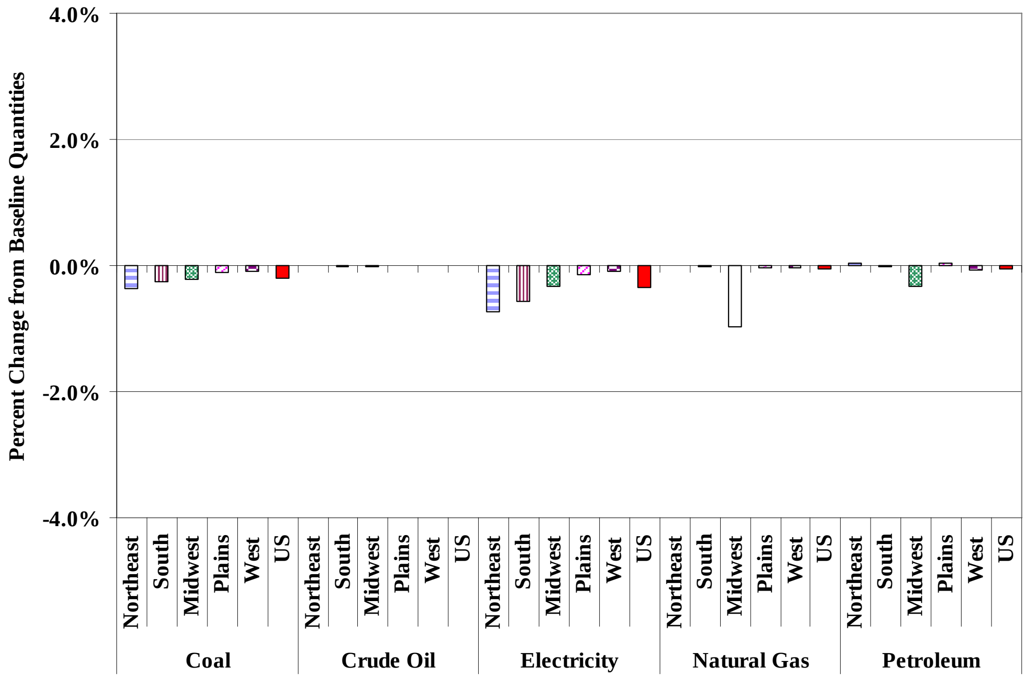

Figure F-2a. PM$_{2.5}$ NAAQS 14/35 Impacts on Regional Energy Output Quantities, 2020

Source: EMPAX-CGE

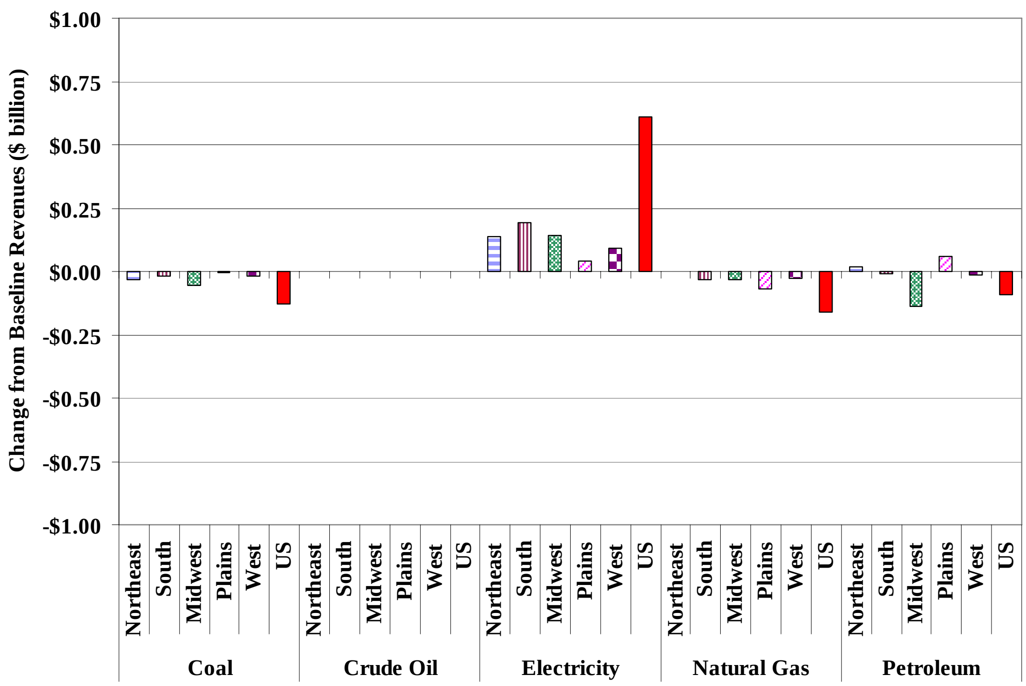

Figure F-2b. PM$_{2.5}$ NAAQS 14/35 Impacts on Regional Energy Output Revenues, 2020

Source: EMPAX-CGE

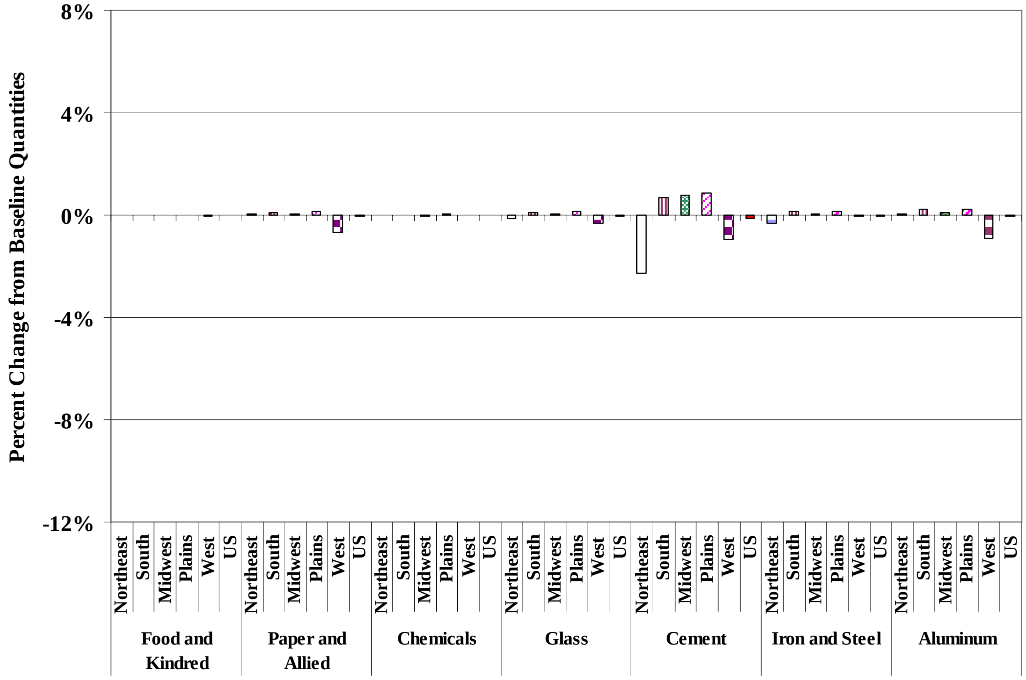

Figure F-3a. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy-Intensive Output Quantities, 2020

Source: EMPAX-CGE

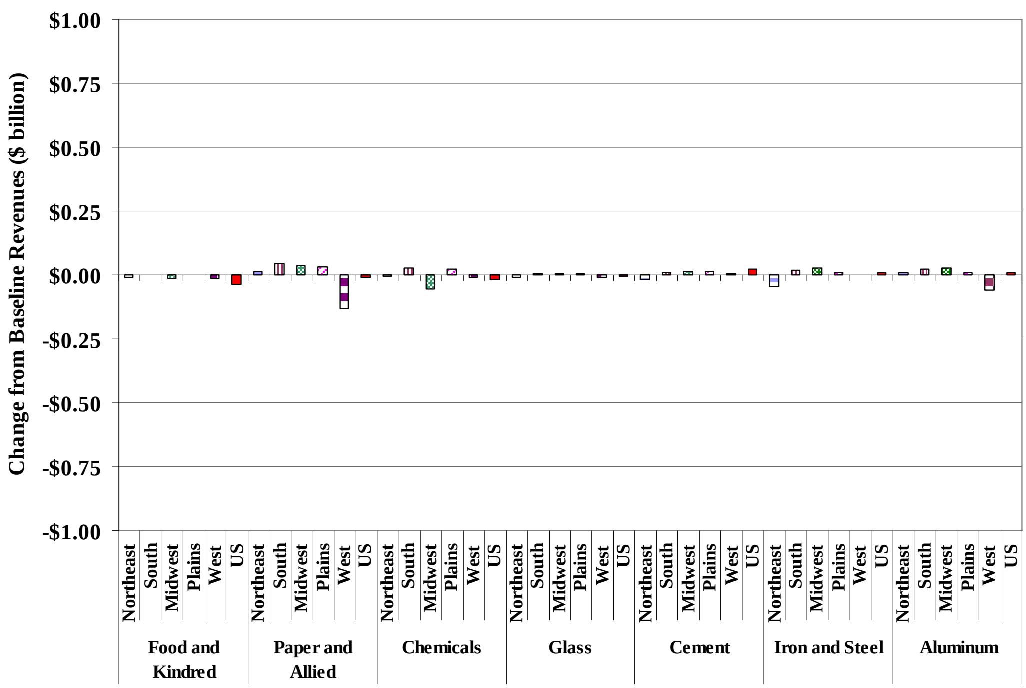

Figure F-3b. $PM_{2.5}$ NAAQS 15/35 Impacts on Regional Energy-Intensive Output Revenues, 2020

Source: EMPAX-CGE

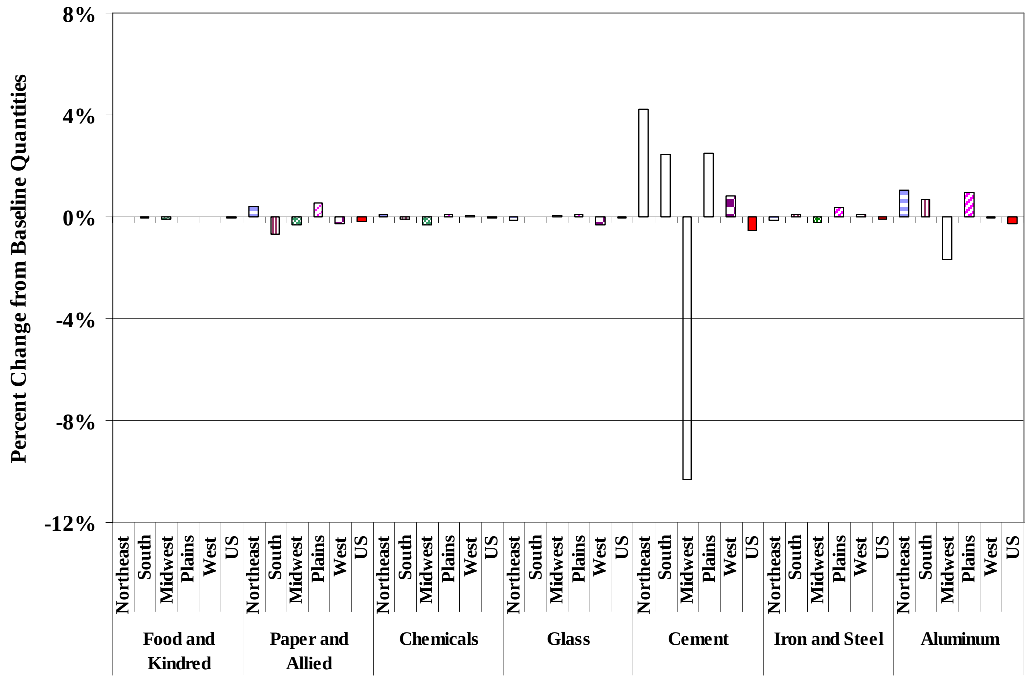

Figure F-4a. $PM_{2.5}$ NAAQS 14/35 Impacts on Regional Energy-Intensive Output Quantities, 2020

Source: EMPAX-CGE

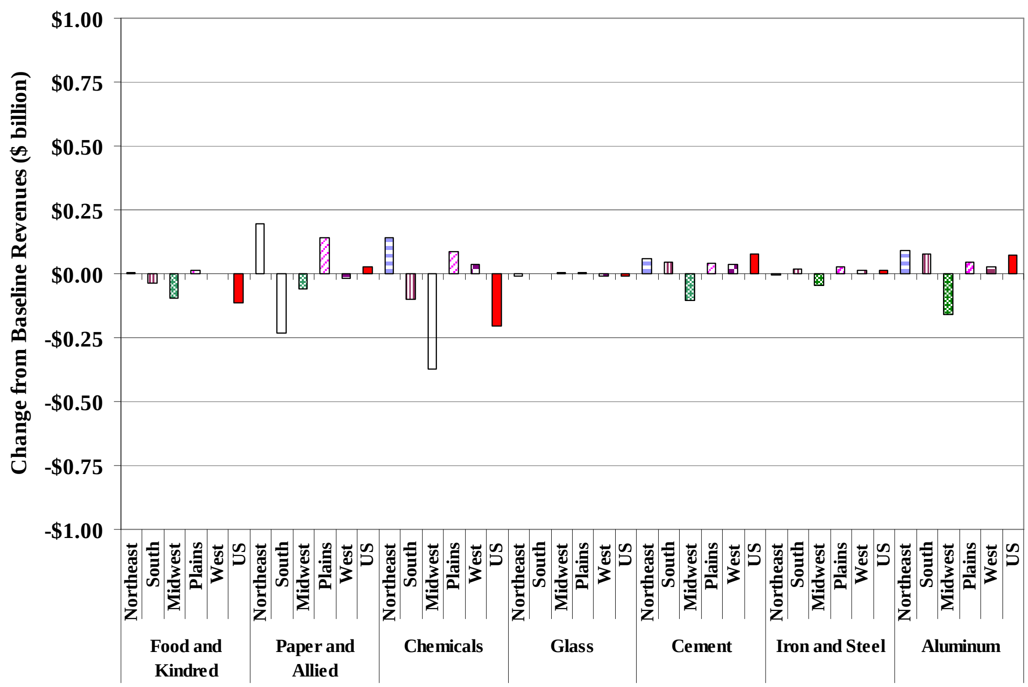

Figure F-4b. $PM_{2.5}$ NAAQS 14/35 Impacts on Regional Energy-Intensive Output Revenues, 2020

Source: EMPAX-CGE

Appendix G: Health-Based Cost-Effectiveness of Reductions in Ambient $PM_{2.5}$ Associated with Illustrative PM NAAQS Attainment Strategies

G.1 Summary

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. The Office of Management and Budget (OMB) recently issued Circular A-4 guidance on regulatory analyses, requiring federal agencies to "prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes." Environmental quality improvements may have multiple health and ecological benefits, making application of CEA more difficult and less straightforward. For the PM NAAQS, CEA may provide a useful framework for evaluation: non-health benefits are substantial, but the majority of quantified benefits come from health effects. Therefore, EPA is including in the PM NAAQS RIA a preliminary and experimental application of one type of CEA—a modified quality-adjusted life-years (QALYs) approach.

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA for environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for non-health benefits, such as improved visibility.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled "Valuing Health for Regulatory Cost-Effectiveness Analysis" which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006). They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses. For this analysis, we use the same approach that was applied in the CEA that accompanied the RIA for the Clean Air Interstate Rule.

The methodology presented in this appendix is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations where it may be inappropriate. It is intended solely to demonstrate one particular approach to estimating the cost-effectiveness of reductions in ambient $PM_{2.5}$ in achieving improvements in public health. Reductions in ambient $PM_{2.5}$ likely will have other health and environmental benefits that will not be reflected in this CEA. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar health-based CEAs. A number of additional methodological issues must be considered when conducting CEAs for environmental policies, including treatment of nonhealth effects, aggregation of acute and long-term health impacts, and aggregation of life extensions and quality-of-life improvements in different populations. The appropriateness of health-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models, among other factors.

Attainment of the revised PM NAAQS is expected to result in substantial reductions in potential population exposure to ambient concentrations of PM by 2020. The benefit-cost analysis presented in the RIA shows that attainment of the revised 15/35 suite of standards achieves substantial health benefits whose monetized value far exceeds costs (net benefits are over $10 billion in 2020). Despite the risk of oversimplifying benefits, cautiously-interpreted cost-effectiveness calculations may provide further evidence of whether the costs associated with attainment strategies for the PM NAAQS are a reasonable health investment for the nation.

This analysis provides estimates of commonly used health-based effectiveness measures, including lives saved, life years saved (from reductions in mortality risk), and QALYs saved (from reductions in morbidity risk) associated with the reduction of ambient $PM_{2.5}$ due to illustrative attainment strategies for the revised standards and a more stringent annual standard. In addition, we use an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILY) to address some of the concerns about aggregation of life extension and quality-of-life impacts. It represents the sum of life years gained due to reductions in premature mortality and the QALY gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy. This analysis focuses on life extensions and improvements in quality of life through reductions in two diseases with chronic impacts: chronic bronchitis (CB) and nonfatal acute myocardial infarctions. Monte Carlo simulations are used to propagate uncertainty in several analytical parameters and characterize the distribution of estimated impacts. While the benefit-cost analysis presented in the RIA characterizes mortality impacts using a number of different sources for the PM mortality effect estimate, for this analysis, we focus on the mortality results generated using the effect estimate derived from the Pope et al. (2002) study.

Presented in three different metrics, the analysis suggests the following:

- In 2020 the illustrative attainment strategy for the revised 15/35 standards will result in:
  - 2,500 (95% CI: 1,000 – 4,100) premature deaths avoided, or
  - 26,000 (95% CI: 18,000 – 34,000) life years gained (discounted at 3 percent), or
  - 43,000 (95% CI: 28,000 – 62,000) MILYs gained (discounted at 3 percent).
- In 2020, the illustrative attainment strategy for the more stringent 14/35 standards will result in:
  - 4,400 (95% CI: 1,700 – 7,100) premature deaths avoided, or

  - 45,000 (95% CI: 32,000 – 59,000) life years gained (discounted at 3 percent), or
  - 75,000 (95% CI: 48,000 – 107,000) MILYs gained (discounted at 3 percent).

- Using a 7 percent discount rate, mean discounted life years gained are 16,000 for the revised 15/35 standards and 29,000 for the alternative 14/35 standards; mean MILYs gained are 28,000 for the 15/35 standards and 49,000 for the alternative 14/35 standards. (The estimates of premature deaths avoided are not affected by the discount rate.)

- The associated reductions in CB and nonfatal acute myocardial infarctions will reduce medical costs by approximately $680 million for the 15/35 scenario and $1,200 million for the 14/35 scenario based on a 3 percent discount rate, or $520 million for the 15/35 scenario and $940 million for the 14/35 scenario based on a 7 percent discount rate.

- Other health and visibility benefits are valued at $530 million for the 15/35 scenario and $1,100 million for the 14/35 scenario.

Direct private compliance costs for the 15/35 attainment strategy, including the extrapolated costs of full attainment in California and Salt Lake City are $5.4 billion, incremental to attainment of the current 15/65 standards in 2020. Full attainment costs for the 14/35 attainment strategy are $7.0 billion incremental to attainment of the current 15/65 standards. Based on these costs, the incremental cost effectiveness (net of cost of illness and other health and visibility benefits) of the 15/35 attainment strategy relative to attainment of the current standards is $98,000/MILY using a 3 percent discount rate and $160,000/MILY using a 7 percent discount rate. Incremental cost effectiveness of the 14/35 attainment strategy relative to attainment of the current standards is $60,000/MILY using a 3 percent discount rate and $100,000/MILY using a 7 percent discount rate. The incremental cost effectiveness of the attainment strategy for the alternative 14/35 standards relative to the attainment strategy for the revised 15/35 standards is $17,000/MILY using a 3 percent discount rate and $29,000 using a 7 percent discount rate. The relatively smaller incremental cost per MILY associated with the attainment strategy for the alternative 14/35 standards is primarily due to the regional control strategies implemented in the Eastern U.S. (which affect a much larger population), and the fact that much of the cost of both the 15/35 and 14/35 attainment strategies is due to the high estimates of costs of attaining the daily standard of 35 $\mu g/m^3$ in California. See Chapters 4 and 5 of this RIA for more discussion of the control strategies and cost estimates.

G.2 Introduction

Analyses of environmental regulations have typically used benefit-cost analysis to characterize impacts on social welfare. Benefit-cost analyses allow for aggregation of the benefits of reducing mortality risks with other monetized benefits of reducing air pollution, including acute and chronic morbidity, and nonhealth benefits such as improved visibility. One of the great advantages of the benefit-cost paradigm is that a wide range of quantifiable benefits can be compared to costs to evaluate the economic efficiency of particular actions. However, alternative paradigms such as CEA and CUA analyses may also provide useful insights. CEA involves estimation of the costs per unit of benefit (e.g., lives or life years saved). CUA is a special type of CEA using preference-based measures of effectiveness, such as QALYs.

CEA and CUA are most useful for comparing programs that have similar goals, for example, alternative medical interventions or treatments that can save a life or cure a disease. They are less readily applicable to programs with multiple categories of benefits, such as those reducing ambient air pollution, because the cost-effectiveness calculation is based on the quantity of a single benefit category. In other words, we cannot readily convert improvements in nonhealth benefits such as visibility to a health metric such as life years saved. For these reasons, environmental economists prefer to present results in terms of monetary benefits and net benefits.

However, QALY-based CUA has been widely adopted within the health economics literature (Neumann, 2003; Gold et al., 1996) and in the analysis of public health interventions (US FDA, 2004). QALY-based analyses have not been as accepted in the environmental economics literature because of concerns about the theoretical consistency of QALYs with individual preferences (Hammitt, 2002), treatment of nonhuman health benefits, and a number of other factors (Freeman, Hammitt, and De Civita, 2002). For environmental regulations, benefit-cost analysis has been the preferred method of choosing among regulatory alternatives in terms of economic efficiency. Recently several academic analyses have proposed the use of life years-based benefit-cost or CEAs of air pollution regulations (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003; Rabl, 2003; Carrothers, Evans, and Graham, 2002). In addition, the World Health Organization has adopted the use of disability-adjusted life years, a variant on QALYs, to assess the global burden of disease due to different causes, including environmental pollution (Murray et al., 2002; de Hollander et al., 1999).

Recently, the U.S. OMB (Circular A-4, 2003) issued new guidance requiring federal agencies to provide both CEA and benefit-cost analyses for major regulations. The OMB Circular A-4 directs agencies to "prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes." We are including a CEA for the illustrative PM NAAQS attainment strategies to illustrate one potential approach for conducting a CEA. EPA is still evaluating the appropriate methods for CEA for environmental regulations with multiple outcomes.

The methodology presented in this appendix is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations governing water, solid waste, or other regulatory objectives. It is intended solely to demonstrate one particular approach to estimating the effectiveness of reductions in ambient $PM_{2.5}$ in achieving improvements in public health. This analysis focuses on effectiveness measured by improvements in life expectancy and reductions in the incidence of two diseases with chronic impacts on quality of life: CB and nonfatal acute myocardial infarctions. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar QALY-based analyses. The appropriateness of QALY-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models.

Preparation of a CEA requires identification of an appropriate measure of rule effectiveness. Given the significant impact of reductions in ambient $PM_{2.5}$ on reductions in the risk of mortality, lives saved is an important measure of effectiveness. However, one of the ongoing controversies in health impact assessment regards whether reductions in mortality risk should be reported and valued in terms of statistical lives saved or in terms of statistical life years saved. Life years saved measures differentiate among premature mortalities based on the remaining life expectancy of affected individuals. In general, under the life years approach, older individuals will gain fewer life years than younger individuals for the same reduction in mortality risk during a given time period, making interventions that benefit older individuals seem less beneficial relative to similar interventions benefiting younger individuals. A further complication in the debate is whether to apply quality adjustments to life years lost. Under this approach, individuals with preexisting health conditions would have fewer QALYs lost relative to healthy individuals for the same loss in life expectancy, making interventions that primarily benefit individuals with poor health seem less beneficial to similar interventions affecting primarily healthy individuals.

In addition to substantial mortality risk reduction benefits, strategies for attaining the revised PM NAAQS will also result in significant reductions in chronic and acute morbidity. Several approaches have been developed to incorporate both morbidity and mortality into a single effectiveness metric. The most common of these is the QALY approach, which expresses all morbidity and mortality impacts in terms of quality of life multiplied by the duration of time with that quality of life. The QALY approach has some appealing characteristics. For example, it can account for morbidity effects as well as losses in life expectancy without requiring the assignment of dollar values to calculate total benefits. By doing so it provides an alternative framework to benefit-cost analysis for aggregating quantitative measures of health impacts.

While used extensively in the economic evaluation of medical interventions (Gold et al., 1996), QALYs have not been widely used in evaluating environmental health regulations. A number of specific issues arise with the use of QALYs in evaluating environmental programs that affect a broad and heterogeneous population and that provide both health and nonhealth benefits. The U.S. Public Health Service report on cost-effectiveness in health and medicine notes the following:

> For decisions that involve greater diversity in interventions and the people to whom they apply, cost-effectiveness ratios continue to provide essential information, but that information must, to a greater degree, be evaluated in light of circumstances and values that cannot be included in the analysis. Individuals in the population will differ widely in their health and disability before the intervention, or in age, wealth, or other characteristics, raising questions about how society values gains for the more and less health, for young and old, for rich and poor, and so on. The assumption that all QALYs are of equal value is less likely to be reasonable in this context. (Gold et al., 1996, p. 11)

Use of QALYs as a measure of effectiveness for environmental regulations is still developing, and while this analysis provides one framework for using QALYs to evaluate environmental regulations, there are clearly many issues, both scientific and ethical, that need to be addressed with additional research. The Institute of Medicine panel evaluating QALYs and other effectiveness measures prepared a report titled “Valuing Health for Regulatory Cost-Effectiveness Analysis” which concluded that “the QALY is the best measure at present on which to standardize Health Adjusted Life Year estimation because of its widespread use, flexibility, and relative simplicity" (Miller, Robinson, and Lawrence, 2006). EPA is evaluating this recommendation and will determine a response for upcoming analyses. For this analysis, for reasons discussed in the text, we use the same MILY approach that was applied in the CEA that accompanied the RIA for the Clean Air Interstate Rule.

This appendix presents cost-effectiveness methodologies for evaluating programs such as attainment strategies for the revised PM NAAQS that are intended to reduce ambient $PM_{2.5}$ starting from the standard QALY literature and seeking a parallel structure to benefit-cost analysis in the use of air quality and health inputs (see Hubbell [2004a] for a discussion of some of the issues that arise in comparing QALY and benefit-cost frameworks in analyzing air pollution impacts). For the purposes of this analysis, we calculate effectiveness using several different metrics, including lives prolonged, life years gained, and modified QALYs. For the life years and QALY-type approaches, we use life table methods to calculate the change in life expectancy expected to result from changes in mortality risk from PM. We use existing estimates of preferences for different health states to obtain QALY weights for morbidity endpoints associated with air pollution. In general, consistent with the Gold et al. (1996) recommendations, we use weights obtained from a societal perspective when available. We explore several different sources for these weights to characterize some of the potential uncertainty in the QALY estimates. We follow many of the principles of the reference case analysis as defined in Gold et al. (1996), although in some cases we depart from the reference case approach when data limitations require us to do so (primarily in the selection of quality-of-life weights for morbidity endpoints). We also depart from the reference case (and the recommendations of the IOM report) in the method of combining life expectancy and quality-of-life gains.

Results in most tables are presented only at a discount rate of 3 percent, rather than at both 3 percent and 7 percent as recommended in EPA and OMB guidance. This is strictly for ease of presentation. Aggregate results at 7 percent are presented in the summary, and the impact of using a 7 percent discount rate instead of 3 percent rate is summarized in a sensitivity analysis.

Monte Carlo simulation methods are used to propagate uncertainty in several of the model parameters throughout the analysis. We characterize overall uncertainty in the results with 95 percent confidence intervals based on the Monte Carlo simulations. In addition, we examine the impacts of changing key parameters, such as the discount rate, on the effectiveness measures and the cost-effectiveness metrics.

The remainder of this appendix provides an overview of the key issues involved in life year- and QALY-based approaches for evaluating the health impacts of air pollution regulations, provides detailed discussions of the steps required for each type of effectiveness calculation, and presents the CEA for the PM NAAQS illustrative attainment strategies. Section G.3 introduces the various effectiveness measures and discusses some of the assumptions required for each. Section G.4 details the methodology used to calculate changes in life years and quality adjustments for mortality and morbidity endpoints. Section G.5 provides the results for the illustrative attainment strategies for the revised and more stringent alternative PM NAAQS and discusses their implications for cost-effectiveness of these attainment strategies.

G.3 Effectiveness Measures

Three major classes of benefits are associated with reductions in air pollution: mortality, morbidity, and nonhealth (welfare). For the purposes of benefit-cost analysis, EPA has presented mortality-related benefits using estimates of avoided premature mortalities, representing the cumulative result of reducing the risk of premature mortality from long-term exposure to $PM_{2.5}$ for a large portion of the U.S. population. Morbidity benefits have been characterized by numbers of new incidences avoided for chronic diseases such as CB, avoided admissions for hospitalizations associated with acute and chronic conditions, and avoided days with symptoms for minor illnesses. Nonhealth benefits are characterized by the monetary value of reducing the impact (e.g., the dollar value of improvements in visibility at national parks).

For the purposes of CEA, we focus the effectiveness measure on the quantifiable health impacts of the reduction in $PM_{2.5}$. Treatment of nonhealth benefits is important and is discussed in some detail later in this section. If the main impact of interest is reductions in mortality risk from air pollution, the effectiveness measures are relatively straightforward to develop. Mortality impacts can be characterized similar to the benefits analysis, by counting the number of premature mortalities avoided, or can be characterized in terms of increases in life expectancy or life years.[1] Estimates of premature mortality have the benefit of being relatively simple to calculate, are consistent with the benefit-cost analysis, and do not impose additional assumptions on the degree of life shortening. However, some have argued that counts of premature mortalities avoided are problematic because a gain in life of only a few months would be considered equivalent to a gain of a many life years, and the true effectiveness of an intervention is the gain in life expectancy or life years (Rabl, 2003; Miller and Hurley, 2003).

Calculations of changes in life years and life expectancy can be accomplished using standard life table methods (Miller and Hurley, 2003). However, the calculations require assumptions about the baseline mortality risks for each age cohort affected by air pollution. A general assumption may be that air pollution mortality risks affect the general mortality risk of the population in a proportional manner. However, some concerns have been raised that air pollution affects mainly those individuals with preexisting cardiovascular and respiratory disease, who may have reduced life expectancy relative to the general population. This issue is explored in more detail below.

Air pollution is also associated with a number of significant chronic and acute morbidity endpoints. Failure to consider these morbidity effects may understate the cost-effectiveness of air pollution regulations or give too little weight to reductions in particular pollutants that have large morbidity impacts but no effect on life expectancy. The QALY approach explicitly incorporates morbidity impacts into measures of life years gained and is often used in health economics to assess the cost-effectiveness of medical spending programs (Gold et al., 1996).

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[1] Life expectancy is an *ex ante* concept, indicating the impact on an entire population's expectation of the number of life years they have remaining, before knowing which individuals will be affected. Life expectancy thus incorporates both the probability of an effect and the impact of the effect if realized. Life years is an *ex post* concept, indicating the impact on individuals who actually die from exposure to air pollution. Changes in population life expectancy will always be substantially smaller than changes in life years per premature mortality avoided, although the total life years gained in the population will be the same. This is because life expectancy gains average expected life years gained over the entire population, while life years gained measures life years gained only for those experiencing the life extension.

Using a QALY rating system, health quality ranges from 0 to 1, where 1 may represent full health, 0 death, and some number in between (e.g., 0.8) an impaired condition. QALYs thus measure morbidity as a reduction in quality of life over a period of life. QALYs assume that duration and quality of life are equivalent, so that 1 year spent in perfect health is equivalent to 2 years spent with quality of life half that of perfect health. QALYs can be used to evaluate environmental rules under certain circumstances, although some very strong assumptions (detailed below) are associated with QALYs. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommended using QALYs when evaluating medical and public health programs that primarily reduce both mortality and morbidity (Gold et al., 1996). Although there are significant nonhealth benefits associated with air pollution regulations, over 90 percent of quantifiable monetized benefits are health-related, as is the case with the attainment strategies for the PM NAAQS. Thus, it can be argued that QALYs are more applicable for these types of regulations than for other environmental policies. However, the value of nonhealth benefits should not be ignored. As discussed below, we have chosen to subtract the value of nonhealth benefits from the costs in the numerator of the cost-effectiveness ratio.

In the following sections, we lay out a phased approach to describing effectiveness. We begin by discussing how the life-extending benefits of air pollution reductions are calculated, and then we incorporate morbidity effects using the QALY approach. We also introduce an alternative aggregated health metric, Morbidity Inclusive Life Years (MILY) to address some of the ethical concerns about aggregating life extension impacts in populations with preexisting disabling conditions.

The use of QALYs is predicated on the assumptions embedded in the QALY analytical framework. As noted in the QALY literature, QALYs are consistent with the utility theory that underlies most of economics only if one imposes several restrictive assumptions, including independence between longevity and quality of life in the utility function, risk neutrality with respect to years of life (which implies that the utility function is linear), and constant proportionality in trade-offs between quality and quantity of life (Pliskin, Shepard, and Weinstein, 1980; Bleichrodt, Wakker, and Johannesson, 1996). To the extent that these assumptions do not represent actual preferences, the QALY approach will not provide results that are consistent with a benefit-cost analysis based on the Kaldor-Hicks criterion.[2] Even if the assumptions are reasonably consistent with reality, because QALYs represent an average valuation of health states rather than the sum of societal WTP, there are no guarantees that the option with the highest QALY per dollar of cost will satisfy the Kaldor-Hicks criterion (i.e., generate a potential Pareto improvement [Garber and Phelps, 1997]).

Benefit-cost analysis based on WTP is not without potentially troubling underlying structures as well, incorporating ability to pay (and thus the potential for equity concerns) and the notion of consumer sovereignty (which emphasizes wealth effects). Table G-1 compares the two approaches across a number of parameters. For the most part, WTP allows parameters to be determined empirically, while the QALY approach imposes some conditions *a priori*.

[2] The Kaldor-Hicks efficiency criterion requires that the "winners" in a particular case be potentially able to compensate the "losers" such that total societal welfare improves. In this case, it is sufficient that total benefits exceed total costs of the regulation. This is also known as a potential Pareto improvement, because gains could be allocated such that at least one person in society would be better off while no one would be worse off.

Table G-1: Comparison of QALY and WTP Approaches

Parameter	*QALY*	*WTP*
Risk aversion	Risk neutral	Empirically determined
Relation of duration and quality	Independent	Empirically determined
Proportionality of duration/ quality trade-off	Constant	Variable
Treatment of time/age in utility function	Utility linear in time	Empirically determined
Preferences	Community/Individual	Individual
Source of preference data	Stated	Revealed and stated
Treatment of income and prices	Not explicitly considered	Constrains choices

G.4 Changes in Premature Death, Life Years, and Quality of Life

To generate health outcomes, we used the same framework as for the benefit-cost analysis described in Chapter 5. For convenience, we summarize the basic methodologies here. For more details, see Chapter 5 and the BenMAP user's manual (http://www.epa.gov/ttn/ecas/benmodels.html).

BenMAP uses health impact functions to generate changes in the incidence of health effects. Health impact functions are derived from the epidemiology literature. A standard health impact function has four components: an effect estimate from a particular epidemiological study, a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics like CDC), the affected population, and the estimated change in the relevant PM summary measure.

A typical health impact function might look like this:

$$\Delta y = y_0 \cdot (e^{\beta \cdot \Delta x} - 1),$$

where y_0 is the baseline incidence, equal to the baseline incidence rate times the potentially affected population; β is the effect estimate; and Δx is the estimated change in $PM_{2.5}$. There are other functional forms, but the basic elements remain the same.

G.4.1 Calculating Reductions in Premature Deaths

As in several recent air pollution health impact assessments (e.g., Kunzli et al., 2000; EPA, 2004), we focus on the prospective cohort long-term exposure studies in deriving the health impact function for the estimate of premature mortality. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli et al., 2001; NRC, 2002). We selected an effect estimate from the extended analysis of the ACS cohort (Pope et al., 2002). This latest re-analysis of the ACS cohort data provides additional refinements to the analysis of PM-related mortality by (a) extending the follow-up period for the ACS study subjects to 16 years, which triples the size of the mortality data set; (b) substantially increasing exposure data, including consideration for cohort exposure to $PM_{2.5}$ following implementation of $PM_{2.5}$ standard in 1999; (c) controlling for a variety of personal risk factors including occupational exposure and diet; and (d) using advanced statistical methods to evaluate specific issues that can adversely affect risk estimates, including the possibility of spatial autocorrelation of survival times in communities located near each other. The effect estimate from Pope et al. (2002) quantifies the relationship between annual mean $PM_{2.5}$ levels and all-cause mortality in adults 30 and older. We selected the effect estimate estimated using the measure of PM representing average exposure over the follow-up period, calculated as the average of 1979–1984 and 1999–2000 $PM_{2.5}$ levels. The effect estimate from this study is 0.0058, which is equivalent to a relative risk of 1.06 for a 10 μg change in $PM_{2.5}$. Although there are other cohort-based studies of the relationship between $PM_{2.5}$ and mortality, none provide the same level of population and geographic coverage as the ACS study.

Age, cause, and county-specific mortality rates were obtained from CDC for the years 1996 through 1998. CDC maintains an online data repository of health statistics, CDC Wonder, accessible at http://wonder.cdc.gov/. The mortality rates provided are derived from U.S. death records and U.S. Census Bureau postcensal population estimates. Mortality rates were averaged across 3 years (1996 through 1998) to provide more stable estimates. When estimating rates for age groups that differed from the CDC Wonder groupings, we assumed that rates were uniform across all ages in the reported age group. For example, to estimate mortality rates for individuals ages 30 and up, we scaled the 25- to 34-year old death count and population by one-half and then generated a population-weighted mortality rate using data for the older age groups.

The reductions in incidence of premature mortality within each age group associated with the illustrative attainment strategies for the revised and more stringent alternative PM NAAQS in 2020 are summarized in Table G-2.

G.4.2 Calculating Changes in Life Years from Direct Reductions in $PM_{2.5}$-Related Mortality Risk

To calculate changes in life years associated with a given change in air pollution, we used a life table approach coupled with age-specific estimates of reductions in premature mortality. We began with the complete unabridged life table for the United States in 2000, obtained from CDC (CDC, 2002). For each 1-year age interval (e.g., zero to one, one to two) the life table provides estimates of the baseline probability of dying during the interval, person years lived in the interval, and remaining life expectancy. From this unabridged life table, we constructed an abridged life table to match the age intervals for which we have predictions of changes in incidence of premature mortality. We used the abridgement method described in CDC (2002). Table G-3 presents the abridged life table for 10-year age intervals for adults over 30 (to match the Pope et al. [2002] study population). Note that the abridgement actually includes one 5-year interval, covering adults 30 to 34, with the remaining age intervals covering 10 years each. This is to provide conformity with the age intervals available for mortality rates.

Table G-2: Estimated Reduction in Incidence of All-cause Premature Mortality Associated with Illustrative Attainment Strategies for the Revised and More Stringent Alternative PM NAAQS in 2020

	Reduction in All-Cause Premature Mortality (95% CI)	
Age Interval	*15/35 Attainment Strategy*	*14/35 Attainment Strategy*
30 – 34	25 (8 – 41)	40 (13 – 68)
35 – 44	76 (25 – 130)	120 (39 – 210)
45 – 54	150 (48 – 250)	250 (80 – 420)
55 – 64	350 (110 – 590)	610 (200 – 1,000)
65 – 74	530 (170 – 890)	970 (310 – 1,600)
75 – 84	610 (200 – 1,000)	1,100 (350 – 1,800)
85+	810 (260 – 1,400)	1,300 (430 – 2,300)
Total	2,500 (820 – 4,300)	4,400 (1,400 – 7,400)

From the abridged life table (Table G-3), we obtained the remaining life expectancy for each age cohort, conditional on surviving to that age. This is then the number of life years lost for an individual in the general population dying during that age interval. This information can then be combined with the estimated number of premature deaths in each age interval calculated with BenMAP (see previous subsection). Total life years gained will then be the sum of life years gained in each age interval:

$$Total Life\ Years = \sum_{i=1}^{N} LE_i \times M_i \ ,$$

where LE_i is the remaining life expectancy for age interval *i*, M_i is the change in incidence of mortality in age interval *i*, and N is the number of age intervals.

For the purposes of determining cost-effectiveness, it is also necessary to consider the time-dependent nature of the gains in life years. Standard economic theory suggests that benefits occurring in future years should be discounted relative to benefits occurring in the present. OMB and EPA guidance suggest discount rates of three and seven percent. As noted earlier, we present gains in future life years discounted at 3 percent. Results based on 7 percent are included in the summary and the overall impact of a 7 percent rate is summarized in Table G-16. Selection of a 3 percent discount rate is also consistent with recommendations from the U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine (Gold et al., 1996).

Table G-3: Abridged Life Table for the Total Population, United States, 2000

Age Interval		Probability of Dying Between Ages x to x+1	Number Surviving to Age x	Number Dying Between Ages x to x+1	Person Years Lived Between Ages x to x+1	Total Number of Person Years Lived Above Age x	Expectation of Life at Age x
Start Age	*End Age*	q_x	l_x	d_x	L_x	T_x	e_x
30	35	0.00577	97,696	564	487,130	4,723,539	48.3
35	45	0.01979	97,132	1,922	962,882	4,236,409	43.6
45	55	0.04303	95,210	4,097	934,026	3,273,527	34.4
55	65	0.09858	91,113	8,982	872,003	2,339,501	25.7
65	75	0.21779	82,131	17,887	740,927	1,467,498	17.9
75	85	0.45584	64,244	29,285	505,278	726,571	11.3
85	95	0.79256	34,959	27,707	196,269	221,293	6.3
95	100	0.75441	7,252	5,471	20,388	25,024	3.5
100+		1.00000	1,781	1,781	4,636	4,636	2.6

Discounted total life years gained is calculated as follows:

$$Discounted\ LY = \int_0^{LE} e^{-rt}\,dt,$$

where r is the discount rate, equal to 0.03 in this case, t indicates time, and LE is the life expectancy at the time when the premature death would have occurred. Life years are further discounted to account for the lag between the reduction in ambient $PM_{2.5}$ and the reduction in mortality risk. We use the same 20-year segmented lag structure that is used in the benefit-cost analysis (see Chapter 5).

The most complete estimate of the impacts of $PM_{2.5}$ on life years is calculated using the Pope et al. (2002) C-R function relating all-cause mortality in adults 30 and over with ambient $PM_{2.5}$ concentrations averaged over the periods 1979–1983 and 1999–2000. Use of all-cause mortality is appropriate if there are no differences in the life expectancy of individuals dying from air pollution-related causes and those dying from other causes. The argument that long-term exposure to $PM_{2.5}$ may affect mainly individuals with serious preexisting illnesses is not supported by current empirical studies. For example, the Krewski et al. (2000) ACS reanalysis suggests that the mortality risk is no greater for those with preexisting illness at time of enrollment in the study. Life expectancy for the general population in fact includes individuals with serious chronic illness. Mortality rates for the general population then reflect prevalence of chronic disease, and as populations age the prevalence of chronic disease increases.

The only reason one might use a lower life expectancy is if the population at risk from air pollution was limited solely to those with preexisting disease. Also, note that the OMB Circular A-4 notes that “if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimate number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts.” As such, use of a general population life expectancy is preferred over disability-specific life expectancies. Our primary life years calculations are thus consistent with the concept of not penalizing individuals with disabling chronic health conditions by assessing them reduced benefits of mortality risk reductions.

For this analysis, direct impacts on life expectancy are measured only through the estimated change in mortality risk based on the Pope et al. (2002) C-R function. The SAB-HES has advised against including additional gains in life expectancy due to reductions in incidence of chronic disease or nonfatal heart attacks (EPA-SAB-COUNCIL-ADV-04-002). Although reductions in these endpoints are likely to result in increased life expectancy, the HES has suggested that the cohort design and relatively long follow-up period in the Pope et al. study should capture any life-prolonging impacts associated with those endpoints. Impacts of CB and nonfatal heart attacks on quality of life will be captured separately in the QALY calculation as years lived with improved quality of life. The methods for calculating this benefit are discussed below.

G.4.2.1Should Life Years Gained Be Adjusted for Initial Health Status?

The methods outlined above provide estimates of the total number of life years gained in a population, regardless of the quality of those life years, or equivalently, assuming that all life years gained are in perfect health. In some CEAs (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003), analysts have adjusted the number of life years gained to reflect the fact that 1) the general public is not in perfect health and thus “healthy” life years are less than total life years gained and 2) those affected by air pollution may be in a worse health state than the general population and therefore will not gain as many “healthy” life years adjusted for quality, from an air pollution reduction. This adjustment, which converts life years gained into QALYs, raises a number of serious ethical issues. Proponents of QALYs have promoted the nondiscriminatory nature of QALYs in evaluating improvements in quality of life (e.g., an improvement from a score of 0.2 to 0.4 is equivalent to an improvement from 0.8 to 1.0), so the starting health status does not affect the evaluation of interventions that improve quality of life. However, for life-extending interventions, the gains in QALY will be directly proportional to the baseline health state (e.g., an individual with a 30-year life expectancy and a starting health status of 0.5 will gain exactly half the QALYs of an individual with the same life expectancy and a starting health status of 1.0 for a similar life-extending intervention). This is troubling because it imposes an additional penalty for those already suffering from disabling conditions. Brock (2002) notes that “the problem of disability discrimination represents a deep and unresolved problem for resource prioritization.”

OMB (2003) has recognized this issue in their Circular A-4 guidance, which includes the following statement:

> When CEA is performed in specific rulemaking contexts, you should be prepared to make appropriate adjustments to ensure fair treatment of all segments of the population. Fairness is important in the choice and execution of effectiveness measures. For example, if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves the lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimated number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts. More generally, when numeric adjustments are made for life expectancy or quality of life, analysts should prefer use of population averages rather than information derived from subgroups dominated by a particular demographic or income group. (p. 13)

This suggests two adjustments to the standard QALY methodology: one adjusting the relevant life expectancy of the affected population, and the other affecting the baseline quality of life for the affected population.

In addition to the issue of fairness, potential measurement issues are specific to the air pollution context that might argue for caution in applying quality-of-life adjustments to life years gained due to air pollution reductions. A number of epidemiological and toxicological studies link exposure to air pollution with chronic diseases, such as CB and atherosclerosis (Abbey et al., 1995; Schwartz, 1993; Suwa et al., 2002). If these same individuals with chronic disease caused by exposure to air pollution are then at increased risk of premature death from air pollution, there is an important dimension of "double jeopardy" involved in determining the correct baseline for assessing QALYs lost to air pollution (see Singer et al. [1995] for a broader discussion of the double-jeopardy argument).

Analyses estimating mortality from acute exposures that ignore the effects of long-term exposure on morbidity may understate the health impacts of reducing air pollution. Individuals exposed to chronically elevated levels of air pollution may realize an increased risk of death and chronic disease throughout life. If at some age they contract heart (or some other chronic) disease as a result of the exposure to air pollution, they will from that point forward have both reduced life expectancy and reduced quality of life. The benefit to that individual from reducing lifetime exposure to air pollution would be the increase in life expectancy plus the increase in quality of life over the full period of increased life expectancy. If the QALY loss is determined based on the underlying chronic condition and life expectancy without regard to the fact that the person would never have been in that state without long-term exposure to elevated air pollution, then the person is placed in double jeopardy. In other words, air pollution has placed more people in the susceptible pool, but then we penalize those people in evaluating policies by treating their subsequent deaths as less valuable, adding insult to injury, and potentially downplaying the importance of life expectancy losses due to air pollution. If the risk of chronic disease and risk of death are considered together, then there is no conceptual problem with measuring QALYs, but this has not been the case in recent applications of QALYs to air pollution (Carrothers, Evans, and Graham, 2002; Coyle et al., 2003). The use of QALYs thus highlights the need for a better understanding of the relationship between chronic disease and long-term exposure and suggests that analyses need to consider morbidity and mortality jointly, rather than treating each as a separate endpoint (this is an issue for current benefit-cost approaches as well).

Because of the fairness and measurement concerns discussed above, for the purposes of this analysis, we do not reduce the number of life years gained to reflect any differences in underlying health status that might reduce quality of life in remaining years. Thus, we maintain the assumption that all direct gains in life years resulting from mortality risk reductions will be assigned a weight of 1.0. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that "since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY" (Gold et al., 1996). However, for the purposes of this analysis, we propose an alternative to the traditional aggregate QALY metric that keeps separate quality adjustments to life expectancy and gains in life expectancy. As such, we do not make any adjustments to life years gained to reflect the less than perfect health of the general population. Gains in quality of life will be addressed as they accrue because of reductions in the incidence of chronic diseases. This is an explicit equity choice in the treatment of issues associated with quality-of-life adjustments for increases in life expectancy that still capitalizes on the ability of QALYs to capture both morbidity and mortality impacts in a single effectiveness measure.

G.5 Calculating Changes in the Quality of Life Years (Morbidity)

In addition to directly measuring the quantity of life gained, measured by life years, it may also be informative to measure gains in the quality of life. Reducing air pollution also leads to reductions in serious illnesses that affect quality of life. These include CB and cardiovascular disease, for which we are able to quantify changes in the incidence of nonfatal heart attacks. To capture these important benefits in the measure of effectiveness, they must first be converted into a life-year equivalent so that they can be combined with the direct gains in life expectancy.

For this analysis, we developed estimates of the QALYs gained from reductions in the incidence of CB and nonfatal heart attacks associated with reductions in ambient $PM_{2.5}$. In general, QALY calculations require four elements:

1. the estimated change in incidence of the health condition,
2. the duration of the health condition,
3. the quality-of-life weight with the health condition, and
4. the quality-of-life weight without the health condition (i.e., the baseline health state).

The first element is derived using the health impact function approach. The second element is based on the medical literature for each health condition. The third and fourth elements are derived from the medical cost-effectiveness and cost-utility literature. In the following two subsections, we discuss the choices of elements for CB and nonfatal heart attacks.

The preferred source of quality-of-life weights are those based on community preferences, rather than patient or clinician ratings (Gold et al., 1996). Several methods are used to estimate quality-of-life weights. These include rating scale, standard gamble, time trade-off, and person trade-off approaches (Gold, Stevenson, and Fryback, 2002). Only the standard gamble approach is completely consistent with utility theory. However, the time trade-off method has also been widely applied in eliciting community preferences (Gold, Stevenson, and Fryback, 2002).

Quality-of-life weights can be directly elicited for individual specific health states or for a more general set of activity restrictions and health states that can then be used to construct QALY weights for specific conditions (Horsman et al., 2003; Kind, 1996). For this analysis, we used weights based on community-based preferences, using time trade-off or standard gamble when available. In some cases, we used patient or clinician ratings when no community preference-based weights were available. Sources for weights are discussed in more detail below. Table G-4 summarizes the key inputs for calculating QALYs associated with chronic health endpoints.

G.5.1 Calculating QALYs Associated with Reductions in the Incidence of Chronic Bronchitis

CB is characterized by mucus in the lungs and a persistent wet cough for at least 3 months a year for several years in a row. CB affects an estimated 5 percent of the U.S. population (American Lung Association, 1999). For gains in quality of life resulting from reduced incidences of PM-induced CB, discounted QALYs are calculated as

$$DISCOUNTED\ QALY GAINED = \sum_i \Delta CB_i \times D_i^* \times \left(w_i - w_i^{CB}\right)$$

where ΔCB_i is the number of incidences of CB avoided in age interval i, w_i is the average QALY weight for age interval i, w_i^{CB} is the QALY weight associated with CB, D_i^* is the discounted duration of life with CB for individuals with onset of disease in age interval i, equal to $\int_{t=1}^{D_i} e^{-rt} dt$, where D_i is the duration of life with CB for individuals with onset of disease in age interval i.

A limited number of studies have estimated the impact of air pollution on new incidences of CB. Schwartz (1993) and Abbey et al. (1995) provide evidence that long-term PM exposure gives rise to the development of CB in the United States. Because this analysis focuses on the impacts of reducing ambient $PM_{2.5}$, only the Abbey et al. (1995) study is used, because it is the only study focusing on the relationship between $PM_{2.5}$ and new incidences of CB. The number of cases of CB in each age interval is derived from applying the impact function from Abbey et al. (1995), to the population in each age interval with the appropriate baseline incidence rate.[3] The effect estimate from the Abbey et al. (1995) study is 0.0137, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.15 for a 10 µg change in $PM_{2.5}$. Table G-5 presents the estimated reduction in new incidences of CB associated with the illustrative PM NAAQS attainment strategies.

[3] Prevalence rates for CB were obtained from the 1999 National Health Interview Survey (American Lung Association, 2002). Prevalence rates were available for three age groups: 18–44, 45–64, and 65 and older. Prevalence rates per person for these groups were 0.0367 for 18–44, 0.0505 for 45–64, and 0.0587 for 65 and older. The incidence rate for new cases of CB (0.00378 per person) was taken directly from Abbey et al. (1995).

Table G-4: Summary of Key Parameters Used in QALY Calculations for Chronic Disease Endpoints

Parameter	*Value(s)*	*Source(s)*
Discount rate	0.03 (0.07 sensitivity analysis)	Gold et al. (1996), U.S. EPA (2000), U.S. OMB (2003)
Quality of life preference score for chronic bronchitis	0.5 – 0.7	Triangular distribution centered at 0.7 with upper bound at 0.9 (Vos, 1999a) (slightly better than a mild/moderate case) and a lower bound at 0.5 (average weight for a severe case based on Vos [1999a] and Smith and Peske [1994])
Duration of acute phase of acute myocardial infarction (AMI)	5.5 days – 22 days	Uniform distribution with lower bound based on average length of stay for an AMI (AHRQ, 2000) and upper bound based on Vos (1999b).
Probability of CHF post AMI	0.2	Vos, 1999a (WHO Burden of Disease Study, based on Cowie et al., 1997)
Probability of angina post AMI	0.51	American Heart Association, 2003 (Calculated as the population with angina divided by the total population with heart disease)
Quality-of-life preference score for post-AMI with CHF (no angina)	0.80 – 0.89	Uniform distribution with lower bound at 0.80 (Stinnett et al., 1996) and upper bound at 0.89 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with CHF and angina	0.76 – 0.85	Uniform distribution with lower bound at 0.76 (Stinnett et al., 1996, adjusted for severity) and upper bound at 0.85 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with angina (no CHF)	0.7 – 0.89	Uniform distribution with lower bound at 0.7, based on the standard gamble elicitation method (Pliskin, Stason, and Weinstein, 1981) and upper bound at 0.89, based on the time trade-off method (Kuntz et al., 1996).
Quality-of-life preference score for post-AMI (no angina, no CHF)	0.93	Only one value available from the literature. Thus, no distribution is specified. Source of value is Kuntz et al. (1996).

CB is assumed to persist for the remainder of an affected individual's lifespan. Duration of CB will thus equal life expectancy conditioned on having CB. CDC has estimated that COPD (of which CB is one element) results in an average loss of life years equal to 4.26 per COPD death, relative to a reference life expectancy of 75 years (CDC, 2003). Thus, we subtract 4.26 from the remaining life expectancy for each age group, up to age 75. For age groups over 75, we apply the ratio of 4.26 to the life expectancy for the 65 to 74 year group (0.237) to the life expectancy for the 75 to 84 and 85 and up age groups to estimate potential life years lost and then subtract that value from the base life expectancy.

Table G-5: Estimated Reduction in Incidence of Chronic Bronchitis Associated with Illustrative Attainment Strategies for the Revised and More Stringent Alternative PM NAAQS in 2020

	Reduction in Incidence (95% Confidence Interval)	
Age Interval	*15/35 Attainment Strategy*	*14/35 Attainment Strategy*
25 – 34	490 (47 – 940)	830 (77 – 1,600)
35 – 44	560 (53 – 1,100)	950 (88 – 1,800)
45 – 54	510 (48 – 960)	880 (81 – 1,700)
55 – 64	490 (46 – 940)	890 (82 – 1,700)
65 – 74	340 (32 – 640)	630 (58 – 1,200)
75 – 84	170 (16 – 320)	310 (28 – 580)
85+	74 (7 – 140)	130 (12 – 250)
Total	2,600 (250 – 5,000)	4,600 (426 – 8,800)

Quality of life with chronic lung diseases has been examined in several studies. In an analysis of the impacts of environmental exposures to contaminants, de Hollander et al. (1999) assigned a weight of 0.69 to years lived with CB. This weight was based on physicians' evaluations of health states similar to CB. Salomon and Murray (2003) estimated a pooled weight of 0.77 based on visual analogue scale, time trade-off, standard gamble, and person trade-off techniques applied to a convenience sample of health professionals. The Harvard Center for Risk Analysis catalog of preference scores reports a weight of 0.40 for severe COPD, with a range from 0.2 to 0.8, based on the judgments of the study's authors (Bell et al., 2001). The Victoria Burden of Disease (BoD) study used a weight of 0.47 for severe COPD and 0.83 for mild to moderate COPD, based on an analysis by Stouthard et al. (1997) of chronic diseases in Dutch populations (Vos, 1999a). Based on the recommendations of Gold et al. (1996), quality-of-life weights based on community preferences are preferred for CEA of interventions affecting broad populations. Use of weights based on health professionals is not recommended. It is not clear from the Victoria BoD study whether the weights used for COPD are based on community preferences or judgments of health professionals. The Harvard catalog score is clearly identified as based on author judgment. Given the lack of a clear preferred weight, we select a triangular distribution centered at 0.7 with an upper bound at 0.9 (slightly better than a mild/moderate case defined by the Victoria BoD study) and a lower bound at 0.5 based on the Victoria BoD study. We will need additional empirical data on quality of life with chronic respiratory diseases based on community preferences to improve our estimates.

Selection of a reference weight for the general population without CB is somewhat uncertain. It is clear that the general population is not in perfect health; however, there is some uncertainty as to whether individuals' ratings of health states are in reference to a perfect health state or to a generally achievable "normal" health state given age and general health status. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that "since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY" (Gold et al., 1996). Following Carrothers, Evans, and Graham (2002), we assumed that the reference weight for the general population without CB is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0. Note that the reference weight for the general population is used solely to determine the incremental quality-of-life improvement applied to the duration of life that would have been lived with the chronic disease. For example, if CB has a quality-of-life weight of 0.7 relative to a reference quality-of-life weight of 0.9, then the incremental quality-of-life improvement in 0.2. If the reference quality-of-life weight is 0.95, then the incremental quality-of-life improvement is 0.25. As noted above, the population is assumed to have a reference weight of 1.0 for all life years gained due to mortality risk reductions.

We present discounted QALYs over the duration of the lifespan with CB using a 3 percent discount rate. Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of CB for each age interval.[4] Based on the assumptions defined above, the mean 3 percent discounted QALY gained per incidence of CB for each age interval along with the 95 percent confidence interval resulting from the Monte Carlo simulation is presented in Table G-6. Table G-6 presents both the undiscounted and discounted QALYs gained per incidence.

Table G-6: QALYs Gained per Avoided Incidence of CB

Age Interval		*QALYs Gained per Incidence*	
Start Age	*End Age*	*Undiscounted*	*Discounted (3%)*
25	34	12.15 (4.40-19.95)	6.52 (2.36-10.71)
35	44	9.91 (3.54-16.10)	5.94 (2.12-9.66)
45	54	7.49 (2.71-12.34)	5.03 (1.82-8.29)
55	64	5.36 (1.95-8.80)	4.03 (1.47-6.61)
65	74	3.40 (1.22-5.64)	2.84 (1.02-4.71)
75	84	2.15 (0.77-3.49)	1.92 (0.69-3.13)
85+		0.79 (0.27-1.29)	0.77 (0.26-1.25)

[4] Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables. For more details, see Gentile (1998).

G.5.2 Calculating QALYs Associated with Reductions in the Incidence of Nonfatal Myocardial Infarctions

Nonfatal heart attacks, or acute myocardial infarctions, require more complicated calculations to derive estimates of QALY impacts. The actual heart attack, which results when an area of the heart muscle dies or is permanently damaged because of oxygen deprivation, and subsequent emergency care are of relatively short duration. Many heart attacks result in sudden death. However, for survivors, the long-term impacts of advanced CHD are potentially of long duration and can result in significant losses in quality of life and life expectancy.

In this phase of the analysis, we did not independently estimate the gains in life expectancy associated with reductions in nonfatal heart attacks. Based on recommendations from the SAB-HES, we assumed that all gains in life expectancy are captured in the estimates of reduced mortality risk provided by the Pope et al. (2002) analysis. We only estimate the change in quality of life over the period of life affected by the occurrence of a heart attack. This may understate the QALY impacts of nonfatal heart attacks but ensures that the overall QALY impact estimates across endpoints do not double-count potential life-year gains.

Our approach adapts a CHD model developed for the Victoria Burden of Disease study (Vos, 1999b). This model accounts for the lost quality of life during the heart attack and the possible health states following the heart attack. Figure G-1 shows the heart attack QALY model in diagrammatic form.

The total gain in QALYs is calculated as:

$$DISCOUNTED\ AMI\ QALY\ GAINED =$$

$$\sum_i \Delta AMI_i \times D_i^{*AMI} \times \left(w_i - w_i^{AMI}\right) + \sum_i \sum_{j=1}^{4} \Delta AMI_i \times p_j D_{ij}^{*PostAMI} \times \left(w_i - w_{ij}^{postAMI}\right)$$

where ΔAMI_i is the number of nonfatal acute myocardial infarctions avoided in age interval *i*, w_i^{AMI} is the QALY weight associated with the acute phase of the AMI, p_j is the probability of being in the *j*th post-AMI status, $w_{ij}^{postAMI}$ is the QALY weight associated with post-AMI health status *j*, w_i is the average QALY weight for age interval i, $D_i^{*AMI} = \int_{t=1}^{D_i^{AMI}} e^{-rt}dt$, the discounted value of D_i^{AMI}, the duration of the acute phase of the AMI, and $D_i^{*postAMI} = \int_{t=1}^{D_i^{postAMI}} e^{-rt}dt$, is the discounted value of $D_{ij}^{PostAMI}$, the duration of post-AMI health status *j*.

D_i^{AMI}

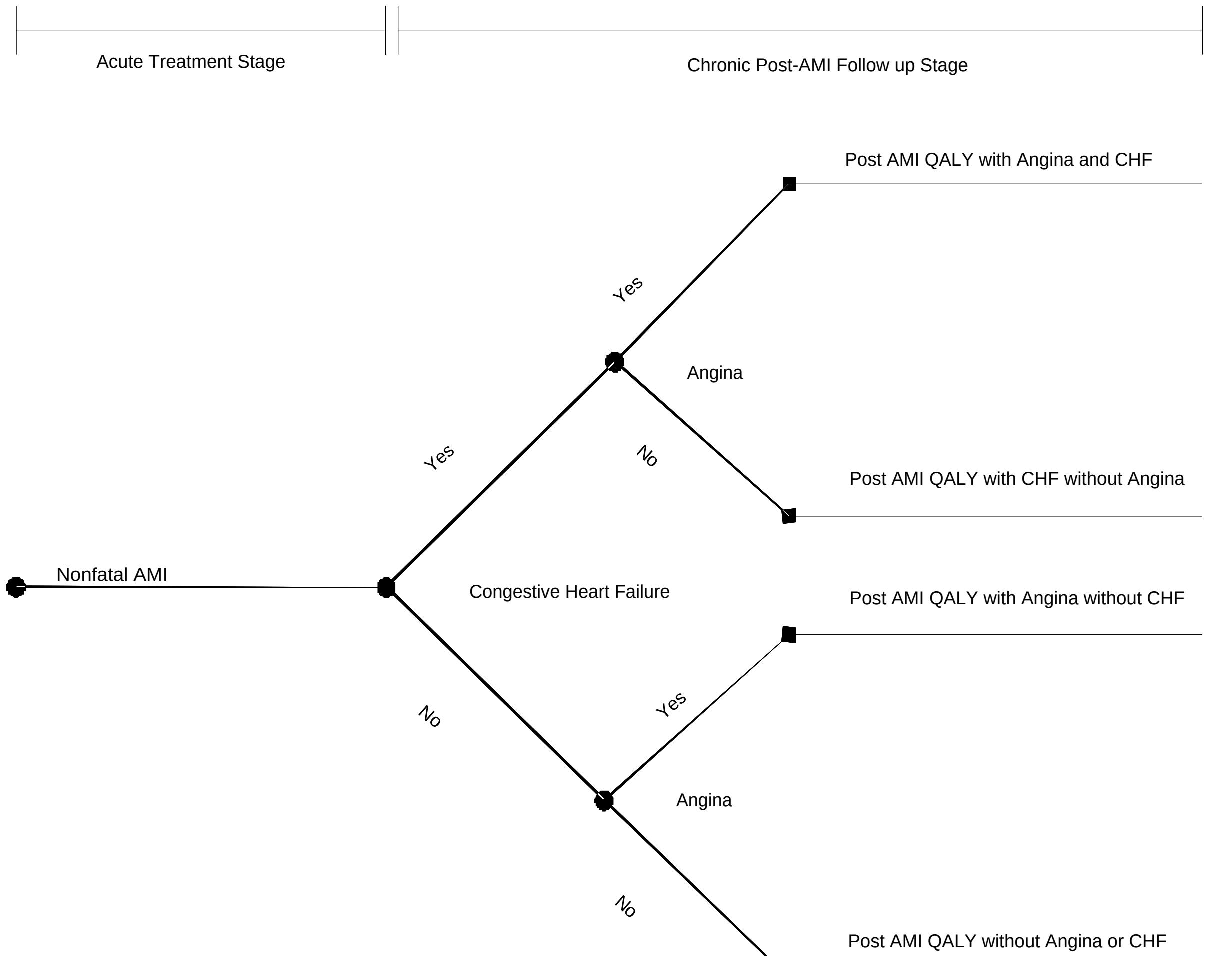

Figure G-1. Decision Tree Used in Modeling Gains in QALYs from Reduced Incidence of Nonfatal Acute Myocardial Infarctions

Nonfatal heart attacks have been linked with short-term exposures to $PM_{2.5}$ in the United States (Peters et al., 2001) and other countries (Poloniecki et al., 1997). We used a recent study by Peters et al. (2001) as the basis for the impact function estimating the relationship between $PM_{2.5}$ and nonfatal heart attacks. Peters et al. is the only available U.S. study to provide a specific estimate for heart attacks. Other studies, such as Samet et al. (2000) and Moolgavkar (2000), show a consistent relationship between all cardiovascular hospital admissions, including for nonfatal heart attacks, and PM. Given the lasting impact of a heart attack on longer-term health costs and earnings, we chose to provide a separate estimate for nonfatal heart attacks based on the single available U.S. effect estimate. The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the United States. These studies provide a weight of evidence for this type of effect. Several epidemiologic studies (Liao et al., 1999; Gold et al., 2000; Magari et al., 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other CHDs (Carthenon et al., 2002; Dekker et al., 2000; Liao et al., 1997, Tsuji et al., 1996). As such, significant impacts of PM on heart rate variability are consistent with an increased risk of heart attacks.

The number of avoided nonfatal AMI in each age interval is derived from applying the impact function from Peters et al. (2001) to the population in each age interval with the appropriate baseline incidence rate.[5] The effect estimate from the Peters et al. (2001) study is 0.0241, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.27 for a 10 μg change in $PM_{2.5}$. Table G-7 presents the estimated reduction in nonfatal AMI associated with the illustrative PM NAAQS attainment strategies.

Table G-7: Estimated Reduction in Nonfatal Acute Myocardial Infarctions Associated with Illustrative Attainment Strategies for the Revised and More Stringent Alternative PM NAAQS in 2020

	Reduction in Incidence(95% Confidence Interval)*	
Age Interval	*15/35 Attainment Strategy*	*14/35 Attainment Strategy*
18 – 24	1 (1 – 2)	4 (2 – 6)
25 – 34	8 (4 – 12)	26 (13 – 40)
35 – 44	170 (84 – 250)	280 (140 – 430)
45 – 54	520 (260 – 790)	930 (460 – 1,400)
55 – 64	1,300 (630 – 1,900)	2,100 (1,100 – 3,200)
65 – 74	1,500 (770 – 2,300)	2,600 (1,300 – 3,900)
75 – 84	980 (490 – 1,500)	1,800 (900 – 2,800)
85+	520 (260 – 780)	940 (460 – 1,400)
Total	5,000 (2,500 – 7,500)	8,700 (4,300 – 13,000)

Acute myocardial infarction results in significant loss of quality of life for a relatively short duration. The WHO Global Burden of Disease study, as reported in Vos (1999b), assumes that the acute phase of an acute myocardial infarction lasts for 0.06 years, or around 22 days. An alternative assumption is the acute phase is characterized by the average length of hospital stay for an AMI in the United States, which is 5.5 days, based on data from the Agency for

[5] Daily nonfatal myocardial infarction incidence rates per person were obtained from the 1999 National Hospital Discharge Survey (assuming all diagnosed nonfatal AMI visit the hospital). Age-specific rates for four regions are used in the analysis. Regional averages for populations 18 and older are 0.0000159 for the Northeast, 0.0000135 for the Midwest, 0.0000111 for the South, and 0.0000100 for the West.

Healthcare Research and Quality's Healthcare Cost and Utilization Project (HCUP).[6] We assumed a distribution of acute phase duration characterized by a uniform distribution between 5.5 and 22 days, noting that due to earlier discharges and in-home therapy available in the United States, duration of reduced quality of life may continue after discharge from the hospital. In the period during and directly following an AMI (the acute phase), we assigned a quality of life weight equal to 0.605, consistent with the weight for the period in treatment during and immediately after an attack (Vos, 1999b).

During the post-AMI period, a number of different health states can determine the loss in quality of life. We chose to classify post-AMI health status into four states defined by the presence or absence of angina and congestive heart failure (CHF). This makes a very explicit assumption that without the occurrence of an AMI, individuals would not experience either angina or CHF. If in fact individuals already have CHF or angina, then the quality of life gained will be overstated. We do not have information about the percentage of the population have been diagnosed with angina or CHF with no occurrence of an AMI. Nor do we have information on what proportion of the heart attacks occurring due to PM exposure are first heart attacks versus repeat attacks. Probabilities for the four post-AMI health states sum to one.

Given the occurrence of a nonfatal AMI, the probability of congestive heart failure is set at 0.2, following the heart disease model developed by Vos (1999b). The probability is based on a study by Cowie et al. (1997), which estimated that 20 percent of those surviving AMI develop heart failure, based on an analysis of the results of the Framingham Heart Study.

The probability of angina is based on the prevalence rate of angina in the U.S. population. Using data from the American Heart Association, we calculated the prevalence rate for angina by dividing the estimated number of people with angina (6.6 million) by the estimated number of people with CHD of all types (12.9 million). We then assumed that the prevalence of angina in the population surviving an AMI is similar to the prevalence of angina in the total population with CHD. The estimated prevalence rate is 51 percent, so the probability of angina is 0.51.

Combining these factors leads to the probabilities for each of the four health states as follows:

I. Post AMI with CHF and angina = 0.102

II. Post AMI with CHF without angina = 0.098

III. Post AMI with angina without CHF = 0.408

IV. Post AMI without angina or CHF = 0.392

Duration of post-AMI health states varies, based in part on assumptions regarding life expectancy with post-AMI complicating health conditions. Based on the model used for established market economies (EME) in the WHO Global Burden of Disease study, as reported in Vos (1999b), we assumed that individuals with CHF have a relatively short remaining life expectancy and thus a relatively short period with reduced quality of life (recall that gains in life expectancy are assumed to be captured by the cohort estimates of reduced mortality risk).

[6] Average length of stay estimated from the HCUP data includes all discharges, including those due to death. As such, the 5.5-day average length of stay is likely an underestimate of the average length of stay for AMI admissions where the patient is discharged alive.

Table G-8 provides the duration (both discounted and undiscounted) of CHF assumed for post-AMI cases by age interval.

Table G-8: Assumed Duration of Congestive Heart Failure

Age Interval		*Duration of Heart Failure (years)*	
Start Age	*End Age*	*Undiscounted*	*Discounted (3%)*
18	24	7.11	6.51
25	34	6.98	6.40
35	44	6.49	6.00
45	54	5.31	4.99
55	64	1.96	1.93
65	74	1.71	1.69
75	84	1.52	1.50
85+		1.52	1.50

Duration of health states without CHF is assumed to be equal to the life expectancy of individuals conditional on surviving an AMI. Ganz et al. (2000) note that "Because patients with a history of myocardial infarction have a higher chance of dying of CHD that is unrelated to recurrent myocardial infarction (for example, arrhythmia), this cohort has a higher risk for death from causes other than myocardial infarction or stroke than does an unselected population." They go on to specify a mortality risk ratio of 1.52 for mortality from other causes for the cohort of individuals with a previous (nonfatal) AMI. The risk ratio is relative to all-cause mortality for an age-matched unselected population (i.e., general population). We adopted the same ratios and applied them to each age-specific all-cause mortality rate to derive life expectancies (both discounted and undiscounted) for each age group after an AMI, presented in Table G-9. These life expectancies are then used to represent the duration of non-CHF post-AMI health states (III and IV).

Table G-9: Assumed Duration of Non-CHF Post-AMI Health States

Age Interval		*Post-AMI Years of Life Expectancy (non-CHF)*	
Start Age	*End Age*	*Undiscounted*	*Discounted (3%)*
18	24	55.5	27.68
25	34	46.1	25.54
35	44	36.8	22.76
45	54	27.9	19.28
55	64	19.8	15.21
65	74	12.8	10.82
75	84	7.4	6.75
85+		3.6	3.47

For the four post-AMI health states, we used QALY weights based on preferences for the combined conditions characterizing each health state. A number of estimates of QALY weights are available for post-AMI health conditions.

The first two health states are characterized by the presence of CHF, with or without angina. The Harvard Center for Risk Analysis catalog of preference scores provides several specific weights for CHF with and without mild or severe angina and one set specific to post-AMI CHF. Following the Victoria Burden of Disease model, we assumed that most cases of angina will be treated and thus kept at a mild to moderate state. We thus focused our selection on QALY weights for mild to moderate angina. The Harvard database includes two sets of community preference-based scores for CHF (Stinnett et al., 1996; Kuntz et al., 1996). The scores for CHF with angina range from 0.736 to 0.85. The lower of the two scores is based on angina in general with no delineation by severity. Based on the range of the scores for mild to severe cases of angina in the second study, one can infer that an average case of angina has a score around 0.96 of the score for a mild case. Applying this adjustment raises the lower end of the range of preference scores for a mild case of angina to 0.76. We selected a uniform distribution over the range 0.76 to 0.85 for CHF with mild angina, with a midpoint of 0.81. The same two studies in the Harvard catalog also provide weights for CHF without angina. These scores range from 0.801 to 0.89. We selected a uniform distribution over this range, with a midpoint of 0.85.

The third health state is characterized by angina, without the presence of CHF. The Harvard catalog includes five sets of community preference-based scores for angina, one that specifies scores for both mild and severe angina (Kuntz et al., 1996), one that specifies mild angina only (Pliskin, Stason, and Weinstein, 1981), one that specifies severe angina only (Cohen, Breall, and Ho, 1994), and two that specify angina with no severity classification (Salkeld, Phongsavan, and Oldenburg, 1997; Stinnett et al., 1996). With the exception of the Pliskin, Stason, and Weinstein score, all of the angina scores are based on the time trade-off method of elicitation. The Pliskin, Stason, and Weinstein score is based on the standard gamble elicitation method. The scores for the nonspecific severity angina fall within the range of the two scores for mild angina specifically. Thus, we used the range of mild angina scores as the endpoints of a uniform distribution. The range of mild angina scores is from 0.7 to 0.89, with a midpoint of 0.80.

For the fourth health state, characterized by the absence of CHF and/or angina, there is only one relevant community preference score available from the Harvard catalog. This score is 0.93, derived from a time trade-off elicitation (Kuntz et al., 1996). Insufficient information is available to provide a distribution for this weight; therefore, it is treated as a fixed value.

Similar to CB, we assumed that the reference weight for the general population without AMI is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0.

Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of nonfatal AMI for each age interval. For the Monte Carlo simulation, all distributions were assumed to be independent. The mean QALYs gained per incidence of nonfatal AMI for each age interval is presented in Table G-10, along with the 95 percent confidence interval resulting from the Monte Carlo simulation. Table G-10 presents both the undiscounted and discounted QALYs gained per incidence.

Table G-10: QALYs Gained per Avoided Nonfatal Myocardial Infarction

Age Interval		*QALYs Gained per Incidence*[a]	
Start Age	*End Age*	*Undiscounted*	*Discounted (3%)*
18	24	4.18 (1.24-7.09)	2.17 (0.70-3.62)
25	34	3.48 (1.09-5.87)	2.00 (0.68-3.33)
35	44	2.81 (0.88-4.74)	1.79 (0.60-2.99)
45	54	2.14 (0.67-3.61)	1.52 (0.51-2.53)
55	64	1.49 (0.42-2.52)	1.16 (0.34-1.95)
65	74	0.97 (0.30-1.64)	0.83 (0.26-1.39)
75	84	0.59 (0.20-0.97)	0.54 (0.19-0.89)
85+		0.32 (0.13-0.50)	0.31 (0.13-0.49)

[a] Mean of Monte Carlo generated distribution; 95% confidence interval presented in parentheses.

G.6 Cost-Effectiveness Analysis

Given the estimates of changes in life expectancy and quality of life, the next step is to aggregate life expectancy and quality-of-life gains to form an effectiveness measure that can be compared to costs to develop cost-effectiveness ratios. This section discusses the proper characterization of the combined effectiveness measure and the appropriate calculation of the numerator of the cost-effectiveness ratio.

G.6.1 Aggregating Life Expectancy and Quality-of-Life Gains

To develop an integrated measure of changes in health, we simply sum together the gains in life years from reduced mortality risk in each age interval with the gains in QALYs from reductions in incidence of CB and acute myocardial infarctions. The resulting measure of effectiveness then forms the denominator in the cost-effectiveness ratio. What is this combined measure of effectiveness? It is not a QALY measure in a strict sense, because we have not adjusted life-expectancy gains for preexisting health status (quality of life). It is however, an effectiveness measure that adds to the standard life years calculation a scaled morbidity equivalent. Thus, we term the aggregate measure morbidity inclusive life years, or MILYs. Alternatively, the combined measure could be considered as QALYs with an assumption that the community preference weight for all life-expectancy gains is 1.0. If one considers that this weight might be considered to be a “fair” treatment of those with preexisting disabilities, the effectiveness measure might be termed “fair QALY” gained. However, this implies that all aspects of fairness have been addressed, and there are clearly other issues with the fairness of QALYs (or other effectiveness measures) that are not addressed in this simple adjustment. The MILY measure violates some of the properties used in deriving QALY weights, such as linear substitution between quality of life and quantity of life. However, in aggregating life expectancy and quality-of-life gains, it merely represents an alternative social weighting that is consistent with the spirit of the recent OMB guidance on CEA. The guidance notes that “fairness is important in the choice and execution of effectiveness measures” (OMB, 2003). The resulting aggregate measure of effectiveness will not be consistent with a strict utility interpretation of QALYs; however, it may still be a useful index of effectiveness.

Applying the life expectancies and distributions of QALYs per incidence for CB and AMI to estimated distributions of incidences yields distributions of life expectancy and QALYs gained due to the PM NAAQS illustrative attainment strategies. These distributions reflect both the quantified uncertainty in incidence estimates and the quantified uncertainty in QALYs gained per incidence.

For the attainment strategy for the revised 15/35 standards, Table G-11 presents the mean 3 percent discounted MILYs gained for each age interval, broken out by life expectancy and quality-of-life categories. Note that quality-of-life gains occur from age 18 and up, while life expectancy gains accrue only after age 29. This is based on the ages of the study populations in the underlying epidemiological studies. It is unlikely that such discontinuities exist in reality, but to avoid overstating effectiveness, we chose to limit the life-expectancy gains to those occurring in the population 30 and over and the morbidity gains to the specific adult populations examined in the studies. Table G-12 provides the same information for the 14/35 attainment strategy.

It is worth noting that around a third of mortality-related benefits are due to reductions in premature deaths among those 75 and older, while only 7 percent of morbidity benefits occur in this age group. This is due to two factors: (1) the relatively low baseline mortality rates in populations under 75, and (2) the relatively constant baseline rates of chronic disease coupled with the relatively long period of life that is lived with increased quality of life without CB and advanced heart disease.

The relationship between age and the distribution of MILYs gained from mortality and morbidity is shown for the 15/35 attainment strategy in Figure G-2 (the relationship is almost identical for the 14/35 attainment strategy). Because the baseline mortality rate is increasing in age at a much faster rate than the prevalence rate for CB, the share of MILYs gained accounted for by mortality is proportional to age. At the oldest age interval, avoiding incidences of CB leads to only a few MILYs gained, due to the lower number of years lived with CB. MILYs gained from avoided premature mortality is low in the youngest age intervals because of the low overall mortality rates in these intervals, although the number of MILYs per incidence is high. In later years, even though the MILYs gained per incidence avoided is low, the number of cases is very high due to higher baseline mortality rates.

Table G-11. Estimated Gains in 3 Percent Discounted MILYs Associated with Illustrative Attainment Strategies for the Revised PM NAAQS (15/35) in 2020[a]

Age	*Life Years Gained from Mortality Risk Reductions (95% CI)*	*QALY Gained from Reductions in Chronic Bronchitis (95% CI)*	*QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)*	*Total Gain in MILYs (95% CI)*
18–24	—	—	3 (0 – 5)	3 (0 – 5)
25–34	580 (170 – 1,000)	3,200 (240 – 7,600)	15 (4 – 32)	3,800 (810 – 8,200)
35–44	1,700 (600 – 2,900)	3,300 (260 – 7,700)	290 (78 – 600)	5,300 (1,900 – 9,900)
45–54	3,000 (970 – 5,000)	2,600 (210 – 6,000)	770 (210 – 1,600)	6,300 (3,000 – 10,000)
55–64	5,800 (1,900 – 9,800)	2,000 (170 – 4,600)	1,400 (360 – 3,000)	9,200 (4,600 – 14,000)
65–74	6,800 (2,200 – 11,000)	960 (83 – 2,300)	1,200 (320 – 2,600)	9,000 (4,100 – 14,000)
75–84	5,400 (1,800 – 9,100)	320 (28 – 770)	510 (140 – 1,000)	6,200 (2,600 – 10,000)
85+	2,900 (940 – 4,900)	56 (5 – 130)	150 (45 – 300)	3,100 (1,200 – 5,100)
Total	26,000 (18,000 – 34,000)	12,000 (1,100 – 29,000)	4,400 (1,200 – 9,100)	43,000 (28,000 – 62,000)

[a] Note that all estimates have been rounded to two significant digits.

Summing over the age intervals provides estimates of total MILYs gained for the PM NAAQS illustrative attainment strategies. The total number of discounted (3 percent) MILYs gained for the 15/35 attainment strategy is 43,000 (95% CI: 28,000 – 62,000) and for the 14/35 attainment strategy is 75,000 (95% CI: 48,000 – 110,000).

G.6.2 Dealing with Acute Health Effects and Nonhealth Effects

Health effects from exposure to particulate air pollution encompass a wide array of chronic and acute conditions in addition to premature mortality (EPA, 1996). Although chronic conditions and premature mortality generally account for the majority of monetized benefits, acute symptoms can affect a broad population or sensitive populations (e.g., asthma exacerbations in asthmatic children. In addition, reductions in air pollution may result in a broad set of nonhealth environmental benefits, including improved visibility in national parks, increased agricultural and forestry yields, reduced acid damage to buildings, and a host of other impacts. QALYs address only health impacts, and the OMB guidance notes that "where regulation may yield several different beneficial outcomes, a cost-effectiveness comparison becomes more difficult to interpret because there is more than one measure of effectiveness to incorporate in the analysis."

Table G-12: Estimated Gains in 3 Percent Discounted MILYs Associated with Illustrative Attainment Strategies for the More Stringent Alternative PM NAAQS (14/35) in 2020[a]

Age	*Life Years Gained from Mortality Risk Reductions (95% CI)*	*QALY Gained from Reductions in Chronic Bronchitis (95% CI)*	*QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)*	*Total Gain in MILYs (95% CI)*
18–24	—	—	8 (2 – 17)	8 (2 – 17)
25–34	950 (310 – 1,600)	5,500 (390 – 13,000)	51 (13 – 100)	6,500 (1,300 – 14,000)
35–44	2,800 (910 – 4,600)	5,600 (310 – 13,000)	500 (130 – 1,000)	8,900 (3,200 – 17,000)
45–54	4,900 (1,600 – 8,300)	4,400 (320 – 10,000)	1,400 (360 – 2,800)	11,000 (5,000 – 18,000)
55–64	10,000 (3,200 – 17,000)	3,600 (280 – 8,400)	2,400 (600 – 5,000)	16,000 (8,000 – 25,000)
65–74	12,000 (3,800 – 21,000)	1,800 (170 – 4,200)	2,100 (520 – 4,200)	16,000 (7,300 – 25,000)
75–84	9,600 (3,200 – 16,000)	590 (38 – 1,400)	960 (250 -1,900)	11,000 (4,600 – 18,000)
85+	4,800 (1,600 – 8,100)	98 (7 – 230)	280 (80 – 550)	5,200 (2,000 – 8,400)
Total	45,000 (32,000 – 59,000)	22,000 (1,500 – 51,000)	7,700 (2,000 – 16,000)	75,000 (48,000 – 110,000)

[a] Note that all estimates have been rounded to two significant digits.

With regard to acute health impacts, Bala and Zarkin (2000) suggest that QALYs are not appropriate for valuing acute symptoms, because of problems with both measuring utility for acute health states and applying QALYs in a linear fashion to very short duration health states. Johnson and Lievense (2000) suggest using conjoint analysis to get healthy-utility time equivalences that can be compared across acute effects, but it is not clear how these can be combined with QALYs for chronic effects and loss of life expectancy. There is also a class of effects that EPA has traditionally treated as acute, such as hospital admissions, which may also result in a loss of quality of life for a period of time following the effect. For example, life after asthma hospitalization has been estimated with a utility weight of 0.93 (Bell et al., 2001; Kerridge, Glasziou, and Hillman, 1995).

How should these effects be combined with QALYs for chronic and mortality effects? One method would be to convert the acute effects to QALYs; however, as noted above, there are problems with the linearity assumption (i.e., if a year with asthma symptoms is equivalent to 0.7 year without asthma symptoms, then 1 day without asthma symptoms is equivalent to 0.0019 QALY gained). This is troubling from both a conceptual basis and a presentation basis. An alternative approach is simply to treat acute health effects like nonhealth benefits and subtract the dollar value (based on WTP or COI) from compliance costs in the CEA.

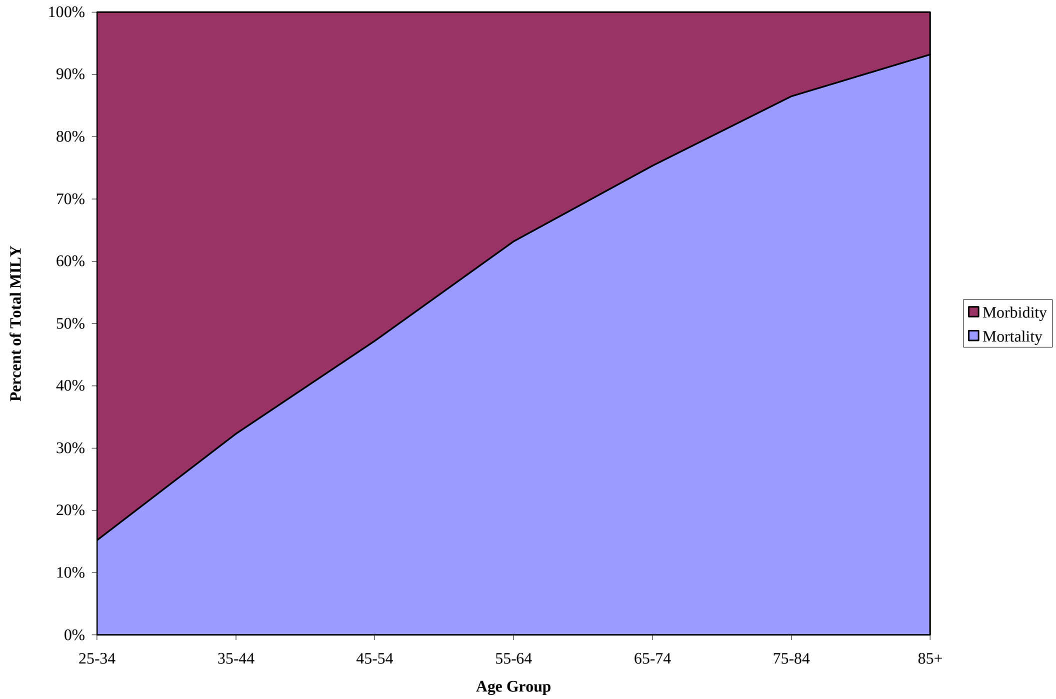

Figure G-2. Distribution of Mortality and Morbidity Related MILY Across Age Groups for Illustrative Attainment Strategy for the Revised PM NAAQS (3 percent Discount Rate)

To address the issues of incorporating acute morbidity and nonhealth benefits, OMB suggests that agencies "subtract the monetary estimate of the ancillary benefits from the gross cost estimate to yield an estimated net cost." As with benefit-cost analysis, any unquantified benefits and/or costs should be noted and an indication of how they might affect the cost-effectiveness ratio should be described. We will follow this recommended "net cost" approach in the illustrative exercise, specifically in netting out the benefits of health improvements other than reduced mortality and chronic morbidity, and the benefits of improvements in visibility at national parks (see Chapter 5 for more details on these benefit categories).

G.6.3 Cost-Effectiveness Ratios

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. The estimate of costs in the numerator should include both the direct costs of the controls necessary to achieve the reduction in ambient $PM_{2.5}$ and the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). In general, because reductions in air pollution do not require direct actions by the affected populations, there are no specific costs to affected individuals (aside from the overall increases in prices that might be expected to occur as control costs are passed on by affected industries). Likewise, because individuals do not engage in any specific actions to realize the health benefit of the pollution reduction, there are no decreases in utility (as might occur from a medical intervention) that need to be adjusted for in the denominator. Thus, the elements of the numerator are direct costs of controls minus the avoided COI associated with CB and nonfatal AMI. In addition, to account for the value of reductions in acute health impacts and nonhealth benefits, we net out the monetized value of these benefits from the numerator to yield a "net cost" estimate. For the MILY aggregate effectiveness measure, the denominator is simply the sum of life years gained from increased life expectancy and the sum of QALYs gained from the reductions in CB and nonfatal AMI.

Avoided costs for CB and nonfatal AMI are based on estimates of lost earnings and medical costs.[7] Using age-specific annual lost earnings and medical costs estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a lifetime present discounted value (in 2000$) due to CB of $150,542 for someone between the ages of 27 and 44; $97,610 for someone between the ages of 45 and 64; and $11,088 for someone over 65. The corresponding age-specific estimates of lifetime present discounted value (in 2000$) using a 7 percent discount rate are $86,026, $72,261, and $9,030, respectively. These estimates assumed that 1) lost earnings continue only until age 65, 2) medical expenditures are incurred until death, and 3) life expectancy is unchanged by CB.

Because the costs associated with a myocardial infarction extend beyond the initial event itself, we consider costs incurred over several years. Using age-specific annual lost earnings estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a present discounted value in lost earnings (in 2000$) over 5 years due to a myocardial infarction of $8,774 for someone between the ages of 25 and 44, $12,932 for someone between the ages of 45 and 54, and $74,746 for someone between the ages of 55 and 65. The corresponding age-specific estimates of lost earnings (in 2000$) using a 7 percent discount rate are $7,855, $11,578, and $66,920, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for populations under 25 or over 65. Thus, we do not include lost earnings in the cost estimates for these age groups.

Two estimates of the direct medical costs of myocardial infarction are used. The first estimate is from Wittels, Hay, and Gotto (1990), which estimated expected total medical costs of MI over 5 years to be $51,211 (in 1986$) for people who were admitted to the hospital and survived hospitalization (there does not appear to be any discounting used). Using the CPI-U for medical care, the Wittels estimate is $109,474 in year 2000$. This estimated cost is based on a medical cost model, which incorporated therapeutic options, projected outcomes, and prices (using "knowledgeable cardiologists" as consultants). The model used medical data and medical decision algorithms to estimate the probabilities of certain events and/or medical procedures being used. The second estimate is from Russell et al. (1998), which estimated first-year direct medical costs of treating nonfatal myocardial infarction of $15,540 (in 1995$), and $1,051 annually thereafter. Converting to year 2000$, that would be $23,353 for a 5-year period (without discounting).

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[7] Gold et al. (1996) recommend not including lost earnings in the cost-of-illness estimates, suggesting that in some cases, they may be already be counted in the effectiveness measures. However, this requires that individuals fully incorporate the value of lost earnings and reduced labor force participation opportunities into their responses to time-tradeoff or standard-gamble questions. For the purposes of this analysis and for consistency with the way costs-of-illness are calculated for the benefit-cost analysis, we have assumed that individuals do not incorporate lost earnings in responses to these questions. This assumption can be relaxed in future analyses with improved understanding of how lost earnings are treated in preference elicitations.

The two estimates from these studies are substantially different, and we have not adequately resolved the sources of differences in the estimates. Because the wage-related opportunity cost estimates from Cropper and Krupnick (1990) cover a 5-year period, we used estimates for medical costs that similarly cover a 5-year period. We used a simple average of the two 5-year estimates, or $65,902, and add it to the 5-year opportunity cost estimate. The resulting estimates are given in Table G-13.

Table G-13: Estimated Costs Over a 5-Year Period (in 2000$) of a Nonfatal Myocardial Infarction

Age Group	*Opportunity Cost*	*Medical Cost*[a]	*Total Cost*
0 – 24	$0	$65,902	$65,902
25-44	$8,774[b]	$65,902	$74,676
45 – 54	$12,253[b]	$65,902	$78,834
55 – 65	$70,619[b]	$65,902	$140,649
>65	$0	$65,902	$65,902

[a] An average of the 5-year costs estimated by Wittels, Hay, and Gotto (1990) and Russell et al. (1998).

[b] From Cropper and Krupnick (1990), using a 3 percent discount rate.

The total avoided COI by age group associated with the reductions in CB and nonfatal acute myocardial infarctions is provided in Table G-14. Note that the total avoided COI associated with the revised PM NAAQS is $520 million and is $1,200 million for the more stringent alternative. Note that this does not include any direct avoided medical costs associated with premature mortality. Nor does it include any medical costs that occur more than 5 years from the onset of a nonfatal AMI. Therefore, this is likely an underestimate of the true avoided COI associated with strategies for attainment of the PM NAAQS.

Table G-14: Avoided Costs of Illness Associated with Reductions in Chronic Bronchitis and Nonfatal Acute Myocardial Infarctions Associated with Attainment Strategies for the Revised and More Stringent PM NAAQS in 2020

	Avoided Cost of Illness (in millions of 2000$)			
	Chronic Bronchitis		*Nonfatal Acute Myocardial Infarction*	
Age Range	*15/35 Attainment Strategy*	*14/35 Attainment Strategy*	*15/35 Attainment Strategy*	*14/34 Attainment Strategy*
18-24	—	—	$0.1	$0.3
25-34	$73	$120	$0.6	$1.9
35-44	$83	$140	$12	$20
45-54	$48	$84	$40	$71
55-64	$47	$85	$170	$290
65-74	$3.6	$6.7	$98	$160
75-84	$1.8	$3.3	$62	$120
85+	$0.8	$1.4	$33	$60
Total	$260	$450	$420	$730

G.7 Discount Rate Sensitivity Analysis

A large number of parameters and assumptions are necessary in conducting a CEA. Where appropriate and supported by data, we have included distributions of parameter values that were used in generating the reported confidence intervals. For the assumed discount rate, we felt it more appropriate to examine the impact of the assumption using a sensitivity analysis rather than through the integrated probabilistic uncertainty analysis.

The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the academic community. OMB and EPA guidance require using both a 7 percent rate and a 3 percent rate. In the most recent benefit-cost analyses of air pollution regulations, a 3 and 7 percent discount rate have been adopted in the primary analysis. A 3 percent discount rate reflects a "social rate of time preference" discounting concept. A 3 percent discount rate is also consistent with the recommendations of the NAS panel on CEA (Gold et al., 1996), which suggests that "a real annual (riskless) rate of 3 percent should be used in the Reference Case analysis." We have also calculated MILYs and the implicit cost thresholds using a 7 percent rate consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements. Further discussion of this topic appears in Chapter 7 of Gold et al. (1996), in Chapter 6 of the EPA *Guidelines for Economic Analysis*, and in OMB Circular A-4.

Table G-15: Summary of Results for the Illustrative Attainment Strategies for the Revised and More Stringent PM NAAQS in 2020[a]

	Result Using 3% Discount Rate (95% Confidence Interval)	
	15/35 Attainment Strategy	*14/35 Attainment Strategy*
Life years gained from mortality risk reductions	26,000 (18,000 – 34,000)	45,000 (32,000 – 59,000)
QALY gained from reductions in chronic bronchitis	12,000 (1,100 – 29,000)	22,000 (1,500 – 51,000)
QALY gained from reductions in acute myocardial infarctions	4,400 (1,200 – 9,100)	7,700 (2,000 – 16,000)
Total gain in MILYs	43,000 (28,000 – 62,000)	75,000 (48,000 – 110,000)
Avoided cost of illness		
Chronic bronchitis	$260 million ($170 million – $410 million)	$450 million ($290 million – $700 million)
Nonfatal AMI	$420 million ($230 million – $680 million)	$730 million ($400 million – $1,200 million)
Implementation strategy costs[b]	$5.4 billion	$7.0 billion
Net cost per MILY	$97,000 ($66,000 – $150,000)	$63,000 ($37,000 – $85,000)

[a] Consistent with recommendations of Gold et al. (1996), all summary results are reported at a precision level of two significant digits to reflect limits in the precision of the underlying elements.

[b] Costs are the private firm costs of control, as discussed in Chapter 6, and reflect discounting using firm specific costs of capital.

Table G-16 presents a summary of results using the 7 percent discount rate and the percentage difference between the 7 percent results and the base case 3 percent results. Adoption of a 7 percent discount rate decreases the estimated life years and QALYs gained from implementing the PM NAAQS. Adopting a discount rate of 7 percent results in a 35 percent reduction in the estimated total MILYs gained in each year, while the cost per MILY increases by approximately 60 percent.

Table G-16: Impacts of Using a 7 Percent Discount Rate on Cost Effectiveness Analysis for the Illustrative Attainment Strategies for the Revised and More Stringent PM NAAQS in 2020

	Result Using 7 Percent Discount Rate		*Percentage Change Relative to Result Using 3 Percent Discount Rate*	
	15/35 Attainment Strategy	*14/35 Attainment Strategy*	*15/35 Attainment Strategy*	*14/35 Attainment Strategy*
Life years gained from mortality risk reductions	16,000	29,000	–38%	–35%
QALY gained from reductions in chronic bronchitis	8,100	14,000	–32%	–36%
QALY gained from reductions in acute myocardial infarctions	3,500	6,000	–20%	–22%
Total gain in MILYs	28,000	49,000	–35%	–35%
Avoided cost of illness				
Chronic bronchitis	$170 million	$290 million	–35%	–35%
Nonfatal AMI	$410 million	$710 million	–3%	–3%
Net cost per MILY	$160,000	$100,000	+65%	+59%

G.8 Conclusions

We calculated the effectiveness of PM NAAQS attainment strategies based on reductions in premature deaths and incidence of chronic disease. We measured effectiveness using several different metrics, including lives saved, life years saved, and QALYs (for improvements in quality of life due to reductions in incidence of chronic disease). We suggested a new metric for aggregating life years saved and improvements in quality of life, morbidity inclusive life years (MILY) which assumes that society assigns a weight of one to years of life extended regardless of preexisting disabilities or chronic health conditions.

CEA of environmental regulations that have substantial public health impacts may be informative in identifying programs that have achieved cost-effective reductions in health impacts and can suggest areas where additional controls may be justified. However, the overall efficiency of a regulatory action can only be judged through a complete benefit-cost analysis that takes into account all benefits and costs, including both health and nonhealth effects. The benefit-cost analysis for the PM NAAQS attainment strategies, provided in Chapter 9, shows that the attainment strategies we modeled have potentially large net benefits, indicating that implementation of the revised PM NAAQS will likely result in improvements in overall public welfare.

G.9 References

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Appendix H: Additional Details on Benefits Methodologies

H.1 Methodology Used to Develop Threshold Adjusted Concentration-Response Functions

For mortality and morbidity outcomes associated with short-term exposure to $PM_{2.5}$, log-linear C-R functions are developed based on a continuous function from the epidemiological studies. Generally, the lowest measured concentrations in the short-term exposure studies were relatively near or below the estimated background levels such that little or no extrapolation of the C-R function is required beyond the range of data in the studies. Among the studies of mortality associated with long-term exposure to $PM_{2.5}$ that have been included in the benefits analysis, the lowest measured long-term levels were in the range 7.5 to 11 $\mu g/m^3$. For the base cases and sensitivity analyses we applied various alternative "cutpoint" models. While there are likely biological thresholds in individuals for specific health responses, the available epidemiological studies do not support or refute the existence of thresholds at the population level for either long-term or short-term PM exposures within the range of air quality observed in the studies. It may therefore be appropriate to consider health risks estimated not only with the reported linear or log-linear C-R functions, but also with modified functions that approximate non-linear, sigmoidal-shaped functions that would better reflect possible population thresholds. We approximated such sigmoidal functions by "hockeystick" functions based on the reported linear or log-linear functions. This approximation consisted of (1) imposing a cutpoint (i.e., an assumed threshold) on the original C-R function, that is intended to reflect an inflection point in a typical sigmoidal shaped function, below which there is little or no population response, and (2) adjusting the slope of the original C-R function above the cutpoint. This approach mirrors the approach used in the Particulate Matter Health Risk Assessment (Post et al., 2005).

If the researchers in the original study fit a log-linear or a linear model through data that actually better support a sigmoidal or "hockeystick" form, the slope of the fitted curve would be smaller than the slope of the upward-sloping portion of the "true" hockeystick relationship, as shown in Figure H-1a. The horizontal portion of the data below the cutpoint would essentially cause the estimated slope to be biased downward relative to the "true" slope of the upwardsloping portion of the hockeystick. The slope of the upward-sloping portion of the hockeystick model should therefore be adjusted upward (from the slope of the reported C-R function), as shown in Figure H-1a. This rationale applies equally in the case of mortality associated with long- and short-term exposure to PM. In each case, under the threshold hypothesis a log-linear curve has been fit to data that are better characterized by a hockeystick model. In the case of a short-term exposure mortality or morbidity study, the curve represents the relationship between daily PM and daily mortality or morbidity; in the case of a long-term exposure mortality study, the curve represents the relationship between annual average PM and annual mortality. In both cases, however, if the "true" relationship looks like a hockeystick, then the log-linear curve fitted to the data would understate the impact of increases in PM (either daily, in the case of a short-term study, or annual average, in the case of a long-term study) on mortality or morbidity at PM levels above the cutpoint.

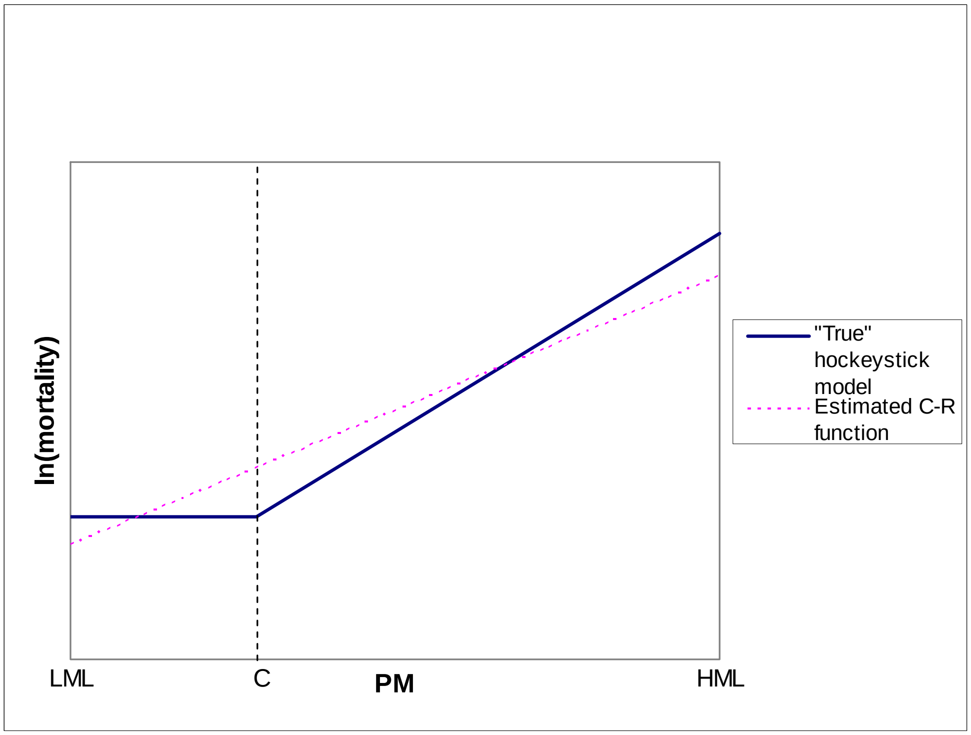


Figure H-1a. Relationship Between Estimated Log-Linear Concentration-Response Function and Hockeystick Model

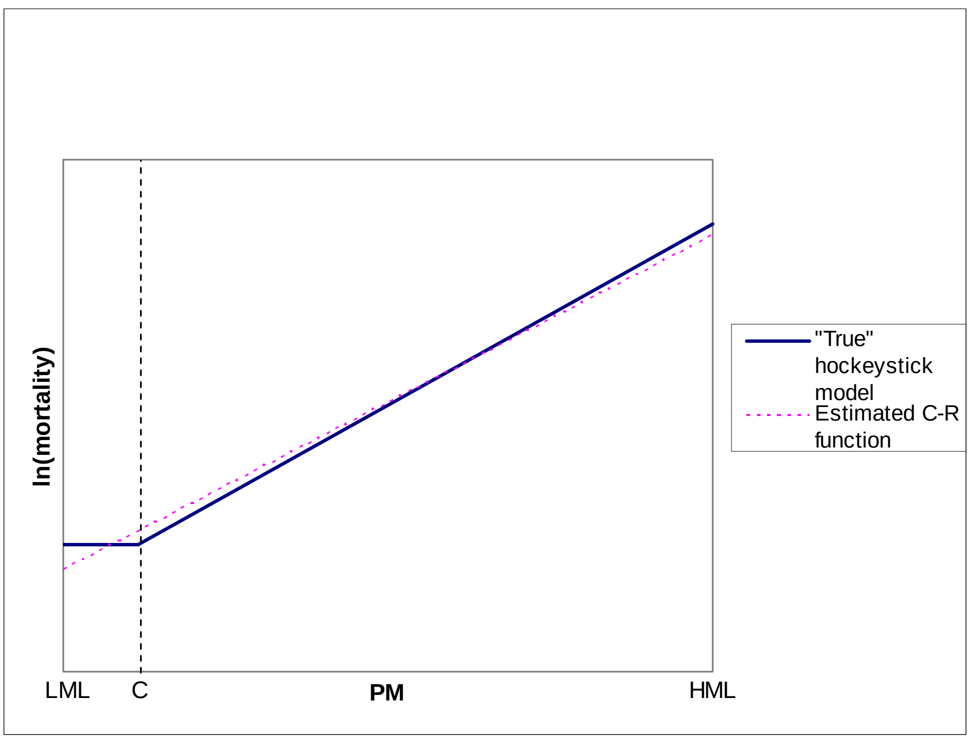


Figure H-1b. Relationship Between Estimated Log-Linear Concentration-Response Function and Hockeystick Model

If the data used in a study do not extend down below the cutpoint or extend only slightly below it, then the extent of the downward bias of the reported PM coefficient will be minimal. This is the case, for example, when the cutpoint is 10 μg/m^3 or 12 μg/m^3 for long-term exposure mortality, given that the lowest measured $PM_{2.5}$ levels in the long-term exposure mortality studies were 7.5, 10, or 11 μg/m^3. In this case, the data in the study provided hardly any information about the relationship between $PM_{2.5}$ and mortality at levels below the cutpoints and would have biased an estimate of the slope of the upward-sloping portion of a hockeystick only minimally if at all, as illustrated in Figure 2.1b.

We used a simple slope adjustment method based on the idea discussed above—that, if the data in the study were best described by a hockeystick model with a cutpoint at c, then the slope estimated in the study using a log-linear model would be approximately a weighted average of the two slopes of the hockeystick—namely, zero and the slope of the upward-sloping portion of the hockeystick. If we let

LML denote the lowest measured PM level in the study,

c denote the cutpoint,

HML denote the highest measured PM level in the study,

β^{est} denote the slope (the PM coefficient) estimated in the study (using a loglinear model), and

β^{T} denote the "true" slope of the upward-sloping portion of the hockeystick,

then, assuming the estimated coefficient reported by the study is (approximately) a weighted average of the slope below the cutpoint (0) and the slope above the cutpoint,

$$\beta^{est} = 0 * \frac{(c - LML)}{(HML - LML)} + \beta^{T} * \frac{(HML - c)}{(HML - LML)}$$

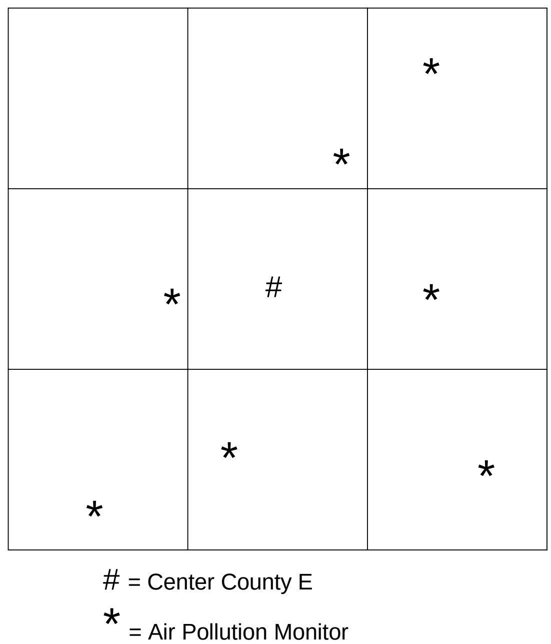
and, solving for β T,

$$\beta^{T} = \beta^{est} * \frac{(HML - LML)}{(HML - c)}$$

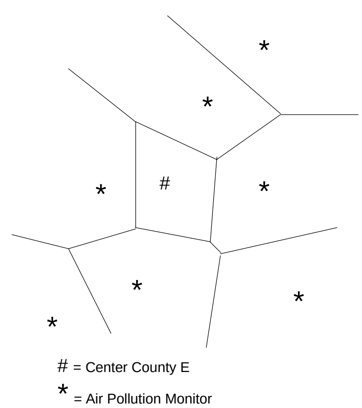
That is, the "true" slope of the upward-sloping portion of the hockeystick would be the slope estimated in the study (using a log-linear model rather than a hockeystick model) adjusted by the inverse of the proportion of the range of PM levels observed in the study that was above the cutpoint. Note that if the LML was below the estimated background level (or if it was not available for the study), the estimated background level was substituted for LML in the above equation. We believe that this slope adjustment method is a reasonable approach to estimating health effects under various assumed cutpoint models. A more definitive evaluation of the impact of alternative cutpoints and non-linear models is a subject that should be explored in further research.

H.2 Spatial Interpolation Method: Voronoi Neighbor Averaging

The first step in VNA is to identify the set of neighboring monitors for each grid cell in the Continental United States. The figure below presents nine grid cells and seven monitors, with the focus on identifying the set of neighboring monitors for grid cell E.

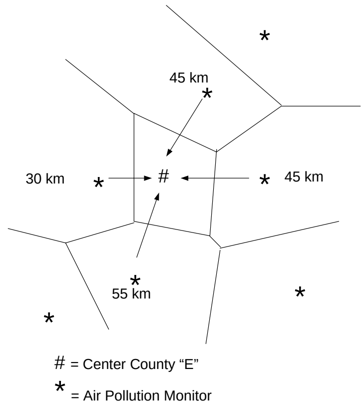


In particular, BenMAP identifies the nearest monitors, or "neighbors," by drawing a polygon, or Voronoi cell, around the center of each grid cell. The polygons have the special property that the boundaries are the same distance from the two closest points.



We then choose those monitors that share a boundary with the center of grid cell E. These are the nearest neighbors, and we use these monitors to estimate the air pollution level for this grid cell.

To estimate the air pollution level in each county, BenMAP calculates the PM metrics for each of the neighboring monitors, and then calculates an inverse-distance weighted average of the metrics. The further the monitor is from the grid cell center, the smaller the weight.



The weight for the monitor 30 kilometers from the center of grid cell E is calculated as follows:

$$weight_1 = \frac{\frac{1}{30}}{\left(\frac{1}{30} + \frac{1}{45} + \frac{1}{45} + \frac{1}{55}\right)} = 0.35$$

The weights for the other monitors would be calculated in a similar fashion. BenMAP would then calculate an inverse-distance weighted average of the nearest neighbors for grid cell E as follows:

Forecast = 0.35*80 μg + 0.23*90 μg+ 0.23*60 μg + 0.19*100 μg = 81.5 μg.

H.3 The Random/Fixed Effects Pooling Procedure

A common method for weighting estimates involves using their variances. Variance takes into account both the consistency of data and the sample size used to obtain the estimate, two key factors that influence the reliability of results. The exact way in which variances are used to weight the estimates from different studies in a pooled estimate depends on the underlying model assumed.

The fixed effects model assumes that there is a single true concentration-response relationship and therefore a single true value for the parameter β. Differences among β's reported by different studies are therefore simply the result of sampling error. That is, each reported β is an estimate of the *same underlying parameter*. The certainty of an estimate is reflected in its variance (the larger the variance, the less certain the estimate). Pooling that assumes a fixed effects model therefore weights each estimate under consideration in proportion to the *inverse* of its variance.

Suppose there are n studies, with the ith study providing an estimate β_i with variance v_i (I = 1, ..., n). Let

$$S = \sum_i \frac{1}{v_i},$$

denote the sum of the inverse variances. Then the weight, w_i, given to the ith estimate, β_i, is

$$w_i = \frac{1/v_i}{S}$$

This means that estimates with small variances (i.e., estimates with relatively little uncertainty surrounding them) receive large weights, and those with large variances receive small weights.

The estimate produced by pooling based on a fixed effects model, then, is just a weighted average of the estimates from the studies being considered, with the weights as defined above. That is,

$$\beta_{fe} = \sum_i w_i \beta_i$$

The variance associated with this pooled estimate is the inverse of the sum of the inverse variances:

$$v_{fe} = \frac{1}{\sum_i 1/v_i}$$

An alternative to the fixed effects model is the random effects model, which allows the possibility that the estimates β_i from the different studies may in fact be estimates of *different* parameters, rather than just different estimates of a single underlying parameter. In studies of the effects of ozone on mortality, for example, if the level of air conditioning use varies among study locations the underlying relationship between mortality and ozone may be different from one study location to another. If air conditioning use causes individuals to stay inside more on days with high ozone, then the mortality risk may be lower in areas with high prevalence of air conditioning. As such, one would expect the true value of β in cities with low air conditioning prevalence to be greater than the true value of β in cities with high air conditioning prevalence. This would violate the assumption of the fixed effects model.

The following procedure can test whether it is appropriate to base the pooling on the random effects model (vs. the fixed effects model):

A test statistic, Q_w, the weighted sum of squared differences of the separate study estimates from the pooled estimate based on the fixed effects model, is calculated as:

$$Q_w = \sum_i \frac{1}{v_i} \left(\beta_{fe} - \beta_i\right)^2$$

Under the null hypothesis that there is a single underlying parameter, β, of which all the β_i 's are estimates, Q_w has a chi-squared distribution with n-1 degrees of freedom. (Recall that n is the number of studies in the meta-analysis.) If Q_w is greater than the critical value corresponding to the desired confidence level, the null hypothesis is rejected. That is, in this case the evidence does not support the fixed effects model, and the random effects model is assumed, allowing the possibility that each study is estimating a different β.

The weights used in a pooling based on the random effects model must take into account not only the within-study variances (used in a meta-analysis based on the fixed effects model) but the between-study variance as well. These weights are calculated as follows:

Using Q_w, the between-study variance, η^2, is:

$$\eta^2 = \frac{Q_w - (n-1)}{\sum 1/v_i - \frac{\sum 1/v_i^2}{\sum 1/v_i}}$$

It can be shown that the denominator is always positive. Therefore, if the numerator is negative (i.e., if $Q_w < n-1$), then η^2 is a negative number, and it is not possible to calculate a random effects estimate. In this case, however, the small value of Q_w would presumably have led to accepting the null hypothesis described above, and the meta-analysis would be based on the fixed effects model. The remaining discussion therefore assumes that η^2 is positive.

Given a value for η^2, the random effects estimate is calculated in almost the same way as the fixed effects estimate. However, the weights now incorporate both the within-study variance (v_i) and the between-study variance (η^2). Whereas the weights implied by the fixed effects model used only v_i, the within-study variance, the weights implied by the random effects model use $v_i + \eta^2$.

Let $v_i^* = v_i + \eta^2$. Then

$$S^* = \sum_i \frac{1}{v_i^*}$$

and

$$w_i^* = \frac{1/v_i^*}{S^*}$$

The estimate produced by pooling based on the random effects model, then, is just a weighted average of the estimates from the studies being considered, with the weights as defined above. That is,

$$\beta_{rand} = \sum_i w_i^* \times \beta_i$$

The variance associated with this random effects pooled estimate is, as it was for the fixed effects pooled estimate, the inverse of the sum of the inverse variances:

$$v_{rand} = \frac{1}{\sum_i 1/v_i^*}$$

The weighting scheme used in a pooling based on the random effects model is basically the same as that used if a fixed effects model is assumed, but the variances used in the calculations are different. This is because a fixed effects model assumes that the variability among the estimates from different studies is due only to sampling error (i.e., each study is thought of as representing just another sample from the same underlying population), while the random effects model assumes that there is not only sampling error associated with each study, but that there is also *between-study* variability—each study is estimating a different underlying β. Therefore, the sum of the within-study variance and the between-study variance yields an overall variance estimate.

Weights can be derived for pooling incidence changes predicted by different studies, using either the fixed effects or the random effects model, in a way that is analogous to the derivation of weights for pooling the β's in the C-R functions. For a given change in pollutant level and a given baseline incidence rate, corresponding to every possible value of β, there is an incidence change. Corresponding to β_i, with variance v_i (calculated from the reported standard error of β_i,) from the ith study, there is therefore an estimate of incidence change, I_i, with variance $v(I)_i$. In practice, we generate a sample mean and a sample variance of incidence changes by calculating an incidence change for each of many β's pulled from the distribution of β's for the study.

This can be done either using Monte Carlo methods (making many random pulls) or by a Latin Hypercube approach, in which we pull the nth percentile β from the distribution of β's, for, e.g., n = 2.5, 7.5, ..., 97.5. Either way, the result is a corresponding sample distribution of incidence changes that would be predicted by the study, from which we calculate the sample mean and the sample variance. The sample means of incidence change from the studies to be pooled are used in exactly the same way as the reported β's are used in the discussion of fixed effects and random effects models above. The sample variances of incidence change are used in the same way as the variances of the β's. The formulas above for calculating fixed effects weights, for testing the fixed effects hypothesis, and for calculating random effects weights can all be used by substituting the sample mean incidence change for the ith study for β_i and the sample variance of incidence change for the ith study for v_i.

Appendix I: Visibility Benefits Methodology

Visibility degradation estimates used in this analysis are generated by the CMAQ model. To conduct the visibility benefits analysis, however, we need visibility data at the county level. To convert CMAQ visibility data from the square grid to the county level, we use the following rule: if a county center falls within a given CMAQ grid cell, we assign that CMAQ grid cell's visibility values to that county. Because the modeled air quality-related changes in visibility are directly used in the benefits analysis, the methodology for predicting visibility changes is not discussed here. The visibility estimation procedure is described in detail in EPA (2000), and is based on the methods in Sisler (1996).

Economic benefits may result from two broad categories of visibility changes: (1) changes in "residential" visibility—i.e., the visibility in and around the locations where people live; and (2) changes in "recreational" visibility at Class I areas—i.e., visibility at Class I national parks and wilderness areas.[1] In this analysis, only those recreational benefits in Class I areas that have been directly studied (in California, the Southeast, and the Southwest) are included in the primary presentation of benefits; residential benefits and recreational benefits in all U.S. Class I areas are presented as alternative calculations of visibility benefits.

Within the category of recreational visibility, further distinctions have been made. There is evidence (Chestnut and Rowe, 1990) that an individual's WTP for improvements in visibility at a Class I area is influenced by whether it is in the region in which the individual lives, or whether it is somewhere else. In general people appear to be willing to pay more for visibility improvements at parks and wilderness areas that are "in-region" than at those that are "out-of-region." This is plausible, because people are more likely to visit, be familiar with, and care about parks and wilderness areas in their own part of the country.

To value estimated visibility changes, we are using an approach consistent with economic theory. Below we discuss an application of the Constant Elasticity of Substitution (CES) utility function approach[2] to value both residential visibility improvements and visibility improvements at Class I areas in the United States. This approach is based on the preference calibration method developed by Smith, Van Houtven, and Pattanayak (1999). The presentation of this methodology is organized as follows. The basic utility model is presented in Section I.1. In Section I.2 we discuss the measurement of visibility, and the mapping from environmental "bads" to environmental "goods." In Sections I.3 and I.4 we summarize the information that is available to estimate the parameters of the model corresponding to visibility at in-region and out-of-region Class I areas, and visibility in residential areas, respectively, and we describe the methods used to estimate these parameters. Section I.5 synthesizes the results.

[1] Hereafter referred to as Class I areas, which are defined as areas of the country such as national parks, national wilderness areas, and national monuments that have been set aside under Section 162(a) of the Clean Air Act to receive the most stringent degree of air quality protection. Class I federal lands fall under the jurisdiction of three federal agencies, the National Park Service, the Fish and Wildlife Service, and the Forest Service.

[2] The constant elasticity of substitution utility function has been chosen for use in this analysis because of its flexibility when illustrating the degree of substitutability present in various economic relationships (in this case, the trade-off between income and improvements in visibility).

I.1 Basic Utility Model

We begin with a CES utility function in which a household derives utility from

(1) "all consumption goods," X,

(2) visibility in the residential area in which the household is located ("residential visibility"),[3]

(3) visibility at Class I areas in the same region as the household ("in-region recreational visibility"), and

(4) visibility at Class I areas outside the household's region ("out-of-region recreational visibility").

There are a total of six regions being considered, so there are five regions for which any household is out of region. The utility function of a household in the n^{th} residential area and the ith region of the country is:

$$U_{ni} = (X^{\rho} + \theta Z_n^{\rho} + \sum_{k=1}^{N_i} \gamma_{ik} Q_{ik}^{\rho} + \sum_{j \neq i} \sum_{k=1}^{N_j} \delta_{jk} Q_{jk}^{\rho})^{1/\rho} \quad ,$$
$$\theta > 0, \gamma_{ik} > 0, \forall i,k, \delta_{jk} > 0, \forall j,k, \ \rho \leq 1.$$

where

Z_n = the level of visibility in the nth residential area;

Q_{ik} = the level of visibility at the k^{th} in-region park (i.e., the kth park in the ith region);

Q_{jk} = the level of visibility at the k^{th} park in the j^{th} region (for which the household is out of region), $j \neq i$;

N_i = the number of Class I areas in the i^{th} region;

N_j = the number of Class I areas in the j^{th} region (for which the household is out of region), $j \neq i$; and

θ, the γ's and δ's are parameters of the utility function corresponding to the visibility levels at residential areas and at in-region and out-of-region Class I areas, respectively.

In particular, the γ_{ik}'s are the parameters corresponding to visibility at in-region Class I areas; the δ_1's are the parameters corresponding to visibility at Class I areas in region 1 (California), if $i \neq 1$; the δ_2's are the parameters corresponding to visibility at Class I areas in region 2 (Colorado Plateau), if $i \neq 2$, and so forth. Because the model assumes that the relationship between residential visibility and utility is the same everywhere, there is only one θ. The parameter ρ in this CES utility function is an important determinant of the slope of the marginal WTP curve

[3]We remind the reader that, although residential and recreational visibility benefits estimation is discussed simultaneously in this section, benefits are calculated and presented separately for each visibility category.

associated with any of the environmental quality variables. When ρ=1, the marginal WTP curve is horizontal. When ρ<1, it is downward sloping.

The household's budget constraint is:

$$m - p \cdot X \leq 0 \ ,$$

where m is income, and p is the price of X. Without loss of generality, set p = 1. The only choice variable is X. The household maximizes its utility by choosing X=m. The indirect utility function for a household in the n^{th} residential area and the ith region is therefore

$$V_{ni}(m, Z_n, Q; \theta, \gamma, \delta, \rho) = (m^\rho + \theta Z_n^\rho + \sum_{k=1}^{N_i} \gamma_{ik} Q_{ik}^\rho + \sum_{j \neq i} \sum_{k=1}^{N_j} \delta_{jk} Q_{jk}^\rho)^{1/\rho} \quad ,$$

where Q denotes the vector of vectors, Q_1, Q_2, Q_3, Q_4, Q_5, and Q_6, and the unsubscripted γ and δ denote vectors as well.

Given estimates of ρ, θ, the γ's and the δ's, the household's utility function and the corresponding WTP functions are fully specified. The household's WTP for any set of changes in the levels of visibility at in-region Class I areas, out-of-region Class I areas, and the household's residential area can be shown to be:

$$WTP_{ni}(\Delta Z, \Delta Q) = m - [m^\rho + \theta(Z_{0n}^\rho - Z_{1n}^\rho) + \sum_{k=1}^{N_i} \gamma_{ik}(Q_{0ik}^\rho - Q_{1ik}^\rho) + \sum_{j \neq i} \sum_{k=1}^{N_j} \delta_{jk}(Q_{0jk}^\rho - Q_{1jk}^\rho)]^{1/\rho} \quad .$$

The household's WTP for a single visibility improvement will depend on its order in the series of visibility improvements the household is valuing. If it is the first visibility improvement to be valued, the household's WTP for it follows directly from the previous equation. For example, the household's WTP for an improvement in visibility at the first in-region park, from $Q_{i1} = Q_{0i1}$ to $Q_{i1} = Q_{1i1}$, is

$$WTP(\Delta Q_{i1}) = m - [m^\rho + \gamma_{i1}(Q_{0i1}^\rho - Q_{1i1}^\rho)]^{1/\rho} \quad ,$$

if this is the first (or only) visibility change the household values.

I.2 Measure of Visibility: Environmental "Goods" Versus "Bads"

In the above model, Q and Z are environmental "goods." As the level of visibility increases, utility increases. The utility function and the corresponding WTP function both have reasonable properties. The first derivative of the indirect utility function with respect to Q (or Z) is positive; the second derivative is negative. WTP for a change from Q_0 to a higher (improved) level of visibility, Q_1, is therefore a concave function of Q_1, with decreasing marginal WTP.

The measure of visibility that is currently preferred by air quality scientists is the deciview, which increases as visibility *decreases*. Deciview, in effect, is a measure of the *lack* of visibility. As deciviews increase, visibility, and therefore utility, decreases. The deciview, then, is a measure of an environmental "bad." There are many examples of environmental "bads"—all types of pollution are environmental "bads." Utility decreases, for example, as the concentration of particulate matter in the atmosphere increases.

One way to value decreases in environmental bads is to consider the "goods" with which they are associated, and to incorporate those goods into the utility function. In particular, if B denotes an environmental "bad," such that:

$$\frac{\partial V}{\partial B} < 0 \ ,$$

and the environmental "good," Q, is a function of B,

$$Q = F(B) \ ,$$

then the environmental "bad" can be related to utility via the corresponding environmental "good":[4]

$$V = V(m, Q) = V(m, F(B)) \ .$$

The relationship between Q and B, F(B), is an empirical relationship that must be estimated.

There is a potential problem with this approach, however. If the function relating B and Q is not the same everywhere (i.e., if for a given value of B, the value of Q depends on other factors as well), then there can be more than one value of the environmental good corresponding to any given value of the environmental bad, and it is not clear which value to use. This has been identified as a problem with translating deciviews (an environmental "bad") into visual range (an environmental "good"). It has been noted that, for a given deciview value, there can be many different visual ranges, depending on the other factors that affect visual range—such as light angle and altitude. We note here, however, that this problem is not unique to visibility, but is a general problem when trying to translate environmental "bads" into "goods."[5]

In order to translate deciviews (a "bad") into visual range (a "good"), we use a relationship derived by Pitchford and Malm (1994) in which

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[4] There may be more than one "good" related to a given environmental "bad." To simplify the discussion, however, we assume only a single "good."

[5] Another example of an environmental "bad" is particulate matter air pollution (PM). The relationship between survival probability (Q) and the ambient PM level is generally taken to be of the form

$Q = 1 - \alpha e^{\beta PM}$. where α denotes the mortality rate (or level) when there is no ambient PM (i.e., when PM=0). However, α is implicitly a function of all the factors other than PM that affect mortality. As these factors change (e.g., from one location to another), α will change (just as visual range changes as light angle changes). It is therefore possible to have many values of Q corresponding to a given value of PM, as the values of α vary.

$$DV = 10 * ln(\frac{391}{VR}),$$

where DV denotes deciview and VR denotes visual range (in kilometers). Solving for VR as a function of DV yields

$$VR = 391 * e^{-0.1DV} \quad .$$

This conversion is based on specific assumptions characterizing the "average" conditions of those factors, such as light angle, that affect visual range. To the extent that specific locations depart from the average conditions, the relationship will be an imperfect approximation.[6]

I.3 Estimating the Parameters for Visibility at Class I Areas: the γ's and δ's

As noted in Section 2, if we consider a particular visibility change as the first or the only visibility change valued by the household, the household's WTP for that change in visibility can be calculated, given income (m), the "shape" parameter, ρ, and the corresponding recreational visibility parameter. For example, a Southeast household's WTP for a change in visibility at in-region parks (collectively) from $Q_1 = Q_{01}$ to $Q_1 = Q_{11}$ is:

$$WTP(DQ_1) = m - [m^r + g_1(Q_{01}^r - Q_{11}^r)]^{1/r}$$

if this is the first (or only) visibility change the household values.

Alternatively, if we have estimates of m as well as WTP_1^{in} and WTP_1^{out} of in-region and out-of-region households, respectively, for a given change in visibility from Q_{01} to Q_{11} in Southeast parks, we can solve for γ_1 and δ_1 as a function of our estimates of m, WTP_1^{in} and WTP_1^{out}, for any given value of ρ. Generalizing, we can derive the values of γ and δ for the j^{th} region as follows:

$$\gamma_j = \frac{(m - WTP_j^{in})^\rho - m^\rho}{(Q_{0j}^\rho - Q_{1j}^\rho)}$$

and

$$\delta_j = \frac{(m - WTP_j^{out})^\rho - m^\rho}{(Q_{0j}^\rho - Q_{1j}^\rho)} \quad .$$

Chestnut and Rowe (1990) and Chestnut (1997) estimated WTP (per household) for specific visibility changes at national parks in three regions of the United States—both for households that are in-region (in the same region as the park) and for households that are out-of-region. The Chestnut and Rowe study asked study subjects what they would be willing to pay for each of three visibility improvements in the national parks in a given

[6] Ideally, we would want the location-, time-, and meteorological condition-specific relationships between deciviews and visual range, which could be applied as appropriate. This is probably not feasible, however.

region. Study subjects were shown a map of the region, with dots indicating the locations of the parks in question. The WTP questions referred to the three visibility improvements in all the parks collectively; the survey did not ask subjects' WTP for these improvements in specific parks individually. Responses were categorized according to whether the respondents lived in the same region as the parks in question ("in-region" respondents) or in a different region ("out-of-region" respondents). The areas for which in-region and out-of-region WTP estimates are available from Chestnut and Rowe (1990), and the sources of benefits transfer-based estimates that we employ in the absence of estimates, are summarized in Table I-1. In all cases, WTP refers to WTP per household.

Table I-1: Available Information on WTP for Visibility Improvements in National Parks

	Region of Household	
Region of Park	*In Region*[a]	*Out of Region*[b]
1. California	WTP estimate from study	WTP estimate from study
2. Colorado Plateau	WTP estimate from study	WTP estimate from study
3. Southeast United States	WTP estimate from study	WTP estimate from study
4. Northwest United States	(based on benefits transfer from California)	
5. Northern Rockies	(based on benefits transfer from Colorado Plateau)	
6. Rest of United States	(based on benefits transfer from Southeast U.S.)	

[a] In-region" WTP is WTP for a visibility improvement in a park in the same region as that in which the household is located. For example, in-region WTP in the "Southeast" row is the estimate of the average Southeast household's WTP for a visibility improvement in a Southeast park.

[b] Out-of-region" WTP is WTP for a visibility improvement in a park that is not in the same region in which the household is located. For example, out-of-region WTP in the "Southeast" row is the estimate of WTP for a visibility improvement in a park in the Southeast by a household outside of the Southeast.

In the primary calculation of visibility benefits for this analysis, only visibility changes at parks within visibility regions for which a WTP estimate was available from Chestnut and Rowe (1990) are considered (for both in- and out-of-region benefits). Primary estimates will not include visibility benefits calculated by transferring WTP values to visibility changes at parks not included in the Chestnut and Rowe study. Transferred benefits at parks located outside of the Chestnut and Rowe visibility regions will, however, be included as an alternative calculation.

The values of the parameters in a household's utility function will depend on where the household is located. The region-specific parameters associated with visibility at Class I areas (that is, all parameters except the residential visibility parameter) are arrayed in Table I-2. The parameters in columns 1 through 3 can be directly estimated using WTP estimates from Chestnut and Rowe (1990) (the columns labeled "Region 1," "Region 2," and "Region 3").

For the three regions covered in Chestnut and Rowe (1990) (California, the Colorado Plateau, and the Southeast United States), we can directly use the in-region WTP estimates from the study to estimate the parameters in the utility functions corresponding to visibility at in-region parks (γ_1); similarly, we can directly use the out-of-region WTP estimates from the study to estimate the parameters for out-of-region parks (δ_1). For the other three regions not covered in the study, however, we must rely on benefits transfer to estimate the necessary parameters.

Table I-2: Summary of Region-Specific Recreational Visibility Parameters to be Estimated in Household Utility Functions

	Region of Park					
Region of Household	*Region 1*	*Region 2*	*Region 3*	*Region 4*	*Region 5*	*Region 6*
Region 1	γ_1[a]	δ_2	δ_3	δ_4	δ_5	δ_6
Region 2	δ_1	γ_2	δ_3	δ_4	δ_5	δ_6
Region 3	δ_1	δ_2	γ_3	δ_4	δ_5	δ_6
Region 4	δ_1	δ_2	δ_3	γ_4	δ_5	δ_6
Region 5	δ_1	δ_2	δ_3	δ_4	γ_5	δ_6
Region 6	δ_1	δ_2	δ_3	δ_4	δ_5	γ_6

[a] The parameters arrayed in this table are region specific rather than park specific or wilderness area specific. For example, δ_1 is the parameter associated with visibility at " Class I areas in region 1" for a household in any region other than region 1. The benefits analysis must derive Class I area-specific parameters (e.g., δ_{1k}, for the kth Class I area in the first region).

While Chestnut and Rowe (1990) provide useful information on households' WTP for visibility improvements in national parks, there are several significant gaps remaining between the information provided in that study and the information necessary for the benefits analysis. First, as noted above, the WTP responses were not park specific, but only region specific. Because visibility improvements vary from one park in a region to another, the benefits analysis must value park-specific visibility changes. Second, not all Class I areas in each of the three regions considered in the study were included on the maps shown to study subjects. Because the focus of the study was primarily national parks, most Class I wilderness areas were not included. Third, only three regions of the United States were included, leaving the three remaining regions without direct WTP estimates.

In addition, Chestnut and Rowe (1990) elicited WTP responses for *three different* visibility changes, rather than a single change. In theory, if the CES utility function accurately describes household preferences, and if all households in a region have the same preference structure, then households' three WTP responses corresponding to the three different visibility changes should all produce the same value of the associated recreational visibility parameter, given a value of ρ and an income, m. In practice, of course, this is not the case.

In addressing these issues, we take a three-phase approach:

(1) We estimate region-specific parameters for the region in the modeled domain covered by Chestnut and Rowe (1990) (California, the Colorado Plateau, and the Southeast)— γ_1, γ_2, and γ_3 and δ_1, δ_2, and δ_3.

(2) We infer region-specific parameters for those regions not covered by the Chestnut and Rowe study (the Northwest United States, the Northern Rockies, and the rest of the United States)— γ_4, γ_5, and γ_6 and δ_4, δ_5, and δ_6.

(3) We derive park- and wilderness area-specific parameters within each region (γ_{1k} and δ_{1k}, for k=1, ..., N_1; γ_{2k} and δ_{2k}, for k=1, ..., N_2; and so forth).

The question that must be addressed in the first phase is how to estimate a single region-specific in-region parameter and a single region-specific out-of-region parameter for each of the three regions covered in Chestnut and Rowe (1990) from study respondents' WTPs for *three different* visibility changes in each region. All parks in a region are treated collectively as if they were a single "regional park" in this first phase. In the second phase, we infer region-specific recreational visibility parameters for regions not covered in the Chestnut and Rowe study (the Northwest United States, the Northern Rockies, and the rest of the United States). As in the first phase, we ignore the necessity to derive park-specific parameters at this phase. Finally, in the third phase, we derive park- and wilderness area-specific parameters for each region.

I.3.1 Estimating Region-Specific Recreational Visibility Parameters for the Region Covered in the Chestnut and Rowe Study (Regions 1, 2, and 3)

Given a value of ρ and estimates of m and in-region and out-of-region WTPs for a change from Q_0 to Q_1 in a given region, the in-region parameter, γ, and the out-of-region parameter, δ, for that region can be solved for. Chestnut and Rowe (1990), however, considered not just one, but three visibility changes in each region, each of which results in a different calibrated γ and a different calibrated δ, even though in theory all the γ's should be the same and similarly, all the δ's should be the same. For each region, however, we must have only a single γ and a single δ.

Denoting $\hat{\gamma}_j$ as our estimate of γ for the j^{th} region, based on all three visibility changes, we chose $\hat{\gamma}_j$ to best predict the three WTPs observed in the study for the three visibility improvements in the j^{th} region. First, we calculated $\hat{\gamma}_{ji}$, i=1, 2, 3, corresponding to each of the three visibility improvements considered in the study. Then, using a grid search method beginning at the average of the three's $\hat{\gamma}_{ji}$, we chose to minimize the sum of the squared differences between the WTPs we predict using $\hat{\gamma}_j$ and the three region-specific WTPs observed in the study. That is, we selected to minimize:

$$\sum_{i=1}^{3} (WTP_{ij}(\hat{\gamma}_j) - WTP_{ij})^2$$

where WTP_{ij} and $WTP_{ij}()$ are the observed and the predicted WTPs for a change in visibility in the j^{th} region from $Q_0 = Q_{0i}$ to $Q_1 = Q_{1i}$, i=1, ..., 3. An analogous procedure was used to select an optimal δ, for each of the three regions in the Chestnut and Rowe study.

I.3.2 Inferring Region-Specific Recreational Visibility Parameters for Regions Not Covered in the Chestnut and Rowe Study (Regions 4, 5, and 6)

One possible approach to estimating region-specific parameters for regions not covered by Chestnut and Rowe (1990) (γ_4, γ_5, and γ_6 and δ_4, δ_5, and δ_6) is to simply assume that households' utility functions are the same everywhere, and that the environmental goods being valued are the same—e.g., that a change in visibility at national parks in California is the same environmental good to a Californian as a change in visibility at national parks in Minnesota is to a Minnesotan.

For example, to estimate δ_4 in the utility function of a California household, corresponding to visibility at national parks in the Northwest United States, we might assume that out-of-region WTP for a given visibility change at national parks in the Northwest United States is the same as out-of-region WTP for the same visibility change at national parks in California (income held constant). Suppose, for example, that we have an estimated mean WTP of out-of-region households for a visibility change from Q_{01} to Q_{11} at national parks in California (region 1), denoted WTP_1^{out}. Suppose the mean income of the out-of-region subjects in the study was m. We might assume that, for the same change in visibility at national parks in the Northwest United States, $WTP_4^{out} = WTP_1^{out}$ among out-of-region individuals with income m.

We could then derive the value of δ_4, given a value of ρ as follows:

$$\delta_4 = \frac{(m - WTP_4^{out})^{\rho} - m^{\rho}}{Q_{04}^{\rho} - Q_{14}^{\rho}}$$

where $Q_{04} = Q_{01}$ and $Q_{14} = Q_{11}$, (i.e., where it is *the same* visibility change in parks in region 4 that was valued at parks in the region 1).

This benefits transfer method assumes that (1) all households have the same preference structures and (2) what is being valued in the Northwest United States (by a California household) is the same as what is being valued in the California (by all out-of-region households). While we cannot know the extent to which the first assumption approximates reality, the second assumption is clearly problematic. National parks in one region are likely to differ from national parks in another region in both quality and quantity (i.e., number of parks).

One statistic that is likely to reflect both the quality and quantity of national parks in a region is the average annual visitation rate to the parks in that region. A reasonable way to gauge the extent to which out-of-region people would be willing to pay for visibility changes in parks in the Northwest United States versus in California might be to compare visitation rates in the two regions.[7] Suppose, for example, that twice as many visitor-days are spent in California parks per year as in parks in the Northwest United States per year. This could be an indication that the parks in California are in some way more desirable than those in the Northwest United States and/or that there are more of them—i.e., that the environmental goods being valued in the two regions ("visibility at national parks") are not the same.

A preferable way to estimate δ_4, then, might be to assume the following relationship:

$$\frac{WTP_4^{out}}{WTP_1^{out}} = \frac{n_4}{n_1}$$

(income held constant), where n_1 = the average annual number of visitor-days to California parks and n_4 = the average annual number of visitor-days to parks in the Northwest United States. This implies that

[7] We acknowledge that reliance on visitation rates does not get at nonuse value.

$$WTP_4^{out} = \frac{n_4}{n_1} * WTP_1^{out}$$

for the same change in visibility in region 4 parks among out-of-region individuals with income m. If, for example, $n_1 = 2n_4$, WTP_4^{out} would be half of WTP_1^{out}. The interpretation would be the following: California national parks have twice as many visitor-days per year as national parks in the Northwest United States; therefore they must be twice as desirable/plentiful; therefore, out-of-region people would be willing to pay twice as much for visibility changes in California parks as in parks in the Northwest United States; therefore a Californian would be willing to pay only half as much for a visibility change in national parks in the Northwest United States as an out-of-region individual would be willing to pay for the same visibility change in national parks in California. This adjustment, then, is based on the premise that the environmental goods being valued (by people out of region) are not the same in all regions.

The parameter δ_4 is estimated as shown above, using this adjusted WTP_4^{out}. The same procedure is used to estimate δ_5 and δ_6. We estimate γ_4, γ_5, and γ_6 in an analogous way, using the in-region WTP estimates from the transfer regions, e.g.,

$$WTP_4^{in} = \frac{n_4}{n_1} * WTP_1^{in} \quad .$$

I.3.3 Estimating Park- and Wilderness Area-Specific Parameters

As noted above, Chestnut and Rowe (1990) estimated WTP for a region's national parks collectively, rather than providing park-specific WTP estimates. The γ's and δ's are therefore the parameters that would be in household utility functions if there were only a single park in each region, or if the many parks in a region were effectively indistinguishable from one another. Also noted above is the fact that the Chestnut and Rowe study did not include all Class I areas in the regions it covered, focusing primarily on national parks rather than wilderness areas. Most Class I wilderness areas were not represented on the maps shown to study subjects. In California, for example, there are 31 Class I areas, including 6 national parks and 25 wilderness areas. The Chestnut and Rowe study map of California included only 10 of these Class I areas, including all 6 of the national parks. It is unclear whether subjects had in mind "all parks and wilderness areas" when they offered their WTPs for visibility improvements, or whether they had in mind the specific number of (mostly) parks that were shown on the maps. The derivation of park- and wilderness area-specific parameters depends on this.

I.3.4 Derivation of Region-Specific WTP for National Parks and Wilderness Areas

If study subjects were lumping all Class I areas together in their minds when giving their WTP responses, then it would be reasonable to allocate that WTP among the specific parks and wilderness areas in the region to derive park- and wilderness area-specific γ's and δ's for the region. If, on the other hand, study subjects were thinking only of the (mostly) parks shown on the map when they gave their WTP response, then there are two possible approaches that could be taken. One approach assumes that households would be willing to pay some additional amount for the same visibility improvement in additional Class I areas that were not shown, and that this additional amount can be estimated using the same benefits transfer approach used to estimate region-specific WTPs in regions not covered by Chestnut and Rowe (1990).

However, even if we believe that households would be willing to pay some additional amount for the same visibility improvement in additional Class I areas that were not shown, it is open to question whether this additional amount can be estimated using benefits transfer methods. A third possibility, then, is to simply omit wilderness areas from the benefits analysis. For this analysis we calculate visibility benefits assuming that study subjects lumped all Class I areas together when stating their WTP, even if these Class I areas were not present on the map.

I.3.5 Derivation of Park- and Wilderness Area-Specific WTPs, Given Region-Specific WTPs for National Parks and Wilderness Areas

The first step in deriving park- and wilderness area-specific parameters is the estimation of park- and wilderness area-specific WTPs. To derive park and wilderness area-specific WTPs, we apportion the region-specific WTP to the specific Class I areas in the region according to each area's share of the region's visitor-days. For example, if WTP_1^{in} and WTP_1^{out} denote the mean household WTPs in the Chestnut and Rowe (1990) study among respondents who were in-region-1 and out-of-region-1, respectively, n_{1k} denotes the annual average number of visitor-days to the kth Class I area in California, and n_1 denotes the annual average number of visitor-days to all Class I areas in California (that are included in the benefits analysis), then we assume that

$$WTP_{1k}^{in} = \frac{n_{1k}}{n_1} * WTP_1^{in} ,$$

and

$$WTP_{1k}^{out} = \frac{n_{1k}}{n_1} * WTP_1^{out} .$$

Using WTP_j^{in} and WTP_j^{out}, either from the Chestnut and Rowe study (for j = 1, 2, and 3) or derived by the benefits transfer method (for j = 4, 5, and 6), the same method is used to derive Class I area-specific WTPs in each of the six regions.

While this is not a perfect allocation scheme, it is a reasonable scheme, given the limitations of data. Visitors to national parks in the United States are not all from the United States, and certainly not all from the region in which the park is located. A very large proportion of the visitors to Yosemite National Park in California, for example, may come from outside the United States. The above allocation scheme implicitly assumes that the relative frequencies of visits to the parks in a region *from everyone in the world* is a reasonable index of the relative WTP of an average household in that region (WTP_j^{in}) or out of that region (but in the United States) (WTP_j^{out}) for visibility improvements at these parks.[8]

[8] This might be thought of as two assumptions: (1) that the relative frequencies of visits to the parks in a region *from everyone in the world* is a reasonable representation of the relative frequency of visits *from people in the United States*—i.e., that the parks that are most popular (receive the most visitors per year) in general are also the

A possible problem with this allocation scheme is that the relative frequency of visits is an indicator of use value but not necessarily of nonuse value, which may be a substantial component of the household's total WTP for a visibility improvement at Class I areas. If park A is twice as popular (i.e., has twice as many visitors per year) as park B, this does not necessarily imply that a household's WTP for an improvement in visibility at park A is twice its WTP for the same improvement at park B. Although an allocation scheme based on relative visitation frequencies has some obvious problems, however, it is still probably the best way to allocate a collective WTP.

I.3.6 Derivation of Park- and Wilderness Area-Specific Parameters, Given Park- and Wilderness Area-Specific WTPs

Once the Class I area-specific WTPs have been estimated, we could derive the park- and wilderness area-specific γ's and δ's using the method used to derive region-specific γ's and δ's. Recall that method involved (1) calibrating γ and δ to each of the three visibility improvements in the Chestnut and Rowe study (producing three γ's and three δ's), (2) averaging the three γ's and averaging the three δ's, and finally, (3) using these average γ and δ as starting points for a grid search to find the optimal γ and the optimal δ—i.e., the γ and δ that would allow us to reproduce, as closely as possible, the three in-region and three out-of-region WTPs in the study for the three visibility changes being valued.

Going through this procedure for each national park and each wilderness area separately would be very time consuming, however. We therefore used a simpler approach, which produces very close approximations to the γ's and δ's produced using the above approach. If:

WTP_j^{in} = the in-region WTP for the change in visibility from Q_0 to Q_1 in the j^{th} region;

WTP_{jk}^{in} = the in-region WTP for the same visibility change (from Q_0 to Q_1) in the k^{th} Class I area in the jth region (= $s_{jk}*WTP_j^{in}$, where s_{jk} is the k^{th} area's share of visitor-days in the j^{th} region);

m = income;

γ_j* = the optimal value of γ for the jth region; and

γ_{jk} = the value of γ_{jk} calibrated to WTP_{jk}^{in} and the change from Q_0 to Q_1;

then[9]:

$$\gamma_j^* \approx \frac{(m - WTP_j^{in})^\rho - m^\rho}{(Q_0^\rho - Q_1^\rho)}$$

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most popular among Americans; and (2) that the relative frequency with which Americans visit each of their parks is a good index of their relative WTPs for visibility improvements at these parks.

[9] γ_j* is only approximately equal to the right-hand side because, although it is the optimal value designed to reproduce as closely as possible all three of the WTPs corresponding to the three visibility changes in the Chestnut and Rowe study, γ_j* will not exactly reproduce any of these WTPs.

and

$$\gamma_{jk} = \frac{(m - WTP_{jk}^{in})^{\rho} - m^{\rho}}{(Q_0^{\rho} - Q_1^{\rho})}$$

which implies that:

$$\gamma_{jk} \approx a_{jk} * \gamma_j^{*} ,$$

where:

$$a_{jk} = \frac{(m - WTP_{jk}^{in})^{\rho} - m^{\rho}}{(m - WTP_j^{in})^{\rho} - m^{\rho}} .$$

We use the adjustment factor, a_{jk}, to derive γ_{jk} from γ_j*, for the k^{th} Class I area in the j^{th} region. We use an analogous procedure to derive δ_{jk} from δ_j* for the k^{th} Class I area in the j^{th} region (where, in this case, we use WTP_j^{out} and WTP_{jk}^{out} instead of WTP_j^{in} and WTP_{jk}^{in}).[10]

I.4 Estimating the Parameter for Visibility in Residential Areas: θ

The estimate of θ is based on McClelland et al. (1991), in which household WTP for improvements in residential visibility was elicited from respondents in Chicago and Atlanta. A notable difference between the Chestnut and Rowe study and the McClelland study is that, while the former elicited WTP responses for three different visibility changes, the latter considered only one visibility change. The estimation of θ was therefore a much simpler procedure, involving a straightforward calibration to the single income and WTP in the study:

$$\theta = \frac{(m - WTP)^{\rho} - m^{\rho}}{(Z_0^{\rho} - Z_1^{\rho})} .$$

I.5 Putting it All Together: The Household Utility and WTP Functions

Given an estimate of θ, derived as shown in Section I.4, and estimates of the γ's and δ's, derived as shown in Section I.3, based on an assumed or estimated value of ρ, the utility and WTP functions for a household in any region are fully specified. We can therefore estimate the value to that household of visibility changes from any baseline level to any alternative level in the household's residential area and/or at any or all of the Class I areas in the United States, in a way that is consistent with economic theory. In particular, the WTP of a household in the ith region and the nth residential area for any set of changes in the levels of visibility at in-region Class I

[10] This method uses a single in-region WTP and a single out-of-region WTP per region. Although the choice of WTP will affect the resulting adjustment factors (the a_{jk}'s) and therefore the resulting γ_{jk}'s and δ_{jk}'s, the effect is negligible. We confirmed this by using each of the three in-region WTPs in California and comparing the resulting three sets of γ_{jk}'s and δ_{jk}'s, which were different from each other by about one one-hundredth of a percent.

areas, out-of-region Class I areas, and the household's residential area (given by equation (24)) is:

$$WTP_{ni}(\Delta Z, \Delta Q) = m - [\, m^{\rho} + \theta(Z_{0n}^{\rho} - Z_{1n}^{\rho}) + \sum_{k=1}^{N_i} \gamma_{ik} (Q_{0ik}^{\rho} - Q_{1ik}^{\rho}) + \sum_{j \neq i} \sum_{k=1}^{N_j} \delta_{jk} (Q_{0jk}^{\rho} - Q_{1jk}^{\rho}) \,]^{1/\rho} \; .$$

The national benefits associated with any suite of visibility changes is properly calculated as the sum of these household WTPs for those changes. The benefit of any subset of visibility changes (e.g., changes in visibility only at Class I areas in California) can be calculated by setting all the other components of the WTP function to zero (that is, by assuming that all other visibility changes that are not of interest are zero). This is effectively the same as assuming that the subset of visibility changes of interest is the first or the only set of changes being valued by households. Estimating benefit components in this way will yield slightly upward biased estimates of benefits, because disposable income, m, is not being reduced by the WTPs for any prior visibility improvements. That is, each visibility improvement (e.g., visibility at Class I areas in the California) is assumed to be the first, and they cannot all be the first. The upward bias should be extremely small, however, because all of the WTPs for visibility changes are likely to be very small relative to income.

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Appendix J: Additional Sensitivity Analyses Related to the Benefits Analysis

The analysis presented in Chapter 5 is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies and the assumptions that are most appropriate to adopt in the face of important uncertainties. The majority of the analytical assumptions used to develop the primary estimates of benefits have been reviewed and approved by EPA's SAB. Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions.

This appendix supplements our primary analysis of benefits with three additional sensitivity calculations. These supplemental estimates examine sensitivity to both valuation issues (e.g., the appropriate income elasticity) and for physical effects issues (e.g., the structure of the cessation lag). These supplemental estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. The individual adjustments in the tables should not simply be added together because 1) there may be overlap among the alternative assumptions and 2) the joint probability among certain sets of alternative assumptions may be low.

J.1 Premature Mortality Cessation Lag Structure

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient $PM_{2.5}$ will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question. The SAB-HES has recognized this lack of direct evidence. However, in early advice, they also note that "although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population" (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9). In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags. The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using "a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions" (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that "an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate" (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its followup advice provided in December 2004, this SAB suggested that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004). The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). The 0-year lag is representative of EPA's assumption in previous RIAs. The 8- and 15-year lags are based on the study periods from the Pope et al. (1995) and Dockery et al. (1993) studies, respectively.[1] However, neither the Pope et al. nor Dockery et al. studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope et al. and Dockery et al. analyses do not supporting or refute the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8- and 15-year lags implicitly assume that all premature mortalities occur at the end of the study periods (i.e., at 8 and 15 years).

[1] Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

In addition to the simple 8- and 15-year lags, we have added three additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 30 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment. The third sensitivity analysis assumes a negative exponential relationship between reduction in exposure and reduction in mortality risk. This structure is based on an analysis by Röösli et al. (2004), which estimates the percentage of total mortality impact in each period t as

$$\%\ \text{ Mortality Reduction(t)} = \frac{\left[(RR-1)e^{-0.5t}+1\right]-1}{\sum_{t=1}^{\infty}\left[(RR-1)e^{-0.5t}+1\right]-1} \qquad \text{(J.1)}$$

The Röösli et al. (2004) analysis derives the lag structure by calculating the rate constant (–0.5) for the exponential lag structure that is consistent with both the relative risk from the cohort studies and the change in mortality observed in intervention type studies (e.g., Pope et al. [1992] and Clancy et al. [2002]). This is the only lag structure examined that is based on empirical data on the relationship between changes in exposure and changes in mortality.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table J-1. These estimates are based on the value of statistical lives saved approach (i.e., $5.5 million per incidence) and are presented for both a 3 and 7 percent discount rate over the lag period.

The results of this sensitivity analyses demonstrate that because of discounting of delayed benefits, the lag structure may also have a large impact on monetized benefits, reducing benefits by 30 percent if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits. For example, the overall impact of moving from the previous 5-year distributed lag to the segmented lag recommended by the SAB-HES in 2004 in the primary estimate is relatively modest, reducing benefits by approximately 5 percent when a 3 percent discount rate is used and 15 percent when a 7 percent discount rate is used. If no lag is assumed, benefits are increased by around 10 percent relative to the segmented lag with a 3 percent discount rate and 30 percent with a 7 percent discount rate.

Table J-1: Sensitivity of Benefits of Premature Mortality Reductions to Alternative Cessation Lag Structures, Using Pope et al (2002) Effect Estimate

Alternative Lag Structures for PM-Related Premature Mortality		*15/35* Value (billion 1999$)[a,b]	*15/35* Percent Difference from Base Estimate	*14/35* Value (billion 1999$)[a,b]	*14/35* Percent Difference from Base Estimate
None	Incidences all occur in the first year				
	3% discount rate	$16.5	10.4%	$29.1	10.4%
	7% discount rate	$16.5	31.2%	$29.1	31.2%
8-year	Incidences all occur in the 8th year				
	3% discount rate	$13.4	–10.3%	$23.6	–10.3%
	7% discount rate	$10.3	–18.3%	$18.1	–18.3%
15-year	Incidences all occur in the 15th year				
	3% discount rate	$10.9	–27.0%	$19.2	–27.0%
	7% discount rate	$6.4	–49.1%	$11.3	–49.1%
Alternative Segmented	20 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20				
	3% discount rate	$14.5	–3.2%	$25.5	–3.2%
	7% discount rate	$11.5	–8.7%	$20.2	–8.7%
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5				
	3% discount rate	$15.7	4.9%	$27.6	4.9%
	7% discount rate	$14.7	17.1%	$25.9	17.1%
Exponential	Incidences occur at an exponentially declining rate following year of change in exposure				
	3% discount rate	$15.8	5.6%	$27.8	5.6%
	7% discount rate	$14.4	14.8%	$25.4	14.8%

[a] Dollar values rounded to two significant digits.

J.2 Visibility Benefits in Additional Class I Areas

The Chestnut and Rowe (1990a) study from which the primary valuation estimates are derived only examined WTP for visibility changes in Class I areas (national parks and wilderness areas) in the southeast, southwest, and California. To obtain estimates of WTP for visibility changes at national parks and wilderness areas in the northeast, northwest, and central regions of the U.S., we have to transfer WTP values from the studied regions. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions.

Based on this benefits transfer methodology (implemented within the preference calibration framework discussed in Chapter 5 and Appendix I), estimated additional visibility benefits in the northwest, central, and northeastern U.S. are provided in Table J-2.

Table J-2: Monetary Benefits Associated with Improvements in Visibility in Additional Federal Class I Areas in 2020 Incremental to 15/65 Attainment Strategy (in millions of 1999$)[a]

Suite of Standards	*Northwest*[b]	*Central*[c]	*Northeast*[d]	*Total*
15/35	$96	$130	$6	$240
14/35	$67	$140	$44	$250

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns

[b] Northwest Class I areas include Crater Lake, Mount Rainier, North Cascades, and Olympic national parks, and Alpine Lakes, Diamond Peak, Eagle Cap, Gearhart Mountain, Glacier Peak, Goat Rocks, Hells Canyon, Kalmiopsis, Mount Adams, Mount Hood, Mount Jefferson, Mount Washington, Mountain Lakes, Pasayten, Strawberry Mountain, and Three Sisters wilderness areas.

[c] Central Class I areas include Craters of the Moon, Glacier, Grand Teton, Theodore Roosevelt, Badlands, Wind Cave, and Yellowstone national parks, and Anaconda-Pintlar, Bob Marshall, Bridger, Cabinet Mountains, Fitzpatrick, Gates of the Mountain, Lostwood, Medicine Lake, Mission Mountain, North Absaroka, Red Rock Lakes, Sawtooth, Scapegoat, Selway-Bitterroot, Teton, U.L. Bend, and Washakie wilderness areas.

[d] Northeast Class I areas include Acadia, Big Bend, Guadalupe Mountains, Isle Royale, Voyageurs, and Boundary Waters Canoe national parks, and Brigantine, Caney Creek, Great Gulf, Hercules-Glades, Lye Brook, Mingo, Moosehorn, Presidential Range-Dry Roosevelt Campobello, Seney, Upper Buffalo, and Wichita Mountains wilderness areas.

J.3 Income Elasticity of Willingness to Pay

As discussed in Chapter 5, our estimates of monetized benefits account for growth in real GDP per capita by adjusting the WTP for individual endpoints based on the central estimate of the adjustment factor for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility). We examined how sensitive the estimate of total benefits is to alternative estimates of the income elasticities. Table J-3 lists the ranges of elasticity values used to calculate the income adjustment factors, while Table J-4 lists the ranges of corresponding adjustment factors. The results of this sensitivity analysis, giving the monetized benefit subtotals for the four benefit categories, are presented in Table J-5.

Consistent with the impact of mortality on total benefits, the adjustment factor for mortality has the largest impact on total benefits. The value of mortality in 2020 ranges from 90 percent to 130 percent of the primary estimate based on the lower and upper sensitivity bounds on the income adjustment factor. The effect on the value of minor and chronic health effects is much less pronounced, ranging from 98 percent to 105 percent of the primary estimate for minor effects and from 93 percent to 106 percent for chronic effects.

Table J-3: Ranges of Elasticity Values Used to Account for Projected Real Income Growth[a]

Benefit Category	*Lower Sensitivity Bound*	*Upper Sensitivity Bound*
Minor Health Effect	0.04	0.30
Severe and Chronic Health Effects	0.25	0.60
Premature Mortality	0.08	1.00
Visibility[b]	—	—

[a] Derivation of these ranges can be found in Kleckner and Neumann (1999) and Chestnut (1997). COI estimates are assigned an adjustment factor of 1.0.

[b] No range was applied for visibility because no ranges were available in the current published literature.

Table J-4: Ranges of Adjustment Factors Used to Account for Projected Real Income Growth[a]Error! Bookmark not defined.

Benefit Category	*Lower Sensitivity Bound*	*Upper Sensitivity Bound*
Minor Health Effect	1.018	1.147
Severe and Chronic Health Effects	1.121	1.317
Premature Mortality	1.037	1.591
Visibility[b]	—	—

[a] Based on elasticity values reported in Table C-4, U.S. Census population projections, and projections of real GDP per capita.

[b] No range was applied for visibility because no ranges were available in the current published literature.

Table J-5: Sensitivity of Monetized Benefits to Alternative Income Elasticities[a]

	Benefits Incremental to 15/65 Attainment Strategy (Millions of 1999$)			
	15/35		*14/35*	
Benefit Category	*Lower Sensitivity Bound*	*Upper Sensitivity Bound*	*Lower Sensitivity Bound*	*Upper Sensitivity Bound*
Minor Health Effect	$130	$140	$210	$220
Severe and Chronic Health Effects	$1,400	$1,600	$2,500	$2,700
Premature Mortality[b]	$13,000	$20,000	$23,000	$34,000
Visibility and Other Welfare Effects[c]	$530	$530	$1,200	$1,200
Total Benefits[b]	$15,000	$22,000	$26,000	$37,000

[a] All estimates rounded to two significant digits.

[b] Using mortality effect estimate from Pope et al. (2002) and 3 percent discount rate.

[c] No range was applied for visibility because no ranges were available in the current published literature.

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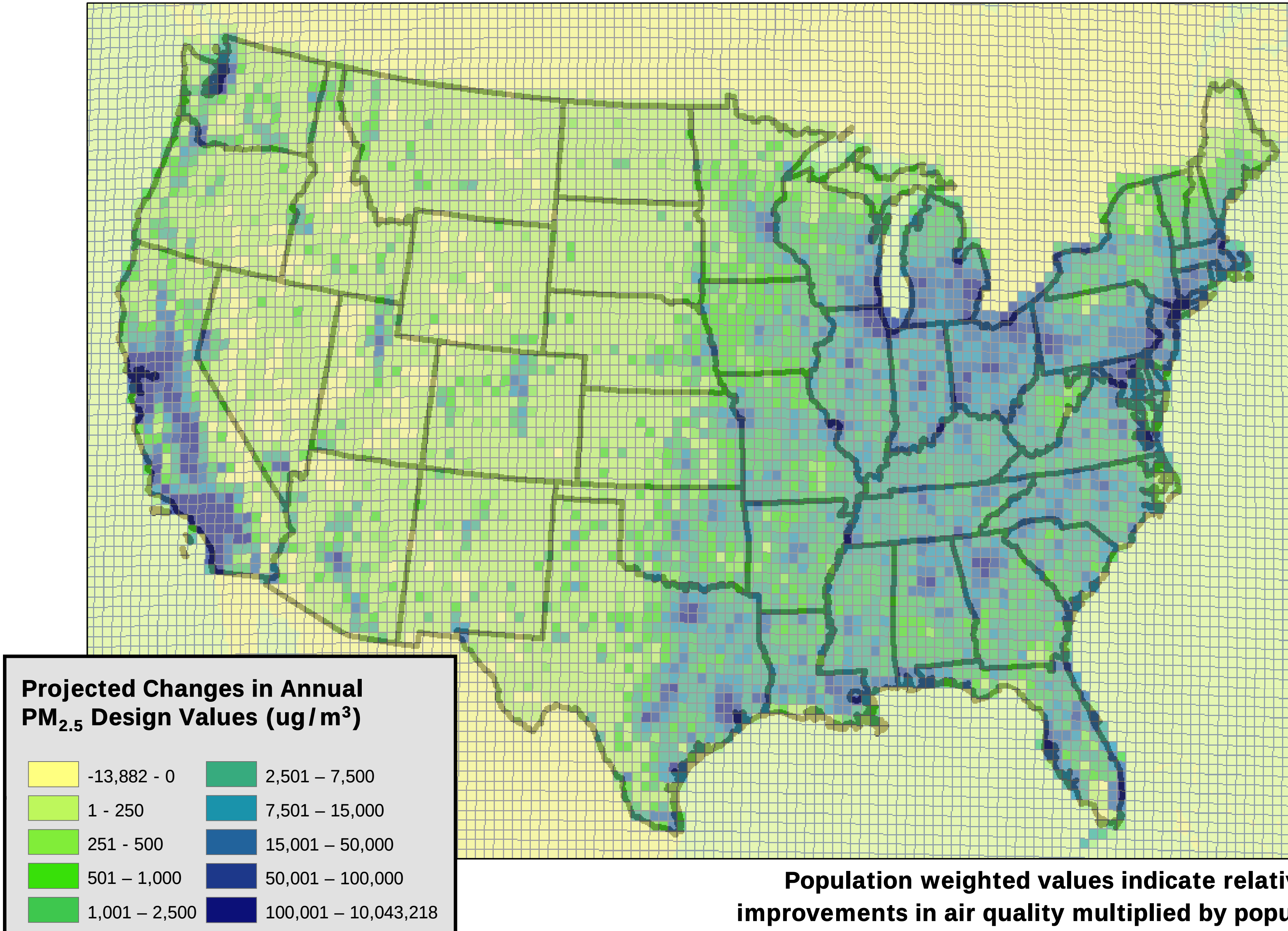
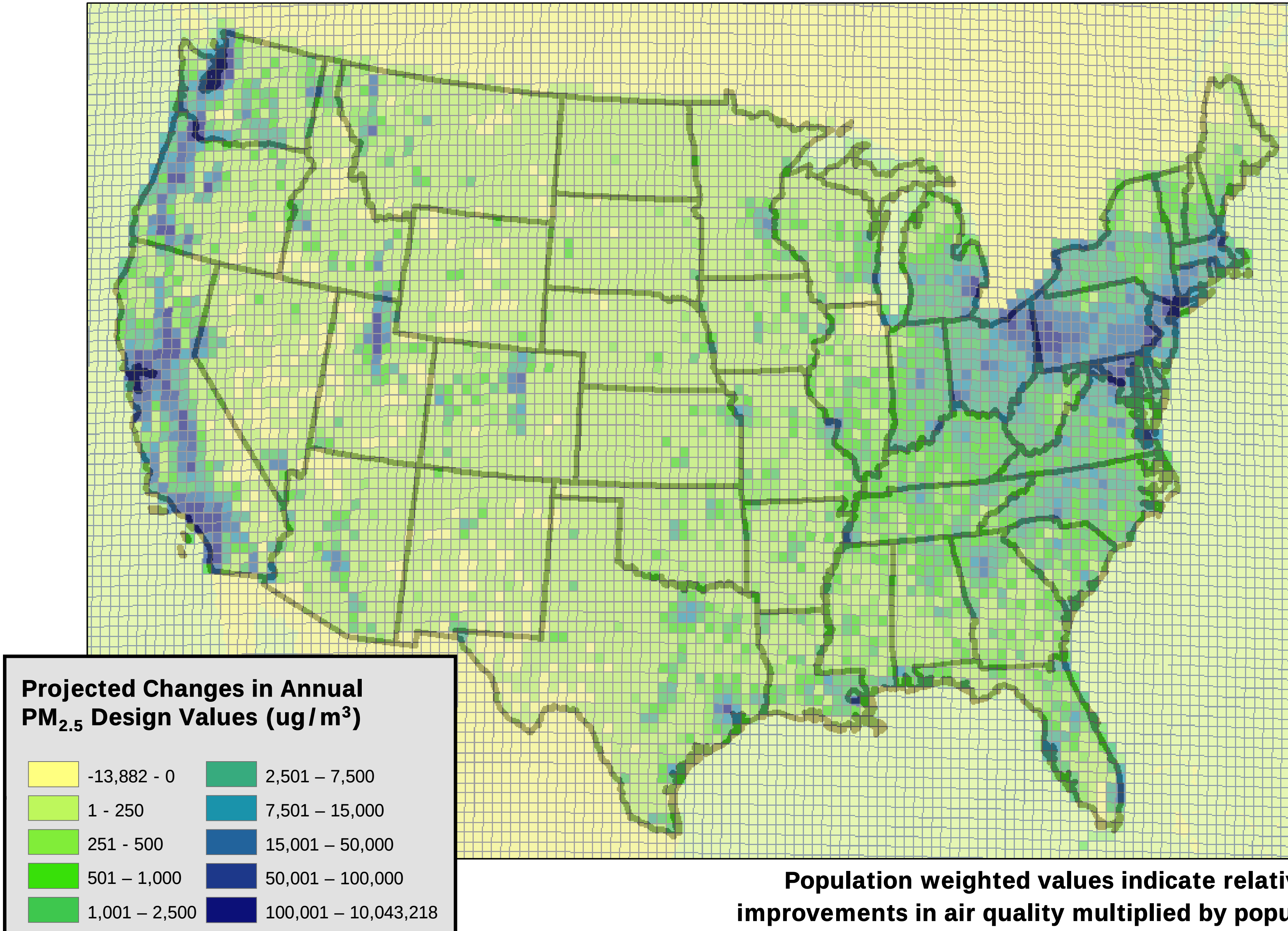
Not cited. U.S. Environmental Protection Agency (EPA). 2004. Air Quality Criteria for Particulate Matter, Volume II. Office of Research and Development. EPA/600/P-99/002bF, October 2004.

Population Weighted Air Quality Changes between Base Case and 15/65



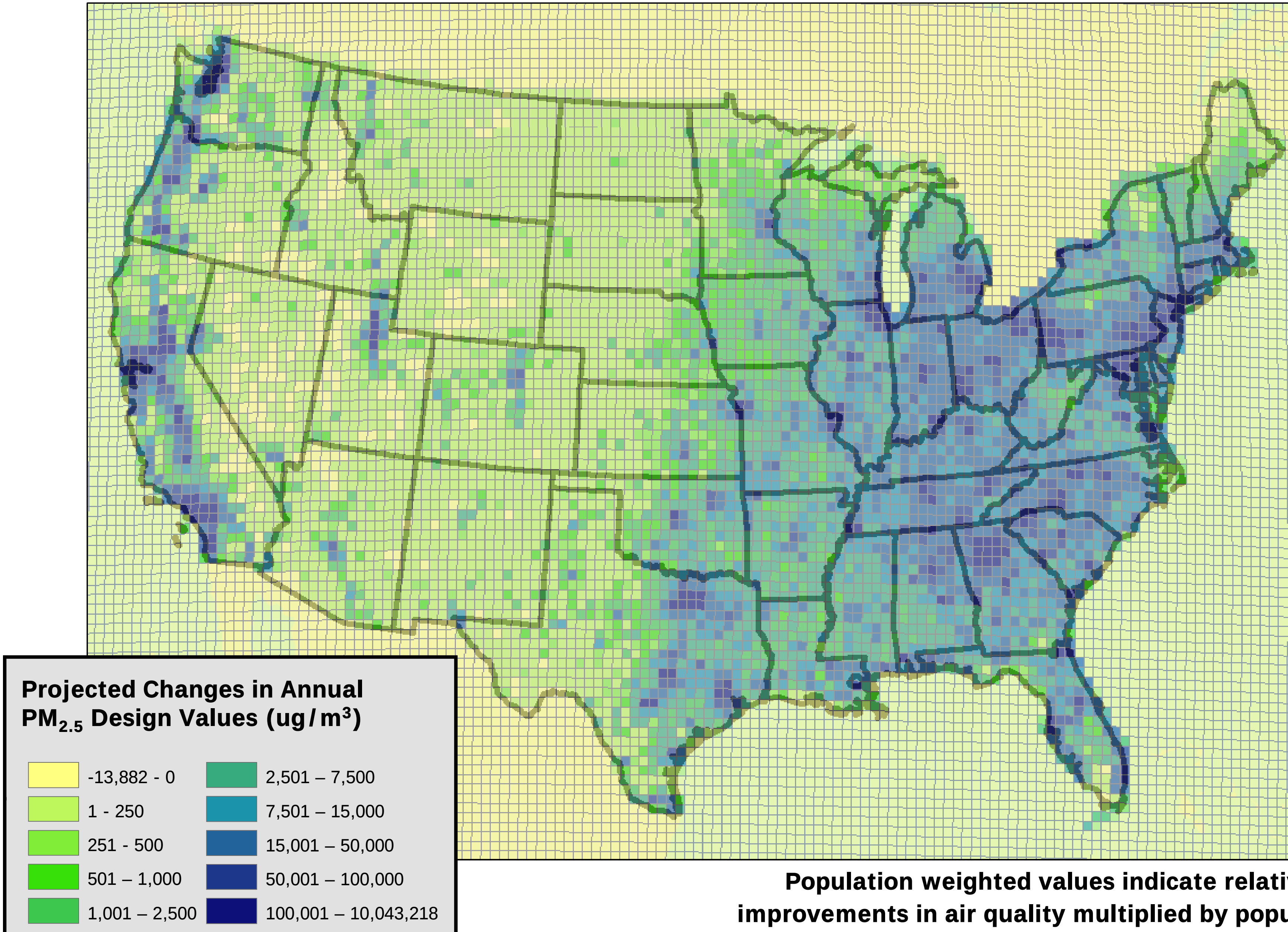
Population weighted values indicate relative improvements in air quality multiplied by population

Population Weighted Air Quality Changes between 15/65 and 15/35



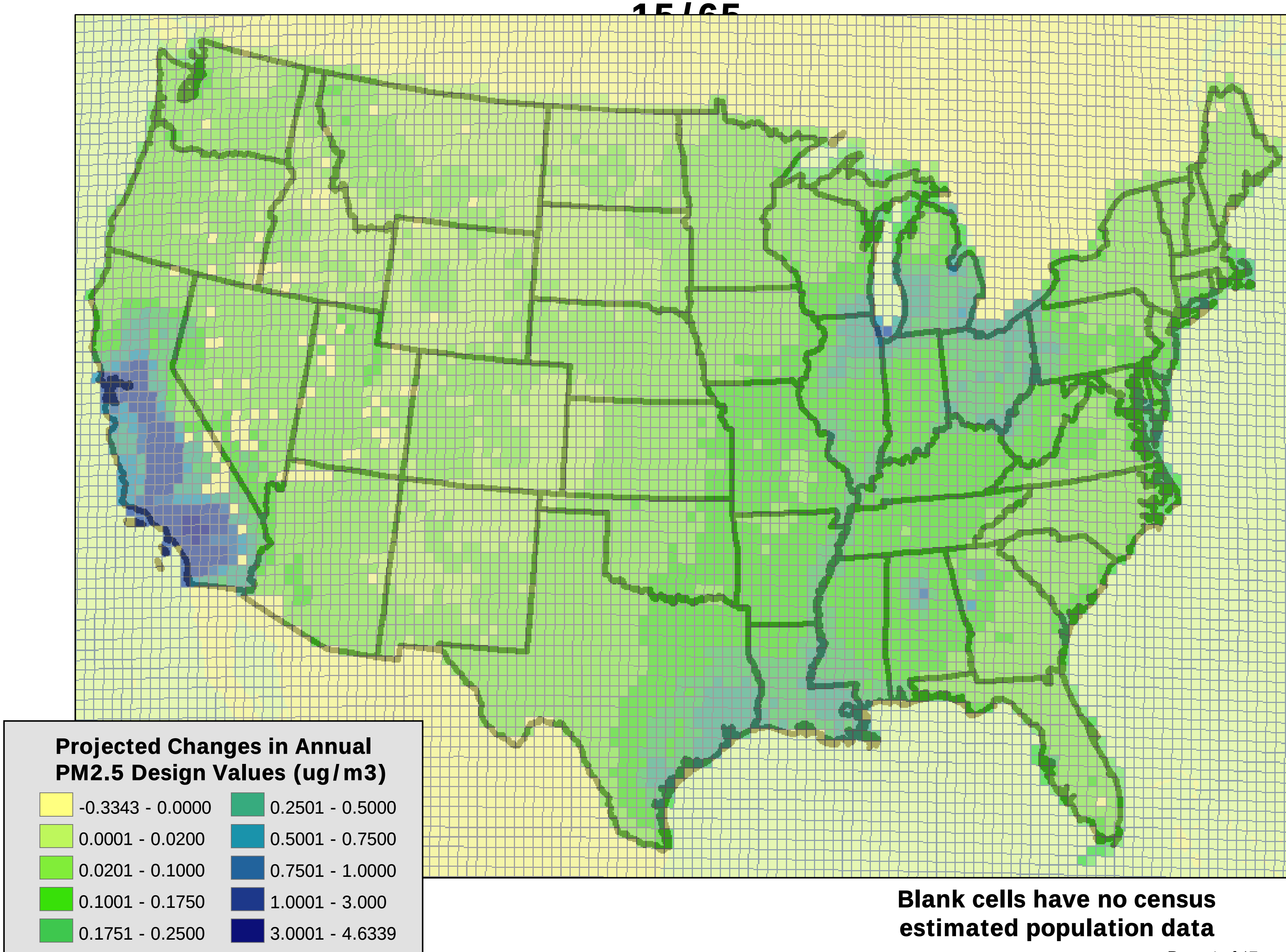
Population weighted values indicate relative improvements in air quality multiplied by population

Population Weighted Air Quality Changes between 15/65 and 14/35



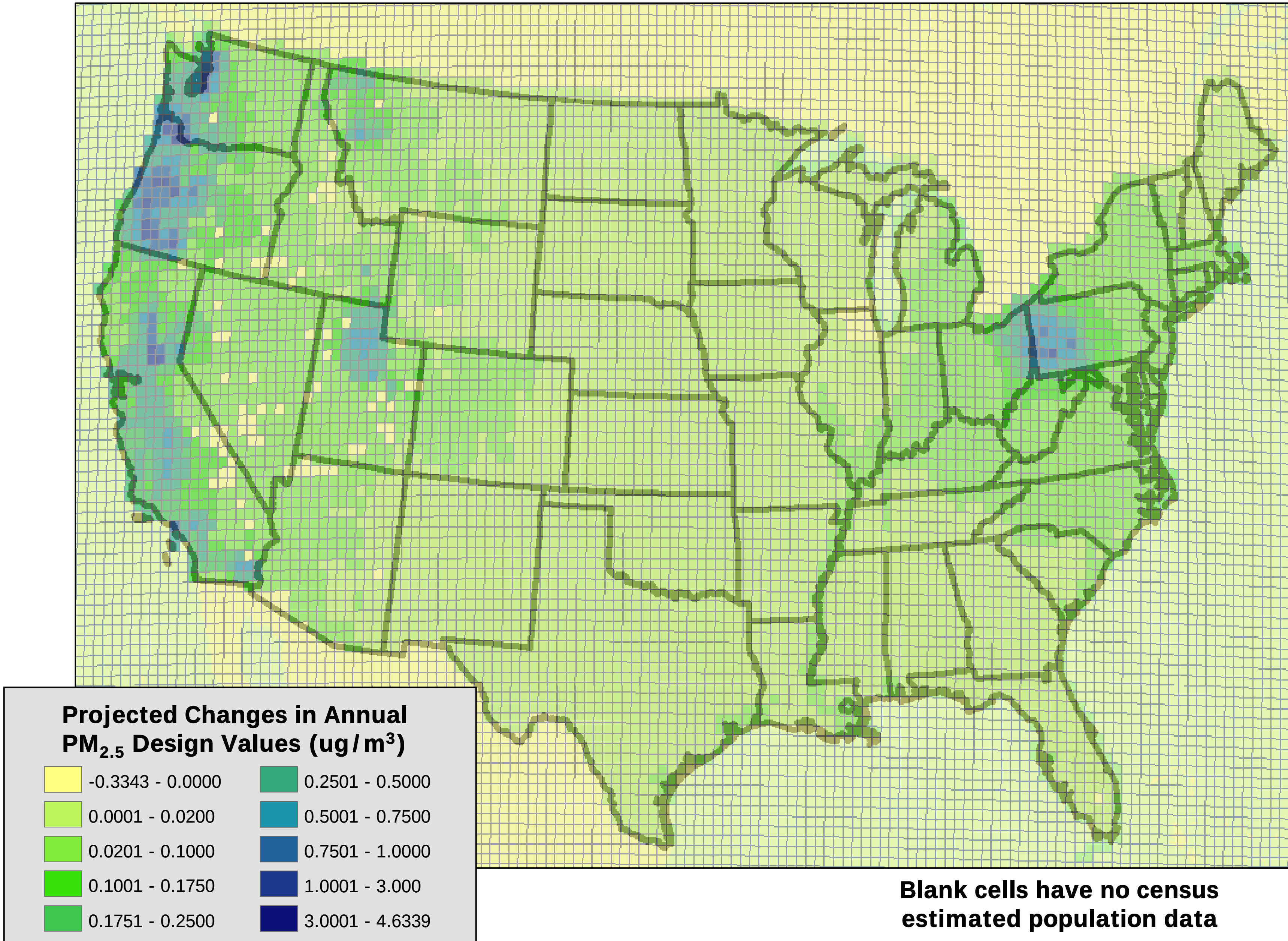
Population weighted values indicate relative improvements in air quality multiplied by population

Unweighted Air Quality Changes between Base Case and 15/65

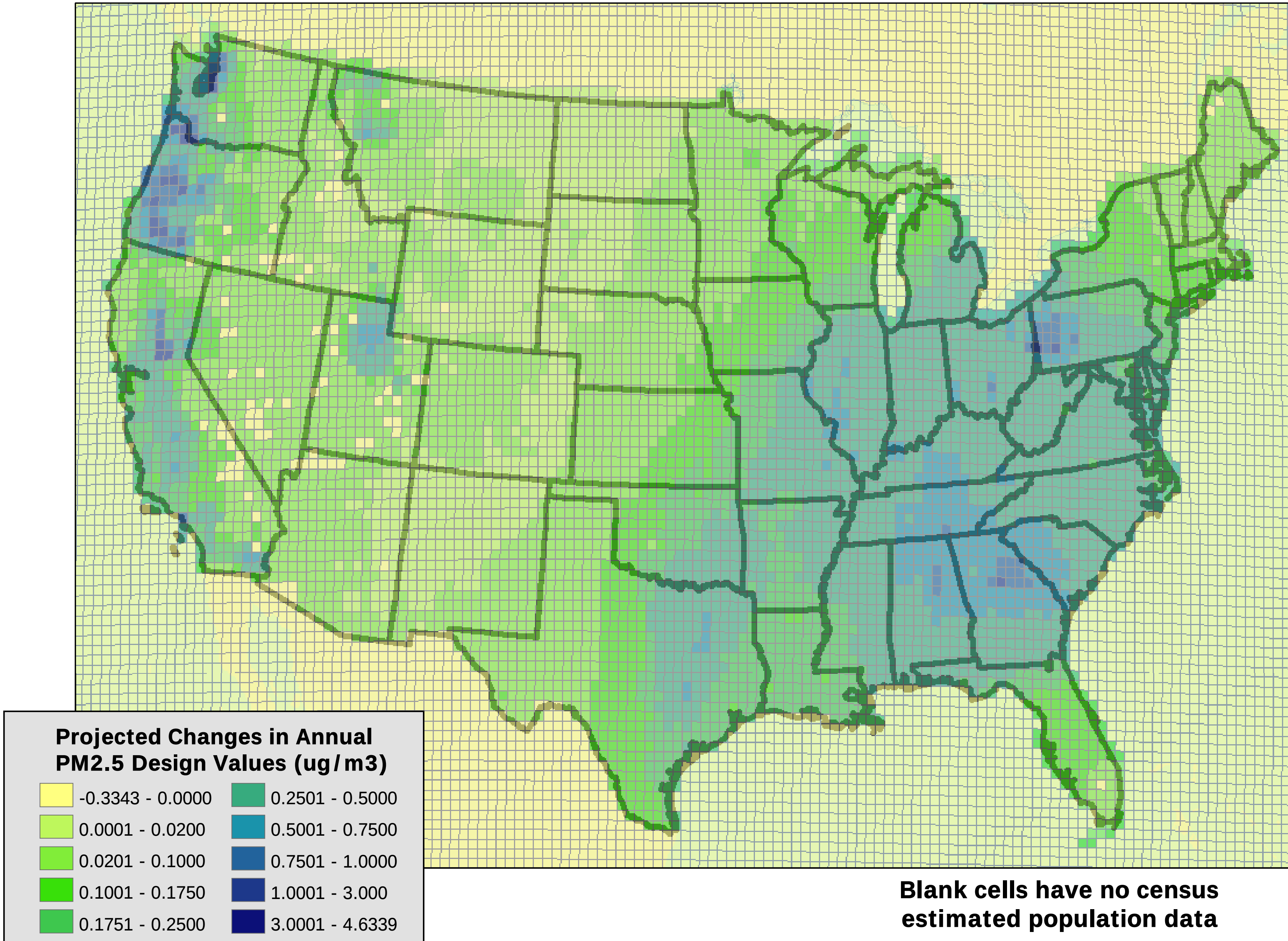


Blank cells have no census estimated population data

Unweighted Air Quality Changes between 15/65 and 15/35

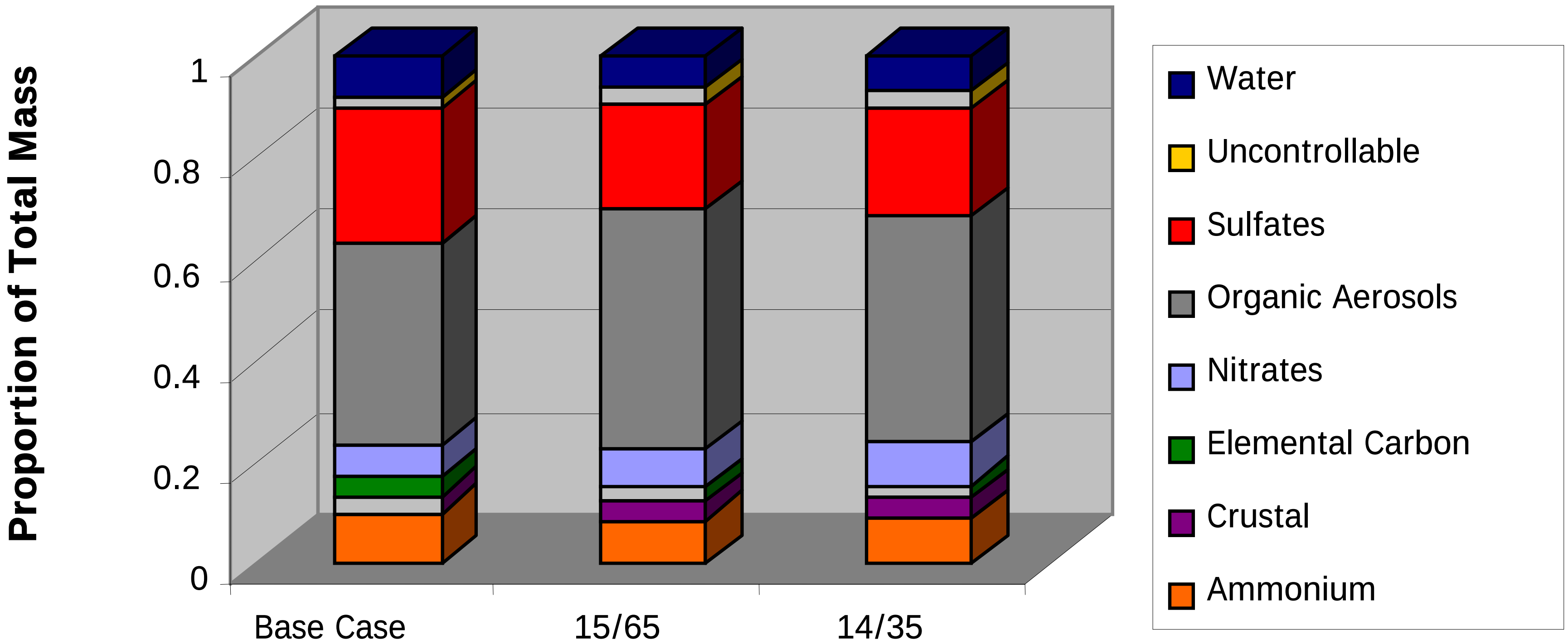


Unweighted Air Quality Changes between 15/65 and 14/35



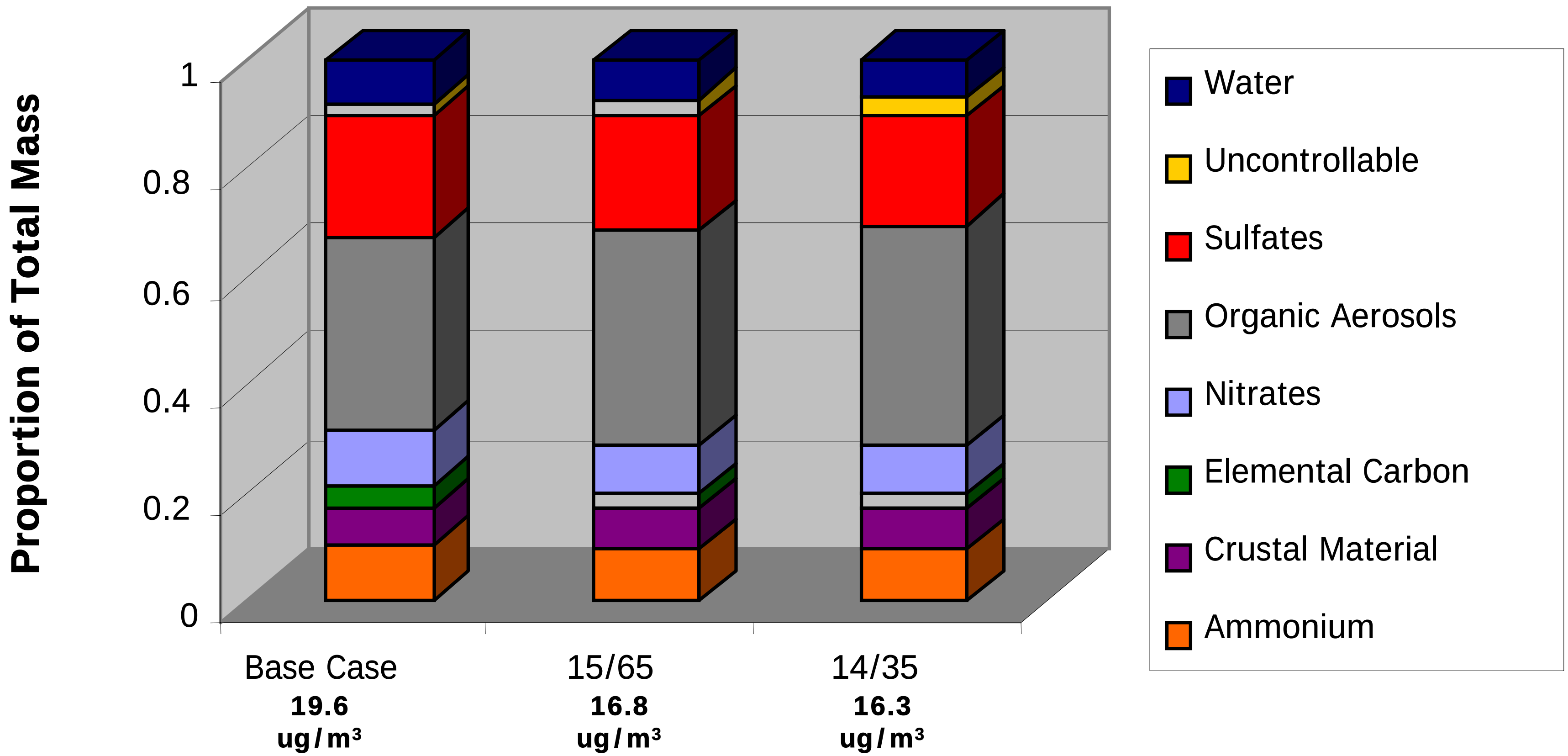
Blank cells have no census estimated population data

Particle Speciation of $PM_{2.5}$ By Control Case for Pittsburgh

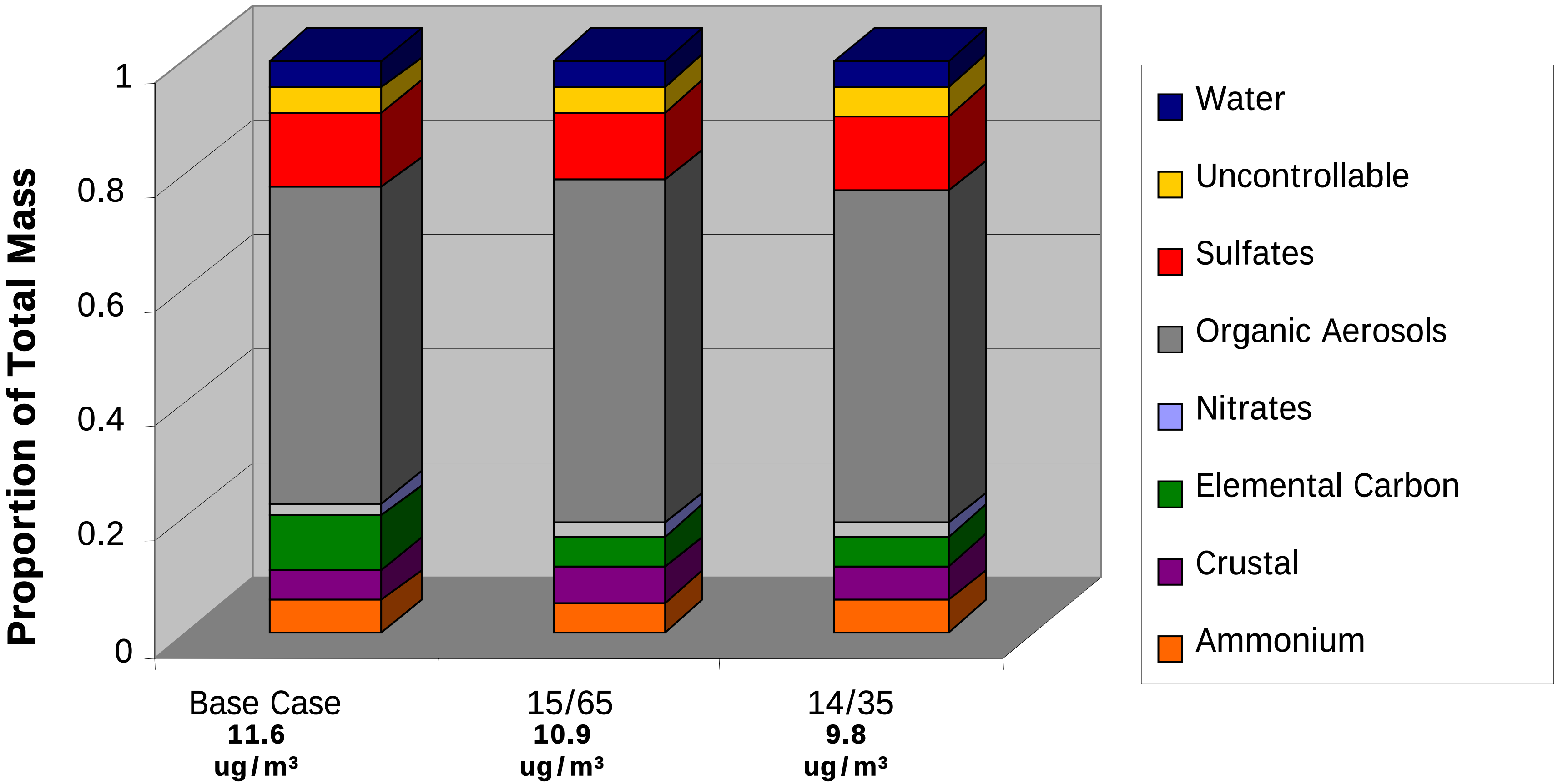


21.2 ug/m³ **16.2 ug/m³** **14.3 ug/m³**

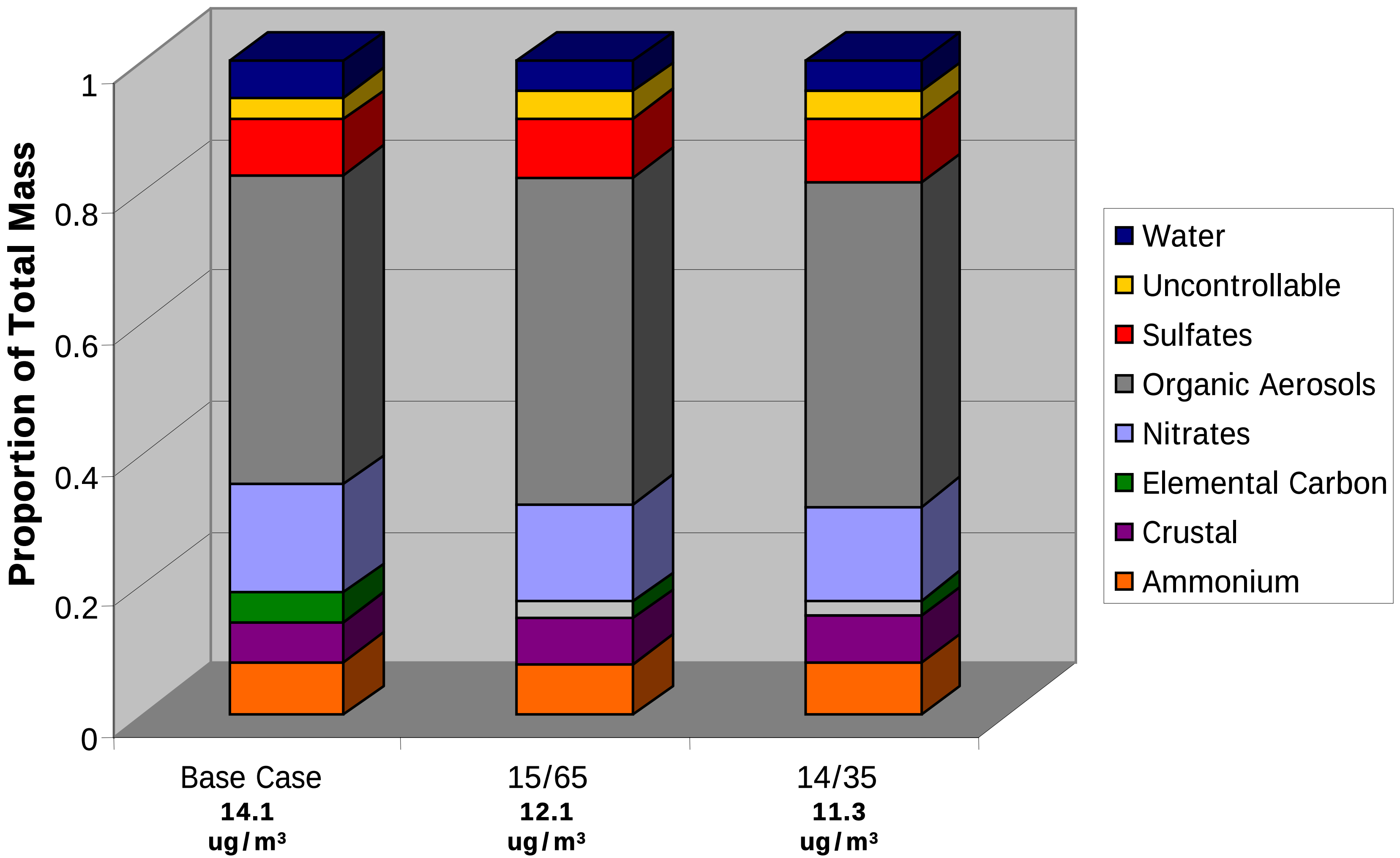
Particle Speciation of $PM_{2.5}$ By Control Case for Detroit



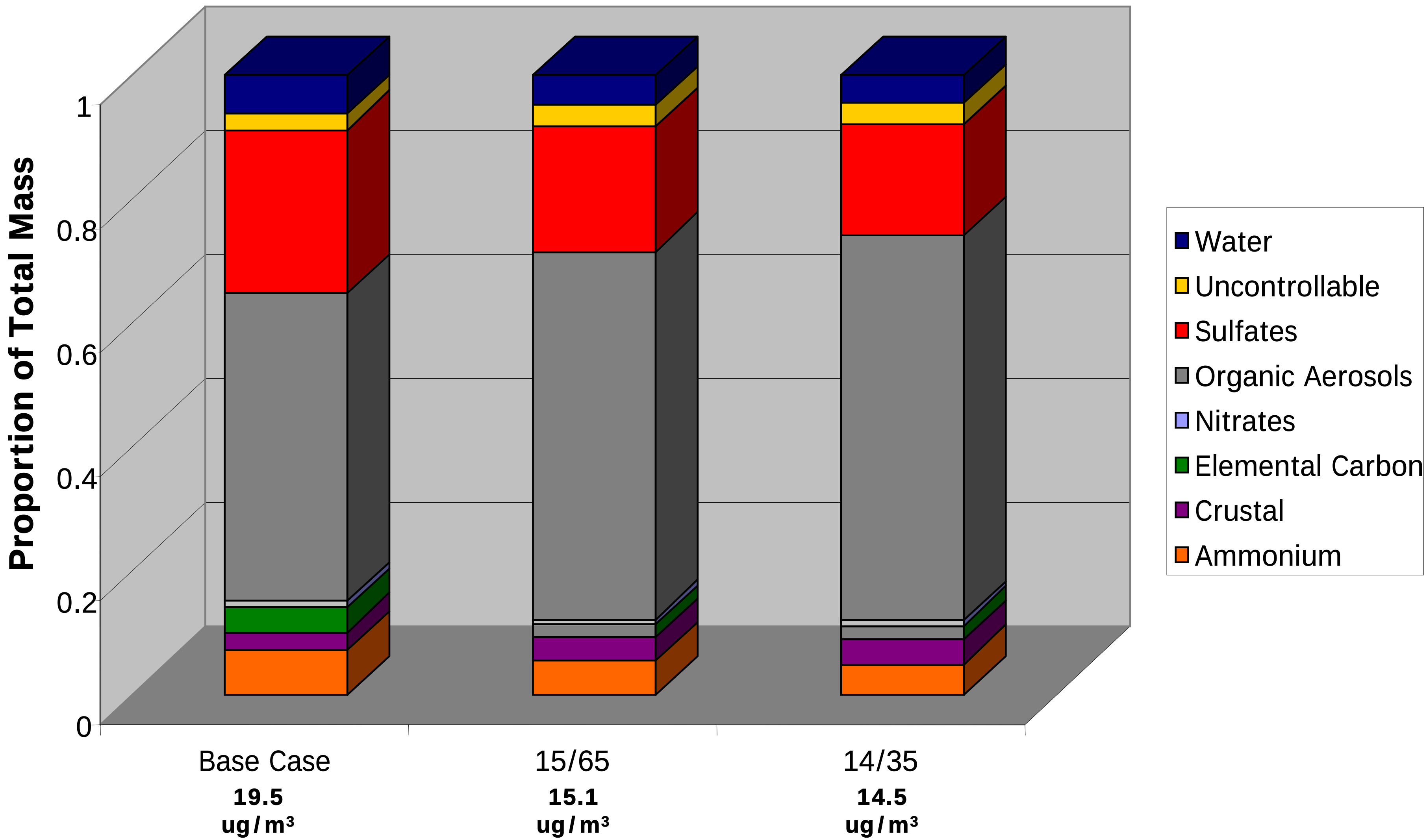
Particle Speciation of $PM_{2.5}$ By Control Case for Seattle



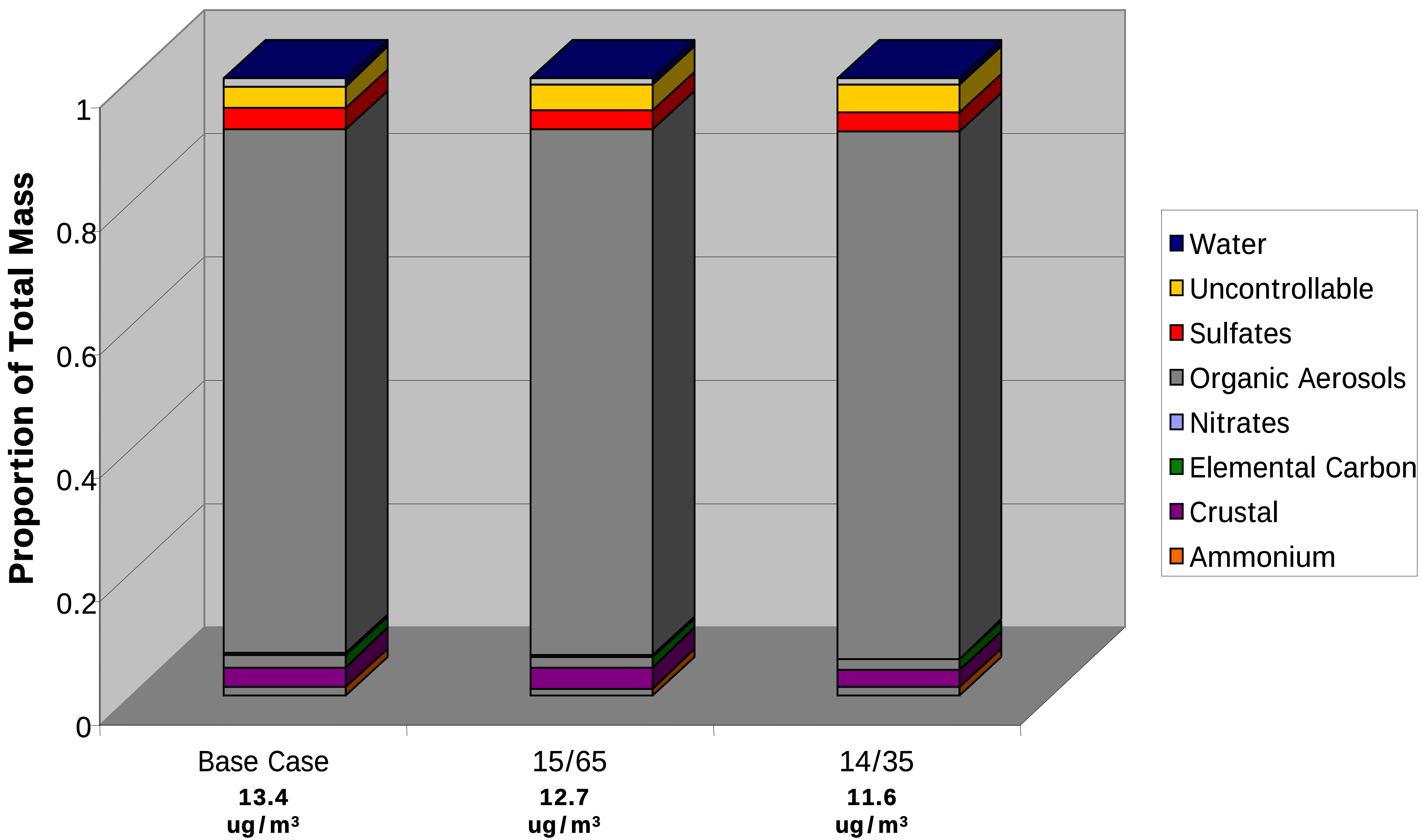
Particle Speciation of $PM_{2.5}$ By Control Case for Salt Lake City



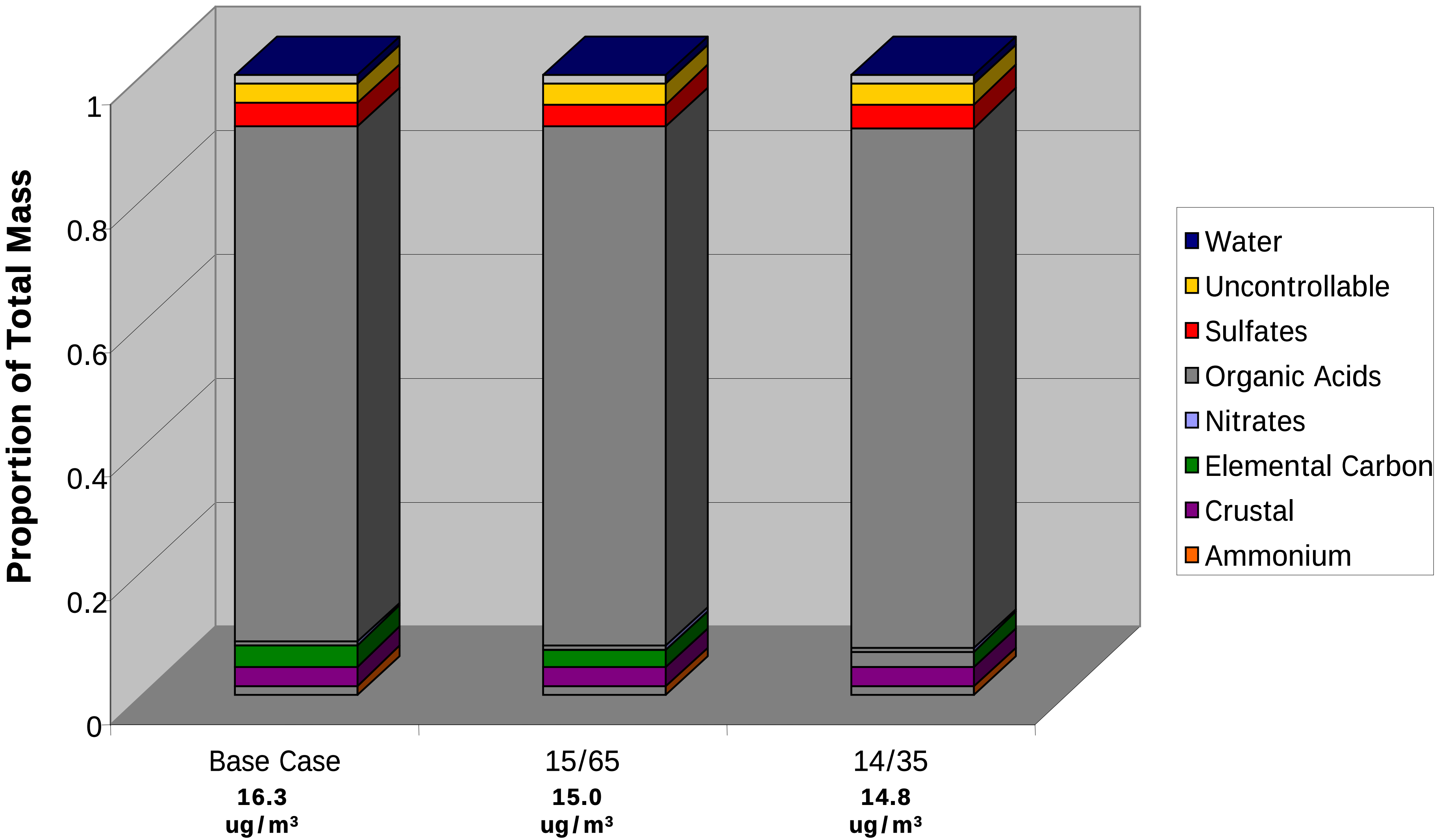
Particle Speciation of $PM_{2.5}$ By Control Case for Atlanta



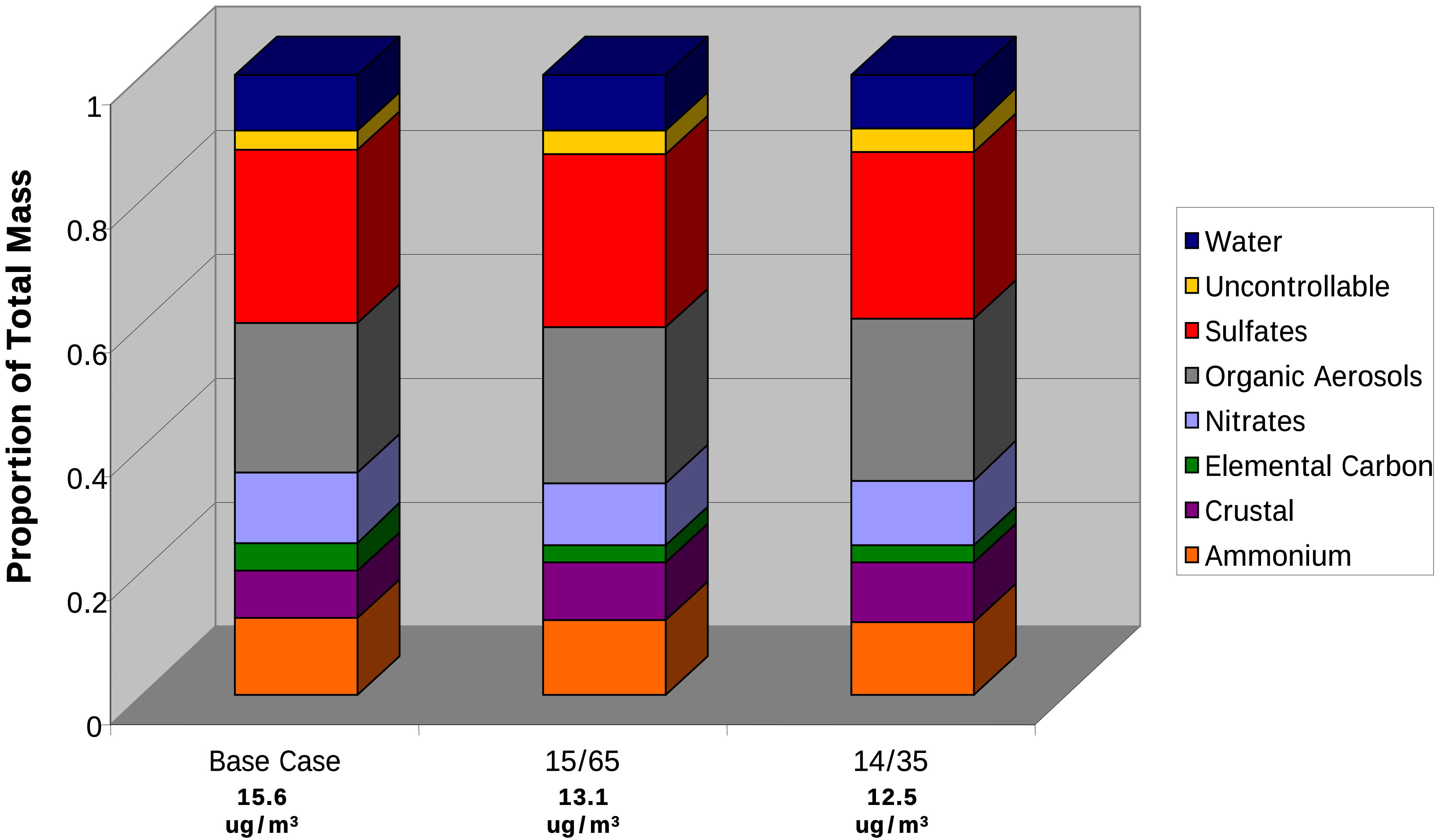
Particle Speciation of $PM_{2.5}$ By Control Case for Eugene, OR



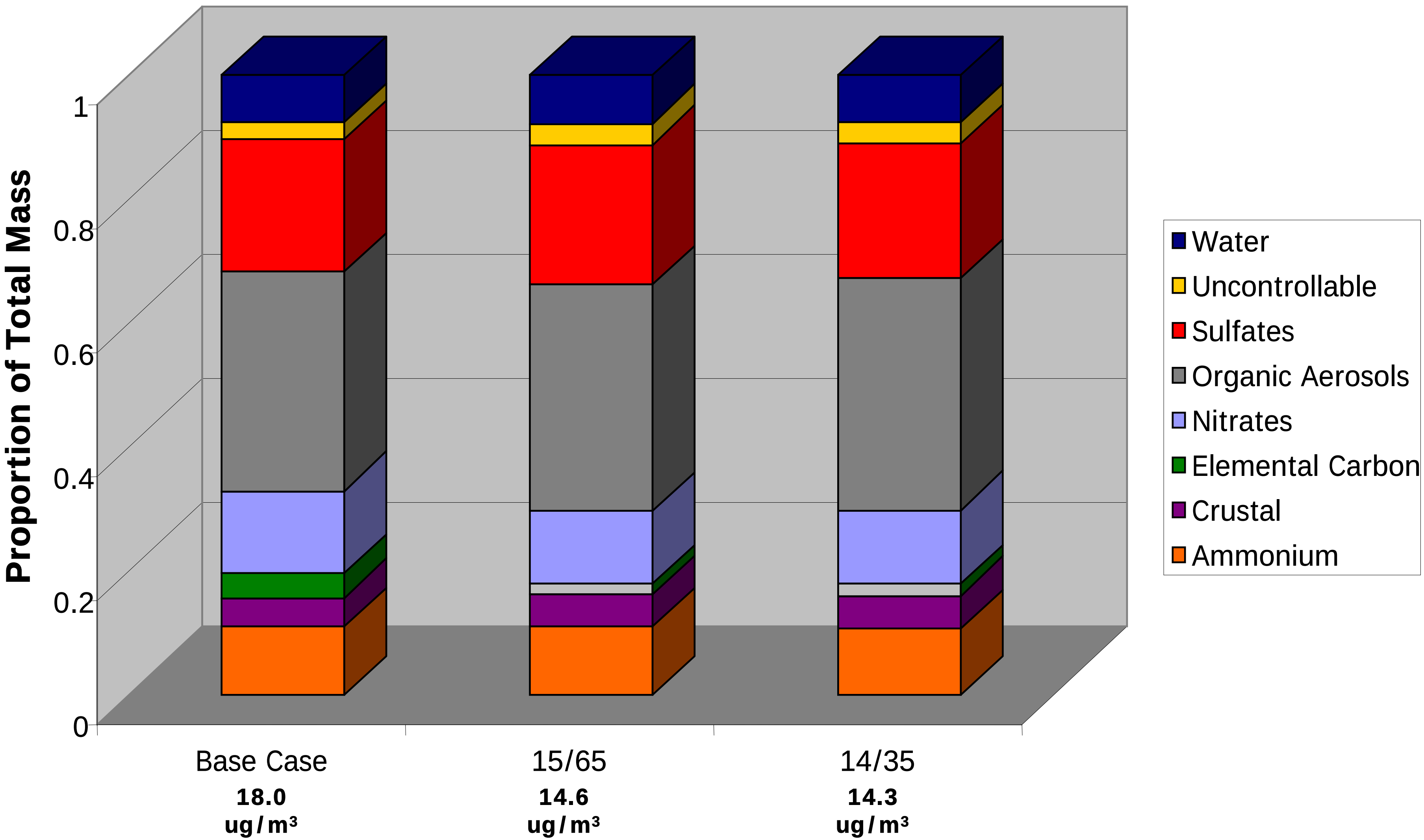
Particle Speciation of $PM_{2.5}$ By Control Case for Libby, MT



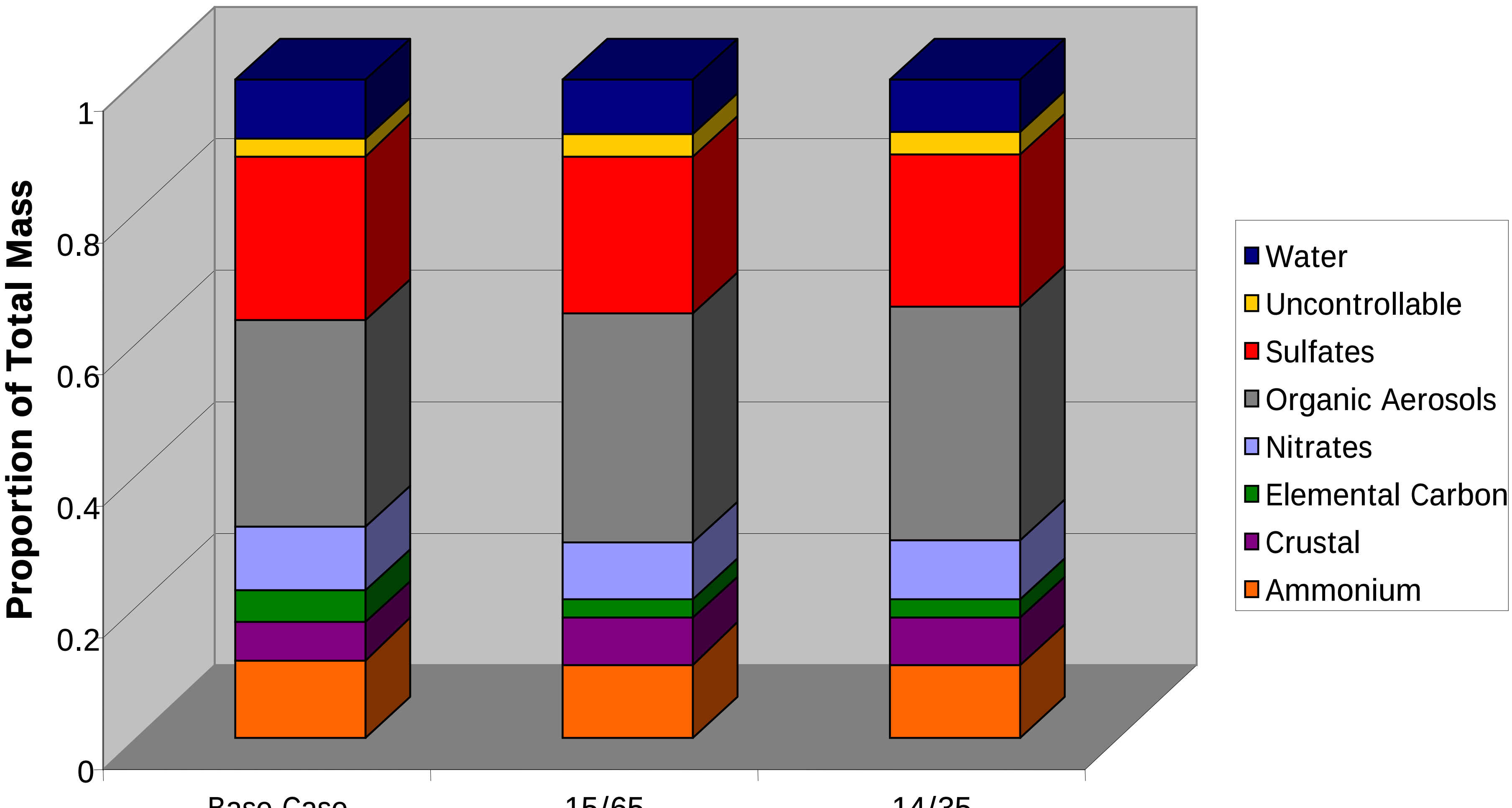
Particle Speciation of $PM_{2.5}$ By Control Case for St. Louis



Particle Speciation of $PM_{2.5}$ By Control Case for Chicago

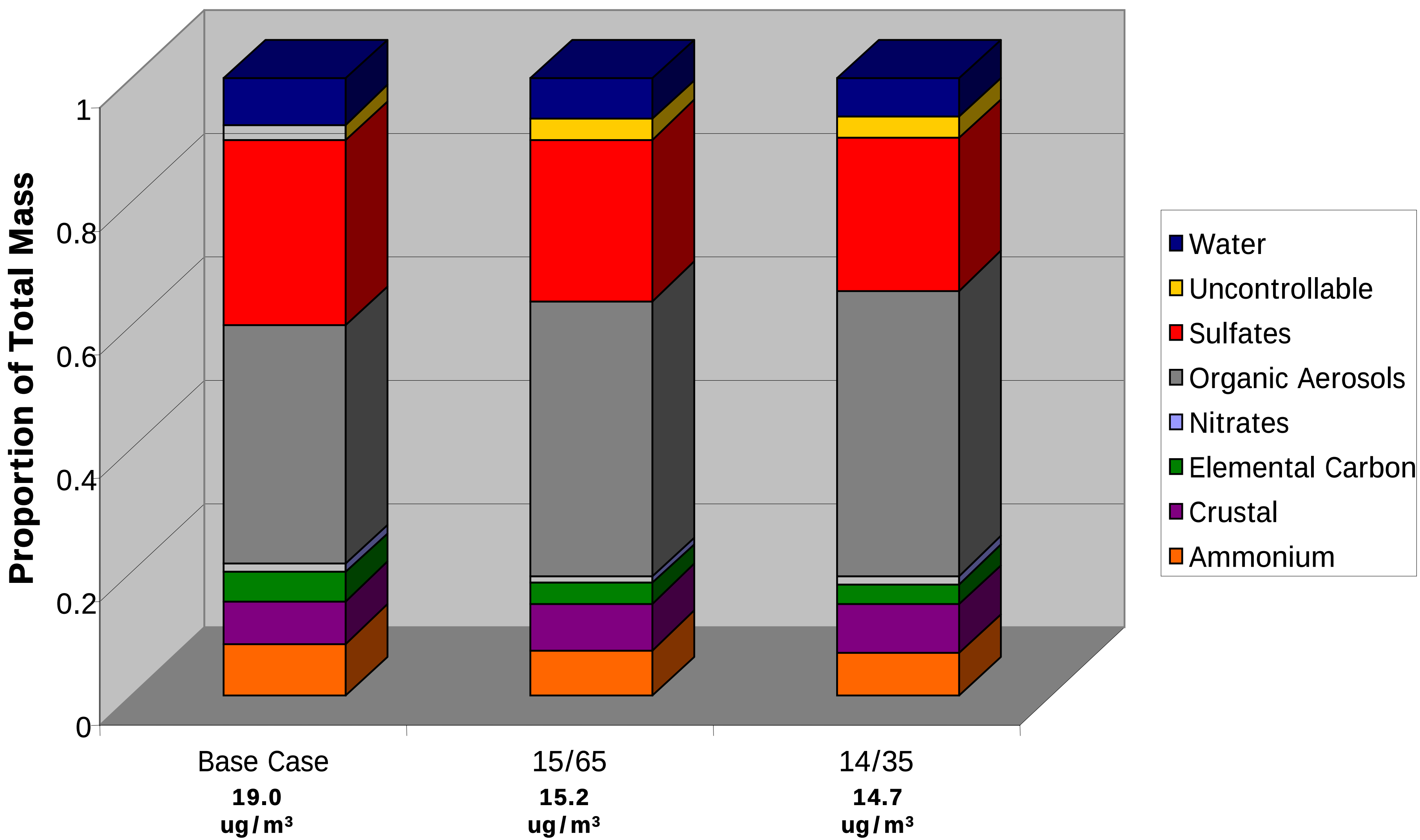


Particle Speciation of $PM_{2.5}$ By Control Case for Cleveland



19.3 ug/m³ | **14.7 ug/m³** | **14.2 ug/m³**

Particle Speciation of $PM_{2.5}$ By Control Case for Birmingham, AL



9/18/06

MEMORANDUM

FROM: Larry Sorrels
U.S. EPA/OAQPS/HEID/ABCG

TO: Neal Fann
U.S. EPA/OAQPS/HEID/ABCG

SUBJECT: Control Measures Changes to AirControlNET 4.1 As Part of Control Measures Validation Review

This memorandum provides a detailed listing of the changes to AirControlNET 4.1 resulting from a review of the control measures data that occurred between February 1, 2006 and April 1, 2006. These revisions occurred as a result of extensive review of the AirControlNET's $PM_{2.5}$, PM_{10}, $SO_{2,}$, and NOx control measures by control measure experts in OAQPS, OPAR, and other offices in EPA. All of these revisions were included in AirControlNET 4.1 as of April 11, 2006 for use in the final $PM_{2.5}$ NAAQS RIA control strategy analyses, and the control measures documentation report for that version of AirControlNET reflects all of these changes.

Revisions to Control Measures Already in AirControlNET 4.1

Correct the commercial cooking control measure - catalytic oxidizer - to only 10% of the emissions in Source Classification Code (SCC) 2302002000. To make this adjustment, change the rule penetration to 10% from 100%. No other data for this measure shall be changed.

Correct the residential wood stove control measure - changeout to an NSPS-compliant wood stove - to have a rule penetration of 10% from the current 100%. No other data for this measure shall be changed.

Add organic carbon (OC) and elemental carbon (EC) control efficiencies to the IMF (increased monitoring frequency) and continuous emission monitoring (CEM)s upgrade control measures. These control efficiencies will be identical to the PM_{10} and $PM_{2.5}$ efficiencies currently there (6.5% and 7.7%), respectively. It will also be made clear that <u>these controls can only be applied to sources that already have an electrostatic precipitator (ESP) or baghouse (fabric filter) installed.</u> No other data for this measure will change.

1) P. III-1229 – Remove the following from the list of affected SCCs for the Wood Pulp and Paper source category/Dry ESP-Wire Plate Type control measure combination:

30700101
30700102
30700105
30700118
30700121
30700122
30700199

2) P. III-1232 – Remove the following from the list of affected SCCs for the Wood Pulp and Paper source category/Wet ESP-Wire Plate Type control measure combination:

30700101
30700102
30700105
30700118
30700121
30700122
30700199

3) P. III-1278 – Remove SCC 30700106 from the list of affected SCCs for the Pulp and Paper Industry (Sulfate Pulping) source category /Flue Gas Desulfurization control measure combination.

4) P. III-1128 – Remove SCCs 30300515, 30300516, and 30300519 from the list of affected SCCs for the Non-Ferrous Metal Processing – Copper source category/Fabric Filter control measure combination and the combination of this source category with ESPs (all types).

5) For all Asphalt Manufacture source category/Fabric Filter (any type) control measure combinations, remove the following SCCs from the affected list: 30500101, 30500102, 30500103, 30500105, 30500106, 30500108, 30500110, 30500111, 30500117, 30500290. The first of these combinations is on p. III-635.

6) Remove the Lime Kilns source category/SNCR (Selective Non-Catalytic Reduction) and Lime Kilns/SCR (Selective Catalytic Reduction) control measure combinations. AirControlNET 4.1 shall not have any post-combustion control on NOx from this source category. The first of these combinations is on p. III-377.

7) Mineral Products – coal cleaning

Delete all add-on controls (all Fabric filters, ESPs, venturi scrubber) for
30501008
30501009
30501011
30501015
30501016
30501021
30501022
30501023
30501024
30501030
30501031
30501032
30501033
30501036
30501037
30501038
30501039
30501040
30501041
30501043
30501044
30501045
30501046
30501047
30501049
30501050
30501051
30501090
30501099

8) Fabricated metal products – welding

Donna Lee Jones of OAQPS/SPPD recommends following control options for fabricated metal products – welding SCCs 30900501 and 30904001.

* FF- cartridge type 25% control
* total enclosure and FF-cartridge type 99%
* hood and FF –cart 98%
* fume gun 75%
* pulse current 50%

Please include these measures and flag them in AirControlNET due to their being no cost data for them.

9) Mineral Products – Stone Quarrying & Processing

Please remove the applicability of dry ESPs and baghouses to the following SCCs (p. III-1080, 1084, 1088, 1092, 1096, 1100, and III-1104):

30502008
30502009
30502010
30502011
30502017
30502020

With this change in applicability, the IMF and CEM upgrade/IMF applicability to these SCCs shall also be removed.

10) Mineral Products Industry (p. III-1264)

Please remove the applicability of FGD (flue gas desulfurization) scrubbers to the following SCCs:

30500612
30599999

11) Mineral Products – Cement Manufacture

Please remove the applicability of fabric filters (any type) to the following SCCs:

30500607
30500608
30500615
30500619
30500699
30500707
30500708
30500719
30500799

For dry ESP – Wire Plate Type applied to Mineral Products – Cement Manufacture, please remove the applicability to these SCCs:

30500607
30500608
30500609
30500610

30500611
30500612
30500613
30500615
30500616
30500617
30500618
30500619
30500624
30500699
30500707
30500708
30500709
30500710
30500712
30500714
30500716
30500717
30500718
30500719
30500719
30500799

12) For Mineral Products – Cement Manufacture, Paper/Nonwoven Filters (p. III-987) please remove the applicability to these SCCs:

30500608
30500615
30500619
30500699
30500708
30500799

13) For Mineral Products – Cement Manufacture, Paper/Nonwoven Filters (p. III-987) please remove the applicability to these SCCs:

30500608
30500615
30500619
30500699
30500708
30500719
30500799

14) For Fabric Filter – any type at Ferrous Metals Processing – Coke, please remove the applicability to these SCCs:

30300302
30300304
30300308
30300334
30300401

15) For Venturi Scrubber applied to Ferrous Metal Processing – Coke, please remove the applicability to these SCCs:

30300302
30300304
30300308

16) For Vacuum Carbonate + Sulfur Recovery Plant applied to By-Product Coke Manufacturing (p. III-1248), please make this control measure applicable only to SCC 30300306. Also, change the control efficiency to 90% from 82%.

17) For FGD scrubbers applied in the Petroleum Industry (p. III-1267), please remove the applicability to these SCCs;

30600101
30600103
30600104
30600105
30600106
30600202
30600301
30600401
30600504
30600805
30600903
30600904
30600999
30601001
30601401
30609903
30609904

18) Remove FGD scrubber's applicability to Sulfur Recovery Plants – Elemental Sulfur (p. III-1302) and Sulfur Recovery Plants – Sulfur Removal (p. III-1304) from the control measures database.

19) Remove the IMF of PM Controls as well as the CEM Upgrade and IMF of PM Controls measure's applicability to the following source categories:

Commercial Institutional Boilers – Liquid Waste
Industrial Boilers – Liquid Waste
Commercial Institutional Boilers – LPG
Industrial Boilers - LPG
Commercial Institutional Boilers – Natural Gas
Industrial Boilers – Natural Gas
Commercial Institutional Boilers – Process Gas
Industrial Boilers – Process Gas

For Commercial Institutional Boilers – Oil , remove the applicability of Dry ESP – Wire Plate Type to SCC 10300501

For Commercial Institutional Boilers – Oil, remove the applicability of IMF of PM Controls and CEM Upgrade and IMF of PM Controls to SCC 103005

For Fabric Filter (Pulse Jet Type) applied to Commercial Institutional Boilers – Wood/Bark, change the control efficiency to 80%. This change is based on AP-42 emission factors for these sources.

For Dry ESP – Wire Plate Type applied to Commercial Institutional Boilers – Wood/Bark, change the control efficiency for both PM_{10} and $PM_{2.5}$ to 90%. This change is based on AP-42 emission factors for these sources.

For Commercial Institutional Boilers – Wood/Bark, change the control efficiency of fabric filters (any type) to 80% for both PM_{10} and $PM_{2.5}$. This change is based on AP-42 emission factors for these sources.

For Industrial Boilers – Oil, remove the applicability of IMF of PM Controls and CEM Upgrade and IMF of PM Controls to SCC 102005.

20) For FGD (both dry and wet) scrubbers applied to Bituminous/Subbituminous Coal, remove the applicability to SCC 10300217. Also, make the same change for Spray Dryer Absorber' and applicability to the same source category.

21) For Distillate Oil (Industrial Boilers), remove the applicability of Wet FGD scrubbers entirely to this source category.

Control Measures Added to AirControlNET 4.1

Area Source SO_2 Control Measure.

This measure will be a switch from high-sulfur (2,500 ppm sulfur content) to low-sulfur (500 ppm) home heating oil for residential users. Resulting control efficiencies are as follows:

75% - SO_2
80% - PM10 and PM2.5
10% - NOx

Note: there are no OC and EC control efficiencies with this measure.

The resulting costs are 1.5 cents/gallon. Presuming a density of 0.8 for home heating oil (HHO), 1 gallon = 0.8*8 = 6.4 lbs of oil. The costs in dollars per ton annually is thus (2000/6.4)*0.015 = $4.70/ton of HHO *(1 ton of oil/0.02 percent of sulfur/ton of oil) = 4.70 * 500 = $2,350/ton sulfur in HHO. Given that reduction of 1 part sulfur in HHO is equal to 1 part SO_2 emissions, then we can say that the cost per ton of SO_2 reduction due to this switch to home heating oil is also $2,350. Note: the study from which this data is taken states there is a 1:1 relationship between fuel sulfur contention reduction and SO_2 emissions reduction.

The cost for this measure in AirControlNET shall be $2,350/ton of SO_2 emissions reduction (2002$).

In addition, there is some evidence of reductions in maintenance costs for residential users due to reduced fouling of heating equipment and reduced cleaning. The costs have not been adjusted for these reductions. Please note this in the new at-a-glance table for this measure.

The SCC this control measure applies to: 2104004000 (Stationary Source Fuel **Combustion – Residential** - Distillate Oil).

Source: Low Sulfur Heating Oil in the Northeast States: An Overview of Benefits, Costs, and Implementation Issues. NESCAUM, Boston, MA. December 2005.

Area and Point Non-EGU PM Control Measures

ESP for Commercial Cooking or "Smog-Hog". Applied to Underfired Charbroilers. This control is to be applied to all commercial cooking category SCCs, but with a rule penetration of only 18.75% (equal to 75% of all commercial cooking emissions with application to 25% of this amount of emissions).

The capital cost of this control: $38,500 (range of capital costs from $2,000 - 75,000).

Annualized capital costs: $5,482. Equipment life of the control is 10 years, and costs are annualized at 7%.
O&M costs: $500.

Total annualized costs: $5,982.

Control efficiency: 99% of $PM_{2.5}$ and PM_{10}. OC and EC reductions are presumed to be identical to the PM reductions.

Plant-Specific $PM_{2.5}$ Control Measure Applications

Below in Table 1 is a list of control measures that exist on $PM_{2.5}$ point sources likely to be impacted control strategies associated with direct PM reductions in areas that our air quality modeling has shown to be nonattainment.

Table 1. New $PM_{2.5}$ Control Measures – for Various Iron and Steel Mill Emissions Points

Source Category	SCCs to be controlled	$PM_{2.5}$ Control measure/percent control	Plants to apply control measure to within SCCs	Costs (1999$)
Blast Furnace Casthouse	30300825	Install capture hoods vented to a baghouse (85% reduction, range of control efficiencies is 80 -90%)	AK Steel, Butler co., Ohio (Plant ID: 1409010006)	This control already installed April 2005, thus no additional control
	"		AK Steel, Ashland, KY (Plant ID: 2101900005)	Capital: $5.32 million; Annualized: $1.2 million*
	"		LTV (now Mittal), Cleveland, OH	"
	"		LTV (now Mittal), East Chicago, IN	"
	"	For this plant, apply control to 25% of	U.S. Steel, Gary, IN (Plant ID: 00121)	"

		emissions		
	30300824		Weirton Steel, Hancock Co., WV (Plant ID: 00001)	"
	30300825		Rouge Steel (now Severstal), Wayne Co., MI (Plant ID: A8640)	None (control already planned)
	30300825		Bethlehem (now Mittai) Steel, Porter Co., IN (Plant ID: 00001)	None (expected control due to MACT standard)
	30300825	For Republic Technologies, Lorain, OH apply control to 50% of emissions	Republic Technologies, Lorain, OH	"
Blast Open Furnace (BOF)-open hoods	30300913	Dedicated secondary capture and control system (use 85% as best estimate of control efficiency, range from 80-90%)	AK Steel, Butler co., Ohio (Plant ID: 1409010006)	None (Control already installed)
	"		Rouge Steel (now Severstal), Wayne Co., MI (Plant ID: A8640)	None (Control already installed)
	"		Bethelehem (now Mittai) Steel, Porter Co., IN (Plant ID: 00001)	Capital cost: $12.7 million, Annualized cost: $1.7 million*
	"		Bethelehem (now Mittai) Steel, Sparrows	"

			Point, MD (Plant ID: 0147)	
	“		LTV (now Mittal), Cleveland, OH	“
	“		LTV (now Mittal), East Chicago, IN	“
	“		National Steel (now U.S. Steel), Granite City, IL (Plant ID: 119813AAI)	“
	“	Apply control to half of emissions at Gary, IN plant	U.S. Steel, Gary, IN (Plant ID: 00121)	“
			Republic Technologies, Lorain, OH	“
	“		WCI Steel, Warren, OH (Plant ID: 0278000463)	“
	“		Weirton Steel, Hancock Co., WV (Plant ID: 0001)	“
	“		Wheeling-Pittsburgh Steel Mingo Junction, OH (Plant ID: 0641090010)	“
Sinter Cooler	30300817	99%	Assume for all plants in this SCC	$5,000 per ton $PM_{2.5}$ reduction

* Based on 7% interest rate and 20 year equipment life.

cc: Tim Smith, US EPA/OAQPS/AQPD/GSG

Appendix M. Projected PM2.5 Annual and Daily Design Values (µg/m^3) based on Air Quality Modeling

State	County	2015 Base Annual DV	2015 Base Daily DV	2020 Base Annual DV	2020 Base Daily DV	2020 15/65 Annual DV	2020 15/65 Daily DV	2020 15/35 Annual DV	2020 15/35 Daily DV	2020 14/35 Annual DV	2020 14/35 Daily DV
Alabama	Baldwin Co	9.1	19.2	9.1	19.0	8.9	18.4	8.8	18.4	8.5	17.5
Alabama	Clay Co	11.0	22.9	10.9	22.3	10.7	21.9	10.7	21.9	9.9	20.5
Alabama	Colbert Co	10.9	22.4	10.9	22.2	10.8	21.9	10.8	21.9	10.1	20.4
Alabama	DeKalb Co	12.1	28.3	12.0	27.6	11.9	27.4	11.9	27.3	11.2	26.2
Alabama	Escambia Co	10.7	21.3	10.6	21.0	10.5	20.8	10.4	20.8	10.1	19.9
Alabama	Houston Co	12.4	25.1	12.3	24.8	12.2	24.6	12.2	24.6	11.7	23.7
Alabama	Jefferson Co	15.9	36.9	15.7	36.3	15.1	34.2	15.1	34.1	14.5	33.0
Alabama	Madison Co	11.3	23.5	11.2	23.0	11.0	22.8	11.0	22.7	10.3	21.3
Alabama	Mobile Co	11.9	24.2	12.1	24.3	11.8	23.9	11.7	23.8	11.5	23.2
Alabama	Montgomery Co	13.1	26.2	12.8	25.5	12.6	25.2	12.6	25.2	12.0	24.1
Alabama	Morgan Co	12.8	26.6	12.8	26.1	12.7	25.7	12.6	25.7	11.8	23.6
Alabama	Russell Co	13.3	30.0	13.2	29.6	13.0	29.4	13.0	29.3	12.4	28.5
Alabama	Shelby Co	12.3	26.1	12.2	25.8	11.9	25.1	11.9	25.1	11.3	23.9
Alabama	Sumter Co	10.6	23.6	10.5	23.0	10.3	22.7	10.3	22.7	9.9	21.6
Alabama	Talladega Co	12.2	27.1	12.3	26.9	12.1	26.4	12.1	26.4	11.1	24.8
Arizona	Gila Co	9.2	22.6	9.1	22.4	9.1	22.3	9.0	22.2	9.0	22.2
Arizona	Maricopa Co	10.4	29.0	10.2	28.5	10.1	28.3	10.1	28.2	10.1	28.2
Arizona	Pima Co	7.2	16.5	7.1	16.4	7.1	16.3	7.1	16.3	7.1	16.3
Arizona	Pinal Co	8.1	18.9	8.0	18.6	8.0	18.5	8.0	18.5	7.9	18.5
Arizona	Santa Cruz Co	11.6	29.2	12.0	30.0	11.9	29.8	11.9	29.7	11.9	29.7
Arkansas	Arkansas Co	10.1	21.4	10.0	20.9	9.8	20.5	9.8	20.4	9.5	19.5
Arkansas	Ashley Co	10.7	23.9	10.6	23.6	10.4	23.3	10.4	23.3	10.1	22.7
Arkansas	Craighead Co	10.1	22.9	9.9	22.4	9.7	22.0	9.7	21.9	9.4	21.0
Arkansas	Crittenden Co	11.1	24.5	11.1	24.3	10.9	23.8	10.9	23.7	10.6	22.9
Arkansas	Faulkner Co	10.6	22.2	10.4	21.7	10.3	21.3	10.3	21.3	10.1	20.5
Arkansas	Jefferson Co	11.5	23.6	11.3	23.2	11.2	22.9	11.2	22.8	11.0	22.2
Arkansas	Mississippi Co	9.8	22.6	9.7	22.0	9.5	21.6	9.5	21.5	9.2	20.7
Arkansas	Phillips Co	10.1	22.3	10.1	22.0	9.9	21.6	9.8	21.6	9.5	20.8
Arkansas	Polk Co	9.4	19.4	9.2	18.6	9.0	18.3	9.0	18.2	8.7	17.5
Arkansas	Pope Co	10.8	22.9	10.6	22.4	10.5	22.2	10.5	22.2	10.3	21.8
Arkansas	Pulaski Co	12.2	26.7	12.0	26.2	11.8	25.9	11.8	25.9	11.5	25.3
Arkansas	Sebastian Co	10.8	21.5	10.5	21.0	10.4	20.8	10.4	20.8	10.1	20.2
Arkansas	Union Co	11.9	26.1	11.8	25.8	11.7	25.4	11.6	25.4	11.4	24.6
Arkansas	White Co	9.8	19.6	9.7	19.2	9.5	18.9	9.5	18.8	9.2	18.1
California	Alameda Co	13.3	59.4	13.2	58.7	11.7	50.7	11.4	49.5	11.5	49.6
California	Butte Co	13.4	50.7	13.0	48.6	12.7	46.3	11.8	42.2	11.7	42.1
California	Calaveras Co	8.3	21.9	8.1	21.1	7.8	19.8	7.7	19.5	7.7	19.5
California	Colusa Co	9.5	33.5	9.3	32.5	9.0	30.3	8.6	28.8	8.6	28.8
California	Contra Costa Co	12.6	61.3	12.5	61.1	11.1	52.6	10.9	51.5	10.9	51.5
California	El Dorado Co	7.5	18.3	7.4	18.0	7.2	17.7	6.8	16.9	6.8	16.9
California	Fresno Co	20.1	73.0	19.6	70.4	17.3	59.6	16.9	58.2	17.0	58.3

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California	Humboldt Co	8.2	24.2	8.1	23.4	8.0	23.1	7.9	22.7	7.9	22.7
California	Imperial Co	14.8	45.7	14.8	44.9	14.4	43.0	13.8	41.5	13.8	41.5
California	Inyo Co	6.1	38.1	6.0	37.7	5.9	36.0	5.8	35.4	5.8	35.4
California	Kern Co	21.3	81.4	20.8	77.9	18.6	68.0	18.2	66.5	18.2	66.6
California	Kings Co	17.2	70.6	16.8	67.6	15.6	61.0	15.2	59.5	15.2	59.6
California	Lake Co	4.8	10.9	4.7	10.6	4.6	10.1	4.6	9.9	4.6	9.9
California	Los Angeles Co	23.7	62.2	23.9	62.7	21.6	58.1	21.3	56.8	21.3	56.8
California	Mendocino Co	7.8	25.3	7.7	25.2	7.5	24.2	7.4	23.8	7.4	23.8
California	Merced Co	15.8	54.4	15.6	53.1	14.4	47.7	14.0	46.3	14.0	46.3
California	Monterey Co	8.4	19.5	8.5	19.5	7.9	17.8	7.7	17.3	7.7	17.3
California	Nevada Co	7.8	23.4	7.7	22.9	7.5	22.2	7.0	20.9	7.0	20.9
California	Orange Co	20.0	41.1	20.2	40.7	18.2	35.6	17.9	35.0	17.9	35.0
California	Placer Co	11.4	38.1	11.2	36.5	9.8	30.6	8.6	26.9	8.6	26.9
California	Riverside Co	27.8	73.5	27.5	73.9	22.7	63.2	22.3	61.1	22.3	61.1
California	Sacramento Co	12.2	49.8	12.1	48.3	10.9	42.0	10.5	40.0	10.5	39.9
California	San Bernardino Co	24.6	65.7	24.6	65.8	21.4	58.1	21.1	56.7	21.1	56.7
California	San Diego Co	15.8	40.7	15.7	40.1	13.7	34.6	13.5	34.0	13.5	34.0
California	San Francisco Co	11.3	52.5	11.4	52.4	9.6	42.4	9.4	41.5	9.4	41.5
California	San Joaquin Co	15.4	51.1	16.0	52.0	14.4	45.3	14.1	44.0	14.1	44.0
California	San Luis Obispo Co	9.4	35.8	9.4	35.6	8.6	31.6	8.4	30.6	8.4	30.6
California	San Mateo Co	10.5	41.9	10.5	41.6	9.6	36.5	9.4	35.7	9.4	35.7
California	Santa Barbara Co	9.5	20.4	9.5	20.3	8.7	18.7	8.5	18.0	8.5	18.0
California	Santa Clara Co	10.7	48.5	12.0	52.3	11.3	48.2	11.2	47.1	11.2	47.1
California	Santa Cruz Co	8.1	19.1	8.0	19.0	7.4	17.3	7.2	16.9	7.2	16.9
California	Shasta Co	9.0	31.0	8.7	30.1	8.6	29.7	8.5	29.3	8.5	29.3
California	Solano Co	11.7	57.7	11.7	57.3	10.2	48.3	9.9	46.6	9.9	46.6
California	Sonoma Co	10.0	38.9	9.8	38.2	9.4	35.3	9.2	34.1	9.2	34.1
California	Stanislaus Co	16.6	61.9	16.2	59.2	14.5	51.5	14.1	49.9	14.1	49.9
California	Sutter Co	11.2	39.3	10.9	37.9	10.5	35.5	9.6	32.0	9.6	32.0
California	Tulare Co	21.2	77.2	20.6	73.6	18.9	65.4	18.5	64.2	18.6	64.3
California	Ventura Co	14.1	38.8	14.0	38.7	12.0	33.4	11.8	32.7	11.8	32.7
California	Yolo Co	10.2	33.0	10.0	31.8	9.1	27.5	8.7	26.2	8.7	26.2
Colorado	Adams Co	9.2	22.9	9.0	22.6	9.0	22.6	9.0	22.3	9.0	22.3
Colorado	Arapahoe Co	8.1	21.4	8.0	21.1	7.9	21.1	7.9	20.9	7.9	20.9
Colorado	Boulder Co	8.5	20.9	8.4	20.6	8.3	20.5	8.3	20.4	8.3	20.4
Colorado	Delta Co	7.9	16.8	7.8	16.5	7.8	16.4	7.8	16.4	7.8	16.4
Colorado	Denver Co	9.7	26.3	9.5	25.9	9.5	26.0	9.5	25.6	9.5	25.6
Colorado	Elbert Co	4.0	10.0	4.0	9.9	4.0	9.8	3.9	9.8	3.9	9.8
Colorado	El Paso Co	7.1	16.6	7.0	16.4	6.9	16.4	6.9	16.2	6.9	16.2
Colorado	Gunnison Co	6.5	17.3	6.4	17.1	6.4	17.1	6.4	17.0	6.4	17.0
Colorado	La Plata Co	5.2	13.3	5.1	13.1	5.1	13.0	5.1	13.0	5.1	13.0
Colorado	Larimer Co	7.5	18.7	7.4	18.4	7.4	18.4	7.4	18.3	7.4	18.3
Colorado	Mesa Co	7.2	17.7	7.1	17.6	7.1	17.5	7.0	17.2	7.0	17.2
Colorado	Pueblo Co	7.5	16.9	7.5	16.7	7.4	16.6	7.4	16.6	7.4	16.6

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Colorado	Routt Co	7.3	15.7	7.2	15.6	7.2	15.5	7.2	15.5	7.2	15.5
Colorado	San Miguel Co	5.4	11.4	5.4	11.2	5.3	11.2	5.3	11.1	5.3	11.1
Colorado	Weld Co	8.5	23.6	8.3	23.2	8.3	23.0	8.3	22.9	8.3	22.9
Connecticut	Fairfield Co	11.0	31.6	10.9	31.2	10.7	31.1	10.6	30.9	10.5	30.6
Connecticut	Hartford Co	10.5	29.1	10.4	28.7	10.3	28.6	10.3	28.5	10.2	28.3
Connecticut	New Haven Co	11.2	29.7	11.1	29.2	10.9	29.2	10.9	29.0	10.8	28.8
Connecticut	New London Co	9.4	23.9	9.3	23.7	9.2	23.6	9.2	23.6	9.1	23.3
Delaware	Kent Co	9.5	0.0	9.4	0.0	9.3	0.0	9.2	0.0	9.0	0.0
Delaware	New Castle Co	13.0	27.4	13.0	27.2	12.9	27.2	12.8	26.9	12.5	26.7
Delaware	Sussex Co	10.5	0.0	10.3	0.0	10.2	0.0	10.1	0.0	9.9	0.0
District of Columbia	District of Columbia	11.7	31.1	11.5	30.7	11.4	30.6	11.3	30.4	11.1	29.9
Florida	Alachua Co	8.3	18.1	8.2	18.0	8.1	17.8	8.1	17.8	7.9	17.4
Florida	Brevard Co	5.8	14.4	5.7	14.2	5.6	14.1	5.6	14.1	5.5	13.6
Florida	Broward Co	6.7	16.7	6.7	16.7	6.6	16.4	6.5	16.3	6.5	16.2
Florida	Citrus Co	6.9	15.9	6.9	15.7	6.8	15.6	6.8	15.5	6.7	15.0
Florida	Duval Co	8.8	21.0	8.8	20.8	8.7	20.6	8.7	20.5	8.4	19.9
Florida	Escambia Co	10.0	20.1	9.9	19.9	9.8	19.7	9.8	19.7	9.5	19.0
Florida	Hillsborough Co	8.7	18.4	8.6	18.2	8.5	18.0	8.5	18.0	8.4	17.4
Florida	Lee Co	6.4	14.4	6.3	14.3	6.3	14.1	6.3	14.1	6.1	13.7
Florida	Leon Co	10.9	22.6	10.8	22.3	10.7	22.1	10.7	22.1	10.4	21.4
Florida	Manatee Co	7.0	16.8	7.0	16.8	6.9	16.5	6.8	16.5	6.7	16.0
Florida	Marion Co	8.0	16.7	7.9	16.5	7.9	16.4	7.8	16.4	7.7	16.0
Florida	Miami-Dade Co	7.8	15.8	7.6	15.6	7.6	15.5	7.5	15.4	7.4	15.2
Florida	Orange Co	8.2	19.1	8.1	18.8	8.1	18.7	8.1	18.7	7.9	18.1
Florida	Palm Beach Co	5.6	14.6	5.6	14.4	5.5	14.3	5.5	14.3	5.4	13.9
Florida	Pinellas Co	7.8	16.9	7.9	17.0	7.7	16.8	7.7	16.8	7.6	16.4
Florida	Polk Co	8.3	18.9	8.7	19.4	8.6	19.2	8.6	19.2	8.5	18.6
Florida	St. Lucie Co	6.7	14.5	6.6	14.3	6.5	14.1	6.5	14.1	6.3	13.6
Florida	Sarasota Co	7.1	17.9	7.1	17.7	6.9	17.4	6.9	17.4	6.8	16.8
Florida	Seminole Co	7.4	15.9	7.3	15.6	7.2	15.5	7.2	15.4	7.0	14.9
Florida	Volusia Co	7.3	15.5	7.2	15.3	7.1	15.1	7.1	15.1	6.9	14.7
Georgia	Bibb Co	13.7	27.0	13.6	26.8	13.5	26.6	13.5	26.5	12.7	25.4
Georgia	Chatham Co	12.4	25.3	12.3	25.0	12.1	24.7	12.1	24.6	11.4	23.4
Georgia	Clarke Co	12.9	26.0	12.6	25.4	12.5	25.1	12.4	25.1	11.4	23.7
Georgia	Clayton Co	13.9	28.7	13.7	27.9	13.5	27.5	13.5	27.5	12.8	26.2
Georgia	Cobb Co	13.5	28.6	13.4	28.0	13.1	27.5	13.1	27.5	12.5	26.2
Georgia	DeKalb Co	13.6	31.5	13.3	30.7	13.0	30.1	13.0	30.0	12.3	28.8
Georgia	Dougherty Co	12.7	28.0	12.6	27.6	12.5	27.4	12.5	27.4	12.0	26.6
Georgia	Floyd Co	14.0	30.9	14.0	30.4	13.8	30.2	13.8	30.1	13.2	28.8
Georgia	Fulton Co	15.5	32.2	15.3	31.5	14.9	30.7	14.9	30.7	14.2	29.6
Georgia	Glynn Co	10.1	23.6	10.0	23.3	9.9	23.1	9.9	23.1	9.4	22.3
Georgia	Gwinnett Co	12.7	0.0	12.5	0.0	12.2	0.0	12.2	0.0	11.5	0.0
Georgia	Hall Co	12.3	25.3	12.0	24.6	11.9	24.3	11.8	24.3	11.1	23.1
Georgia	Houston Co	10.4	0.0	10.5	0.0	10.5	0.0	10.4	0.0	9.9	0.0

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Georgia	Lowndes Co	10.1	24.6	10.0	24.3	9.9	24.2	9.9	24.2	9.6	23.3
Georgia	Muscogee Co	13.4	34.2	13.2	33.8	13.1	33.5	13.0	33.4	12.5	32.5
Georgia	Paulding Co	11.7	30.5	11.7	29.8	11.5	29.3	11.5	29.3	10.8	27.4
Georgia	Richmond Co	13.0	28.0	12.7	27.5	12.7	27.4	12.6	27.3	11.8	26.2
Georgia	Walker Co	12.1	24.5	12.0	24.1	11.9	23.8	11.9	23.7	11.1	22.5
Georgia	Washington Co	12.6	0.0	12.6	0.0	12.5	0.0	12.5	0.0	11.6	0.0
Georgia	Wilkinson Co	13.6	29.3	13.4	29.1	13.4	29.0	13.3	28.9	12.7	28.0
Idaho	Ada Co	8.9	32.2	8.8	31.7	8.8	31.6	8.8	31.4	8.8	31.4
Idaho	Bannock Co	9.1	40.2	9.1	40.0	9.1	39.9	8.8	38.7	8.8	38.7
Idaho	Bonneville Co	6.6	20.2	6.6	20.1	6.5	20.0	6.5	19.9	6.5	19.9
Idaho	Canyon Co	9.2	32.6	9.1	31.9	9.1	31.7	9.0	31.5	9.0	31.5
Idaho	Power Co	10.5	36.6	10.4	36.4	10.4	36.3	10.1	35.1	10.1	35.1
Idaho	Shoshone Co	12.4	36.2	12.4	36.0	12.3	35.9	12.2	35.6	12.2	35.6
Illinois	Adams Co	11.3	23.5	11.1	22.9	10.9	22.6	10.9	22.6	10.4	21.4
Illinois	Champaign Co	10.6	23.7	10.5	23.4	10.3	23.2	10.3	23.1	9.9	22.6
Illinois	Cook Co	15.5	37.1	15.3	36.5	14.5	35.3	14.5	35.3	14.2	34.7
Illinois	DuPage Co	12.6	30.8	12.4	30.5	12.0	29.8	12.0	29.7	11.7	29.4
Illinois	Kane Co	12.3	29.8	12.1	29.3	11.7	28.9	11.8	28.8	11.5	28.4
Illinois	Lake Co	11.3	27.2	11.1	26.9	10.6	26.3	10.6	26.2	10.4	26.0
Illinois	La Salle Co	0.0	28.3	0.0	28.0	0.0	27.6	0.0	27.5	0.0	27.1
Illinois	McHenry Co	11.1	29.1	10.9	28.7	10.7	28.2	10.7	28.1	10.4	27.7
Illinois	McLean Co	11.7	25.2	11.5	25.0	11.3	24.6	11.3	24.5	10.8	23.9
Illinois	Macon Co	12.0	30.0	11.9	29.7	11.7	29.4	11.7	29.4	11.4	28.6
Illinois	Madison Co	15.2	35.5	15.1	35.3	14.6	34.4	14.6	34.3	14.0	33.2
Illinois	Peoria Co	12.2	29.0	12.1	28.4	11.6	27.5	11.6	27.5	10.9	26.0
Illinois	Randolph Co	10.7	22.8	10.5	22.4	10.4	22.0	10.3	21.9	9.9	21.0
Illinois	Rock Island Co	10.5	23.2	10.3	22.8	10.2	22.5	10.2	22.5	9.9	21.8
Illinois	St. Clair Co	14.6	30.4	14.5	30.2	14.1	29.4	14.0	29.3	13.4	28.2
Illinois	Sangamon Co	11.4	26.5	11.2	25.8	11.0	25.4	11.0	25.4	10.6	24.4
Illinois	Will Co	13.2	32.0	13.0	31.7	12.7	31.0	12.7	31.0	12.4	30.5
Indiana	Allen Co	12.0	30.0	11.7	29.6	11.6	29.3	11.6	29.2	11.2	28.8
Indiana	Clark Co	13.6	31.1	13.4	30.4	13.2	30.0	13.2	29.9	12.7	28.7
Indiana	Delaware Co	11.7	27.0	11.5	26.4	11.4	26.2	11.4	26.1	11.0	25.4
Indiana	Dubois Co	12.9	0.0	12.7	0.0	12.5	0.0	12.5	0.0	12.1	0.0
Indiana	Elkhart Co	12.7	29.7	12.4	29.2	12.2	28.6	12.2	28.5	11.9	28.0
Indiana	Floyd Co	12.0	26.9	11.9	26.5	11.7	26.1	11.7	26.0	11.2	25.1
Indiana	Henry Co	10.7	24.2	10.5	23.9	10.4	23.7	10.3	23.7	10.0	23.3
Indiana	Howard Co	12.1	29.9	11.9	29.4	11.8	29.1	11.7	29.0	11.4	28.4
Indiana	Knox Co	10.8	24.4	10.6	23.8	10.4	23.4	10.4	23.3	10.1	22.3
Indiana	Lake Co	13.4	40.8	13.3	40.4	12.4	36.9	12.4	36.8	12.2	36.5
Indiana	La Porte Co	11.6	27.7	11.4	27.3	10.9	26.1	10.9	26.0	10.6	25.7
Indiana	Madison Co	11.8	27.1	11.5	26.7	11.4	26.4	11.4	26.4	11.0	25.9
Indiana	Marion Co	13.5	33.1	13.2	32.5	13.1	32.3	13.1	32.1	12.7	31.5
Indiana	Porter Co	12.5	29.5	12.3	29.1	10.9	26.3	10.9	26.3	10.6	26.0

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Indiana	St. Joseph Co	12.2	29.8	11.9	29.3	11.6	28.5	11.6	28.4	11.3	28.0
Indiana	Spencer Co	11.3	23.2	11.1	22.4	10.9	22.1	10.9	22.0	10.4	21.2
Indiana	Vanderburgh Co	12.7	29.1	12.5	28.7	12.3	28.4	12.3	28.3	11.7	27.1
Indiana	Vigo Co	12.0	28.7	11.8	28.3	11.7	28.0	11.7	27.9	11.3	27.1
Iowa	Black Hawk Co	9.9	24.3	9.7	24.2	9.6	23.9	9.6	23.9	9.5	23.0
Iowa	Cerro Gordo Co	9.1	24.3	9.0	23.8	8.9	23.6	8.9	23.6	8.8	23.3
Iowa	Clinton Co	10.5	27.2	10.3	26.6	10.1	26.2	10.1	26.2	9.9	25.9
Iowa	Emmet Co	7.6	19.2	7.4	18.8	7.4	18.5	7.4	18.5	7.3	18.1
Iowa	Johnson Co	9.9	25.8	9.8	25.4	9.7	25.2	9.7	25.1	9.5	24.7
Iowa	Linn Co	9.9	27.2	9.8	27.0	9.7	26.6	9.6	26.6	9.5	25.5
Iowa	Muscatine Co	11.2	28.7	11.1	28.4	11.0	28.0	11.0	28.0	10.8	26.9
Iowa	Polk Co	9.1	23.1	8.9	22.6	8.8	22.5	8.8	22.4	8.7	22.3
Iowa	Pottawattamie Co	9.0	21.2	8.9	21.0	8.9	20.8	8.8	20.8	8.8	20.5
Iowa	Scott Co	10.7	26.1	10.5	25.6	10.4	25.3	10.4	25.3	10.1	24.9
Iowa	Van Buren Co	8.9	22.8	8.7	22.4	8.6	22.1	8.6	22.1	8.4	21.3
Iowa	Woodbury Co	8.8	22.3	8.7	21.8	8.6	21.6	8.6	21.6	8.5	21.5
Kansas	Johnson Co	10.1	23.6	9.9	23.1	9.8	22.9	9.8	22.9	9.6	22.6
Kansas	Linn Co	9.0	19.9	8.9	19.6	8.7	19.3	8.7	19.3	8.6	18.7
Kansas	Sedgwick Co	9.7	21.7	9.6	21.4	9.5	21.2	9.5	21.1	9.4	20.7
Kansas	Shawnee Co	9.6	21.1	9.4	20.8	9.3	20.5	9.3	20.5	9.2	20.0
Kansas	Sumner Co	8.8	18.8	8.6	18.4	8.5	18.2	8.5	18.2	8.4	17.9
Kansas	Wyandotte Co	11.9	26.4	11.7	25.9	11.5	25.7	11.5	25.6	11.4	25.3
Kentucky	Bell Co	11.4	24.8	10.9	23.9	10.8	23.6	10.8	23.6	10.3	22.7
Kentucky	Boyd Co	11.5	25.2	11.4	25.0	11.0	24.5	11.0	24.4	10.6	23.9
Kentucky	Bullitt Co	11.9	25.5	11.7	24.8	11.5	24.5	11.5	24.5	11.0	23.6
Kentucky	Campbell Co	10.7	27.3	10.5	26.8	10.3	26.3	10.3	26.2	9.8	25.2
Kentucky	Carter Co	9.2	19.8	9.0	19.3	8.8	18.9	8.8	18.8	8.4	18.1
Kentucky	Christian Co	11.1	22.9	10.9	22.6	10.8	22.4	10.8	22.3	10.3	21.6
Kentucky	Daviess Co	11.4	24.7	11.3	24.3	11.1	24.0	11.1	23.9	10.6	22.9
Kentucky	Fayette Co	12.2	26.0	11.9	25.5	11.7	25.2	11.7	25.1	11.2	24.4
Kentucky	Franklin Co	10.5	24.9	10.2	24.1	10.0	23.8	10.0	23.7	9.5	23.0
Kentucky	Hardin Co	11.0	24.1	10.8	23.5	10.7	23.2	10.6	23.2	10.1	22.2
Kentucky	Jefferson Co	13.8	33.4	13.6	32.9	13.4	32.6	13.4	32.5	12.9	31.6
Kentucky	Kenton Co	11.5	28.7	11.3	28.2	11.1	27.6	11.0	27.5	10.5	26.5
Kentucky	McCracken Co	11.4	23.9	11.3	23.5	11.1	23.2	11.1	23.1	10.6	22.1
Kentucky	Madison Co	10.4	21.3	10.1	20.6	9.9	20.3	9.9	20.2	9.5	19.4
Kentucky	Perry Co	10.1	0.0	9.8	0.0	9.6	0.0	9.6	0.0	9.2	0.0
Kentucky	Pike Co	10.7	21.3	10.4	20.6	10.2	20.3	10.2	20.2	9.8	19.4
Kentucky	Warren Co	11.2	24.5	11.1	24.1	10.9	23.8	10.9	23.7	10.4	22.7
Louisiana	Caddo Parish	11.4	24.6	11.3	24.3	11.1	24.0	11.1	24.0	10.9	23.3
Louisiana	Calcasieu Parish	10.2	26.5	10.2	26.2	9.9	25.7	9.9	25.6	9.7	24.7
Louisiana	East Baton Rouge Parish	12.7	27.4	12.9	27.8	12.6	27.2	12.5	27.1	12.4	26.8
Louisiana	Iberville Parish	12.0	27.4	12.2	27.7	11.8	27.2	11.7	27.1	11.5	26.7
Louisiana	Jefferson Parish	11.4	24.7	11.5	25.1	11.1	24.4	11.0	24.3	10.8	24.0

State	County	2015 Base Annual DV	2015 Base Daily DV	2020 Base Annual DV	2020 Base Daily DV	2020 15/65 Annual DV	2020 15/65 Daily DV	2020 15/35 Annual DV	2020 15/35 Daily DV	2020 14/35 Annual DV	2020 14/35 Daily DV
Louisiana	Lafayette Parish	9.9	22.8	9.8	22.6	9.6	22.0	9.6	21.9	9.4	21.1
Louisiana	Orleans Parish	11.6	26.4	11.7	26.7	11.3	25.9	11.2	25.8	11.0	25.3
Louisiana	Ouachita Parish	10.9	23.8	10.8	23.5	10.7	23.2	10.7	23.2	10.6	22.6
Louisiana	St. Bernard Parish	8.8	17.7	8.8	17.6	8.4	17.0	8.4	16.9	8.1	16.2
Louisiana	Tangipahoa Parish	10.2	21.5	10.2	21.4	9.8	20.5	9.8	20.5	9.6	19.8
Louisiana	Terrebonne Parish	9.0	20.8	9.0	20.8	8.8	20.5	8.8	20.5	8.6	20.0
Louisiana	West Baton Rouge Parish	12.3	26.4	12.5	26.7	12.2	26.1	12.1	26.0	12.0	25.7
Maine	Androscoggin Co	9.4	25.2	9.2	24.7	9.2	24.6	9.2	24.5	9.1	24.4
Maine	Aroostook Co	10.4	25.1	10.3	25.1	10.3	25.1	10.3	25.0	10.3	25.0
Maine	Cumberland Co	10.0	29.2	9.8	28.6	9.8	28.6	9.7	28.5	9.7	28.4
Maine	Hancock Co	5.3	17.1	5.3	17.0	5.2	16.8	5.2	16.8	5.2	16.5
Maine	Kennebec Co	9.4	24.8	9.2	24.4	9.2	24.3	9.2	24.3	9.1	24.2
Maine	Oxford Co	9.2	22.9	9.1	22.6	9.1	22.5	9.1	22.5	9.0	22.3
Maine	Penobscot Co	9.0	24.8	8.9	24.5	8.8	24.5	8.8	24.4	8.8	24.2
Maine	York Co	8.4	23.4	8.2	23.1	8.2	23.0	8.2	22.9	8.1	22.7
Maryland	Anne Arundel Co	11.1	33.2	11.0	33.1	10.9	33.0	10.8	32.7	10.6	32.3
Maryland	Baltimore Co	11.3	32.6	11.2	32.3	11.1	32.1	11.0	31.9	10.8	31.5
Maryland	Harford Co	9.9	26.0	9.8	25.8	9.7	25.7	9.6	25.5	9.5	25.2
Maryland	Montgomery Co	9.2	27.2	9.1	27.1	9.0	26.9	8.9	26.7	8.7	26.3
Maryland	Washington Co	10.0	28.7	9.9	28.3	9.8	28.2	9.6	27.9	9.5	27.6
Maryland	Baltimore city	13.0	35.5	12.9	35.2	12.7	35.0	12.6	34.7	12.4	34.4
Massachusetts	Berkshire Co	10.4	26.0	10.3	25.6	10.3	25.5	10.2	25.4	10.2	25.2
Massachusetts	Hampden Co	11.6	32.9	11.4	32.4	11.3	32.4	11.3	32.3	11.2	32.1
Massachusetts	Plymouth Co	9.1	24.4	9.0	24.2	8.9	24.1	8.9	24.1	8.8	23.9
Massachusetts	Suffolk Co	10.4	25.4	10.1	25.1	10.0	25.0	10.0	24.9	9.9	24.7
Michigan	Allegan Co	10.8	31.1	10.6	30.6	10.3	29.9	10.3	29.8	10.1	29.4
Michigan	Bay Co	10.4	27.5	10.2	27.1	9.9	26.2	9.9	26.1	9.7	25.7
Michigan	Berrien Co	10.9	28.4	10.7	28.1	10.4	27.5	10.4	27.4	10.1	27.1
Michigan	Chippewa Co	7.7	24.1	7.9	24.4	7.8	24.0	7.8	24.0	7.7	23.6
Michigan	Genesee Co	11.2	29.2	11.0	28.7	10.7	28.0	10.6	27.9	10.4	27.2
Michigan	Ingham Co	11.5	30.0	11.3	29.4	11.0	28.8	11.0	28.6	10.7	28.1
Michigan	Kalamazoo Co	12.8	32.7	12.6	32.3	12.3	31.7	12.3	31.6	12.0	31.1
Michigan	Kent Co	12.0	31.9	11.8	31.3	11.5	30.7	11.5	30.6	11.3	30.2
Michigan	Macomb Co	11.4	29.3	11.2	29.1	10.9	28.7	10.9	28.5	10.6	28.1
Michigan	Monroe Co	12.8	30.1	12.5	29.4	12.2	28.9	12.1	28.7	11.8	28.1
Michigan	Muskegon Co	10.8	30.1	10.6	29.5	10.4	28.8	10.4	28.7	10.2	28.0
Michigan	Oakland Co	13.0	33.2	12.9	33.2	12.6	32.6	12.5	32.3	12.2	31.8
Michigan	Ottawa Co	11.6	28.6	11.4	27.8	11.1	27.2	11.1	27.1	10.9	26.5
Michigan	Saginaw Co	9.7	25.8	9.5	25.6	8.9	24.4	8.8	24.3	8.6	24.0
Michigan	St. Clair Co	12.5	32.5	12.6	32.3	12.3	31.7	12.3	31.5	11.9	30.8
Michigan	Washtenaw Co	12.3	30.2	12.1	29.7	11.7	28.9	11.7	28.7	11.3	28.1
Michigan	Wayne Co	17.4	39.0	17.3	39.0	16.9	38.4	16.8	38.1	16.4	37.5
Minnesota	Dakota Co	8.9	24.1	8.7	23.6	8.6	23.3	8.6	23.3	8.5	23.0
Minnesota	Hennepin Co	9.4	25.5	9.3	25.1	9.2	24.9	9.2	24.9	9.1	24.6

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Minnesota	Mille Lacs Co	6.5	19.7	6.4	19.4	6.4	19.2	6.4	19.2	6.3	19.0
Minnesota	Olmsted Co	9.6	25.1	9.4	24.8	9.3	24.6	9.3	24.6	9.2	23.9
Minnesota	Ramsey Co	10.6	28.2	10.5	27.8	10.4	27.5	10.4	27.5	10.3	27.1
Minnesota	St. Louis Co	8.0	21.6	8.0	21.7	7.8	21.4	7.8	21.3	7.8	21.0
Minnesota	Scott Co	9.0	22.5	8.8	21.9	8.8	21.8	8.8	21.7	8.7	21.6
Minnesota	Stearns Co	8.5	23.3	8.3	22.9	8.3	22.7	8.3	22.7	8.2	22.4
Mississippi	Adams Co	9.5	24.3	9.5	24.1	9.2	23.6	9.2	23.5	9.0	22.6
Mississippi	Bolivar Co	10.5	25.5	10.4	25.1	10.2	24.7	10.2	24.7	9.9	23.7
Mississippi	DeSoto Co	10.7	21.8	10.6	21.5	10.4	21.0	10.4	20.9	10.0	19.6
Mississippi	Forrest Co	11.2	25.0	11.1	24.7	10.9	24.4	10.9	24.4	10.6	23.7
Mississippi	Hancock Co	8.9	18.5	8.9	18.4	8.5	17.8	8.5	17.7	8.3	17.2
Mississippi	Harrison Co	9.3	21.0	9.3	20.9	9.1	20.7	9.1	20.6	8.8	20.0
Mississippi	Hinds Co	11.5	24.4	11.3	24.0	11.1	23.7	11.1	23.6	10.9	22.9
Mississippi	Jackson Co	10.3	20.8	10.4	20.8	10.1	20.4	10.1	20.3	9.8	19.4
Mississippi	Jones Co	12.6	24.3	12.5	23.9	12.3	23.6	12.3	23.5	11.9	22.6
Mississippi	Lauderdale Co	10.7	24.7	10.6	24.3	10.4	23.9	10.4	23.9	10.0	23.0
Mississippi	Lee Co	10.6	20.1	10.4	19.5	10.3	19.2	10.3	19.2	9.8	18.1
Mississippi	Lowndes Co	11.4	25.0	11.2	24.5	11.1	24.2	11.1	24.1	10.6	22.5
Mississippi	Pearl River Co	9.8	21.1	9.7	20.9	9.5	20.6	9.4	20.5	9.2	19.8
Mississippi	Rankin Co	10.9	23.9	10.7	23.5	10.5	23.2	10.5	23.1	10.3	22.5
Mississippi	Scott Co	9.5	20.8	9.3	20.3	9.2	20.0	9.2	20.0	8.9	19.1
Mississippi	Warren Co	10.3	23.0	10.3	22.8	10.0	22.3	9.9	22.2	9.7	21.3
Missouri	Buchanan Co	10.7	24.3	10.6	23.9	10.4	23.7	10.4	23.6	10.3	23.3
Missouri	Cass Co	9.6	22.3	9.4	21.9	9.3	21.7	9.3	21.7	9.2	21.3
Missouri	Cedar Co	9.7	22.0	9.5	21.6	9.4	21.4	9.3	21.4	9.1	20.8
Missouri	Clay Co	11.1	26.1	11.0	25.7	10.8	25.5	10.8	25.4	10.7	25.3
Missouri	Greene Co	10.4	22.9	10.2	22.5	10.1	22.2	10.1	22.2	9.8	21.5
Missouri	Jackson Co	10.6	24.7	10.4	24.2	10.3	23.9	10.3	23.9	10.1	23.6
Missouri	Jasper Co	11.8	23.1	11.6	22.6	11.5	22.3	11.5	22.3	11.3	21.5
Missouri	Jefferson Co	12.6	28.1	12.4	27.7	12.2	27.3	12.2	27.3	11.7	25.9
Missouri	Monroe Co	9.5	24.2	9.3	23.8	9.2	23.5	9.2	23.5	8.9	22.7
Missouri	St. Charles Co	12.3	29.9	12.1	29.5	11.9	29.1	11.9	29.0	11.2	27.7
Missouri	Ste. Genevieve Co	11.8	25.8	11.7	25.6	11.5	25.1	11.4	25.1	11.0	23.6
Missouri	St. Louis Co	12.3	27.9	12.1	27.5	12.0	27.2	11.9	27.1	11.5	26.3
Missouri	St. Louis city	13.5	30.4	13.4	30.3	13.0	29.6	12.9	29.5	12.4	28.8
Montana	Cascade Co	5.8	17.9	5.8	17.8	5.8	17.8	5.7	17.6	5.7	17.6
Montana	Flathead Co	8.1	24.5	8.0	24.1	8.0	24.0	7.8	23.3	7.8	23.3
Montana	Gallatin Co	8.5	27.4	8.4	27.2	8.3	27.0	8.3	26.9	8.3	26.9
Montana	Lake Co	9.3	28.0	9.2	27.8	9.2	27.7	9.0	26.9	9.0	26.9
Montana	Lincoln Co	15.0	42.4	14.9	42.2	14.8	41.8	14.5	41.3	14.6	41.3
Montana	Missoula Co	10.6	32.1	10.5	32.0	10.4	31.6	9.4	28.6	9.4	28.6
Montana	Ravalli Co	9.0	27.6	8.9	27.3	8.9	27.2	8.8	26.9	8.8	26.9
Montana	Rosebud Co	6.8	16.8	6.8	16.8	6.8	16.8	6.8	16.8	6.8	16.7
Montana	Sanders Co	6.3	16.5	6.3	16.4	6.2	16.3	6.2	16.2	6.2	16.2

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Montana	Silver Bow Co	8.4	26.4	8.4	26.1	8.4	26.0	8.3	25.8	8.3	25.8
Montana	Yellowstone Co	7.3	19.2	7.2	18.9	7.2	18.7	7.1	18.7	7.1	18.7
Nebraska	Cass Co	8.9	21.3	8.8	20.9	8.7	20.8	8.7	20.7	8.6	20.5
Nebraska	Douglas Co	9.4	22.6	9.2	22.3	9.2	22.2	9.2	22.1	9.1	21.9
Nebraska	Hall Co	7.6	20.0	7.5	19.7	7.4	19.4	7.4	19.4	7.3	19.1
Nebraska	Lancaster Co	8.7	21.2	8.6	20.8	8.5	20.6	8.5	20.6	8.4	20.3
Nebraska	Lincoln Co	6.4	16.0	6.3	15.7	6.2	15.6	6.2	15.6	6.2	15.5
Nebraska	Sarpy Co	8.9	22.0	8.8	21.8	8.7	21.6	8.7	21.6	8.6	21.4
Nebraska	Scotts Bluff Co	5.5	14.5	5.5	14.3	5.4	14.1	5.4	14.1	5.4	14.0
Nebraska	Washington Co	8.6	21.5	8.5	21.1	8.4	20.9	8.4	20.9	8.3	20.7
Nevada	Clark Co	10.1	27.6	9.8	26.7	9.7	26.5	9.7	26.4	9.7	26.4
Nevada	Washoe Co	8.8	27.9	8.7	27.2	8.6	26.5	8.4	26.0	8.4	26.0
New Hampshire	Cheshire Co	10.1	27.3	9.9	26.9	9.9	26.9	9.8	26.8	9.8	26.7
New Hampshire	Coos Co	9.0	21.1	8.9	20.8	8.9	20.7	8.9	20.6	8.8	20.3
New Hampshire	Merrimack Co	8.0	24.1	7.9	23.9	7.9	23.9	7.9	23.8	7.8	23.6
New Hampshire	Sullivan Co	8.4	24.6	8.3	24.3	8.3	24.2	8.3	24.2	8.2	24.0
New Jersey	Bergen Co	11.0	27.3	10.9	27.0	10.8	26.9	10.7	26.7	10.6	26.5
New Jersey	Camden Co	11.1	32.1	11.0	31.9	10.9	31.8	10.8	31.6	10.6	31.3
New Jersey	Gloucester Co	11.1	29.0	11.2	28.9	11.0	28.8	10.9	28.6	10.7	28.3
New Jersey	Hudson Co	12.0	32.8	11.8	32.5	11.7	32.4	11.6	32.2	11.5	32.0
New Jersey	Mercer Co	10.9	28.8	10.7	28.6	10.6	28.6	10.6	28.4	10.4	28.0
New Jersey	Middlesex Co	9.6	26.8	9.5	26.7	9.4	26.7	9.4	26.5	9.2	26.2
New Jersey	Morris Co	9.6	28.5	9.5	28.2	9.4	28.1	9.3	27.9	9.2	27.5
New Jersey	Union Co	12.2	32.8	12.0	32.4	11.9	32.3	11.8	32.1	11.7	31.8
New Jersey	Warren Co	10.3	26.8	10.2	26.7	10.1	26.6	10.0	26.5	9.9	26.2
New Mexico	Bernalillo Co	6.2	18.2	6.4	18.7	6.4	18.6	6.4	18.6	6.4	18.6
New Mexico	Chaves Co	6.4	14.8	6.4	14.7	6.3	14.7	6.3	14.6	6.3	14.5
New Mexico	Dona Ana Co	10.5	30.0	10.3	29.6	10.3	29.4	10.3	29.4	10.2	29.3
New Mexico	Grant Co	5.8	13.4	5.7	13.3	5.7	13.3	5.7	13.3	5.7	13.2
New Mexico	Lea Co	6.4	14.4	6.4	14.3	6.3	14.3	6.3	14.3	6.3	14.2
New Mexico	Sandoval Co	9.9	26.9	9.9	27.0	9.8	26.9	9.8	26.9	9.8	26.9
New Mexico	San Juan Co	6.1	13.4	6.0	13.3	6.0	13.3	6.0	13.3	6.0	13.3
New Mexico	Santa Fe Co	4.7	10.4	4.6	10.3	4.6	10.2	4.6	10.2	4.6	10.2
New York	Bronx Co	12.8	33.2	12.7	32.9	12.6	32.9	12.5	32.7	12.4	32.5
New York	Chautauqua Co	8.3	22.0	8.2	21.6	8.0	21.3	7.9	20.9	7.7	20.7
New York	Erie Co	11.2	28.7	11.1	28.3	10.9	28.0	10.8	27.7	10.7	27.4
New York	Essex Co	5.4	15.1	5.3	14.9	5.3	14.8	5.3	14.6	5.2	14.3
New York	Kings Co	11.8	28.9	11.8	28.7	11.6	28.6	11.5	28.4	11.4	28.2
New York	Monroe Co	9.2	24.3	9.1	23.9	9.0	23.8	8.9	23.6	8.8	23.4
New York	Nassau Co	9.7	26.6	9.7	26.6	9.5	26.4	9.5	26.2	9.3	26.0
New York	New York Co	14.0	33.2	13.8	32.9	13.7	32.9	13.7	32.6	13.5	32.4
New York	Niagara Co	9.8	24.5	9.7	24.2	9.6	23.8	9.6	23.5	9.4	23.1
New York	Onondaga Co	8.7	24.1	8.6	23.7	8.5	23.6	8.5	23.4	8.4	23.1
New York	Orange Co	9.6	24.8	9.4	24.4	9.4	24.3	9.3	24.2	9.2	23.9

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New York	Queens Co	10.7	29.9	10.6	29.7	10.5	29.7	10.5	29.5	10.4	29.3
New York	Richmond Co	9.5	26.2	9.3	26.0	9.2	25.9	9.2	25.7	9.0	25.6
New York	St. Lawrence Co	7.5	23.6	7.4	23.3	7.4	23.0	7.4	22.9	7.3	22.7
New York	Steuben Co	7.4	20.9	7.3	20.6	7.2	20.5	7.2	20.3	7.0	19.9
New York	Suffolk Co	9.7	25.6	9.6	25.4	9.5	25.3	9.5	25.1	9.3	24.8
New York	Westchester Co	9.9	25.2	9.8	24.9	9.7	24.8	9.7	24.7	9.6	24.5
North Carolina	Alamance Co	10.5	22.5	10.2	21.6	10.1	21.4	10.1	21.3	9.8	20.6
North Carolina	Buncombe Co	10.6	20.9	10.2	20.2	10.1	20.0	10.1	20.0	9.7	19.1
North Carolina	Cabarrus Co	11.3	22.1	10.8	21.1	10.8	21.0	10.7	21.0	10.4	20.2
North Carolina	Caswell Co	10.0	21.3	9.7	20.5	9.6	20.3	9.5	20.2	9.2	19.5
North Carolina	Catawba Co	12.3	25.6	11.8	24.8	11.7	24.6	11.7	24.6	11.3	23.8
North Carolina	Chatham Co	9.2	18.8	9.0	18.2	8.9	18.0	8.9	17.9	8.6	17.4
North Carolina	Cumberland Co	11.4	23.0	11.1	22.3	11.1	22.2	11.0	22.1	10.7	21.5
North Carolina	Davidson Co	12.4	24.7	11.9	23.7	11.8	23.5	11.8	23.5	11.4	22.7
North Carolina	Duplin Co	9.6	20.0	9.5	19.8	9.5	19.7	9.4	19.6	9.1	19.1
North Carolina	Durham Co	10.8	25.1	10.5	24.4	10.4	24.2	10.4	24.2	10.1	23.3
North Carolina	Forsyth Co	11.2	25.8	10.7	24.8	10.7	24.6	10.6	24.6	10.3	23.7
North Carolina	Gaston Co	11.1	21.3	10.6	20.5	10.5	20.3	10.5	20.3	10.1	19.5
North Carolina	Guilford Co	10.9	25.4	10.5	24.5	10.4	24.3	10.3	24.3	10.0	23.4
North Carolina	Haywood Co	11.4	25.4	11.0	25.0	10.9	24.9	10.9	24.8	10.5	24.2
North Carolina	Jackson Co	9.8	21.7	9.5	21.2	9.4	21.0	9.4	21.0	9.0	20.5
North Carolina	Lenoir Co	9.0	18.8	8.9	18.5	8.8	18.3	8.8	18.2	8.5	17.5
North Carolina	McDowell Co	11.7	24.4	11.2	23.6	11.1	23.4	11.1	23.4	10.7	22.6
North Carolina	Mecklenburg Co	11.9	25.8	11.5	24.9	11.4	24.8	11.4	24.7	11.0	24.0
North Carolina	Mitchell Co	11.0	23.2	10.6	22.6	10.5	22.5	10.5	22.4	10.1	21.6
North Carolina	Montgomery Co	9.2	20.1	9.0	19.5	8.9	19.4	8.9	19.3	8.5	18.6
North Carolina	Onslow Co	8.9	19.8	8.8	19.6	8.7	19.4	8.7	19.4	8.4	18.8
North Carolina	Orange Co	10.0	20.1	9.7	19.4	9.6	19.3	9.6	19.2	9.3	18.6
North Carolina	Pitt Co	9.8	22.1	9.6	21.7	9.5	21.5	9.5	21.4	9.2	20.7
North Carolina	Robeson Co	9.9	19.1	9.7	18.7	9.6	18.5	9.6	18.5	9.3	17.9
North Carolina	Swain Co	10.2	21.6	9.8	21.1	9.7	20.9	9.7	20.9	9.2	20.2
North Carolina	Wake Co	10.9	25.1	10.7	24.4	10.6	24.3	10.6	24.2	10.3	23.5
North Carolina	Wayne Co	11.2	22.0	11.1	21.6	11.0	21.4	10.9	21.4	10.6	20.7
North Dakota	Billings Co	4.3	10.3	4.3	10.2	4.2	10.1	4.2	10.1	4.2	10.1
North Dakota	Burke Co	5.3	13.9	5.3	14.1	5.3	14.0	5.3	14.0	5.3	14.0
North Dakota	Burleigh Co	6.1	14.7	6.0	14.5	6.0	14.4	6.0	14.4	6.0	14.4
North Dakota	Cass Co	7.3	20.4	7.1	20.0	7.1	19.8	7.1	19.8	7.1	19.7
North Dakota	Mercer Co	5.7	14.7	5.7	14.7	5.7	14.7	5.7	14.6	5.7	14.6
Ohio	Athens Co	8.8	20.6	8.6	20.2	8.5	19.9	8.4	19.8	8.1	19.1
Ohio	Butler Co	12.6	28.8	12.3	28.2	12.1	27.8	12.1	27.7	11.6	26.7
Ohio	Clark Co	11.7	28.0	11.4	27.4	11.2	27.0	11.1	26.9	10.7	26.1
Ohio	Cuyahoga Co	15.4	40.0	15.2	39.7	14.7	39.1	14.4	38.3	14.1	38.0
Ohio	Franklin Co	13.7	33.5	13.4	33.1	13.1	32.7	13.1	32.5	12.7	32.0
Ohio	Hamilton Co	14.3	34.2	14.1	33.6	13.7	33.0	13.7	32.9	13.1	31.9

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Ohio	Jefferson Co	14.2	34.2	14.0	33.8	13.7	33.2	12.5	31.0	12.4	30.8
Ohio	Lake Co	10.9	27.4	10.7	26.8	10.4	25.9	10.2	25.3	10.0	24.7
Ohio	Lawrence Co	12.9	28.4	12.8	27.9	12.5	27.2	12.4	27.0	12.1	26.2
Ohio	Lorain Co	11.2	28.8	11.0	28.4	10.7	27.7	10.5	27.3	10.2	26.6
Ohio	Lucas Co	12.5	32.2	12.3	31.8	11.9	31.3	11.9	31.1	11.6	30.6
Ohio	Mahoning Co	11.9	31.5	11.6	31.2	11.3	30.7	11.0	29.7	10.8	29.9
Ohio	Montgomery Co	12.4	29.9	12.1	29.4	11.7	28.9	11.7	28.7	11.2	28.1
Ohio	Portage Co	11.2	28.9	11.0	28.6	10.6	28.0	10.4	27.3	10.2	27.3
Ohio	Preble Co	10.4	26.0	10.2	25.5	10.1	25.2	10.1	25.1	9.7	24.4
Ohio	Scioto Co	15.6	34.3	15.4	33.8	15.1	33.3	15.0	33.2	14.5	32.4
Ohio	Stark Co	13.2	27.8	12.9	27.3	12.7	27.0	12.4	26.3	12.2	26.3
Ohio	Summit Co	13.2	30.9	12.9	30.4	12.7	29.9	12.4	29.3	12.0	28.9
Ohio	Trumbull Co	12.1	34.2	11.8	33.8	11.6	33.3	11.2	32.1	11.0	32.3
Oklahoma	Caddo Co	7.6	18.1	7.6	18.1	7.5	17.8	7.5	17.8	7.4	17.5
Oklahoma	Canadian Co	7.4	16.1	7.3	15.7	7.2	15.4	7.2	15.4	7.0	14.9
Oklahoma	Carter Co	8.4	18.3	8.3	17.8	8.2	17.5	8.2	17.4	7.9	16.7
Oklahoma	Cherokee Co	9.9	21.4	9.7	20.8	9.5	20.5	9.5	20.5	9.3	19.8
Oklahoma	Garfield Co	8.6	20.9	8.5	20.5	8.4	20.3	8.4	20.2	8.2	19.8
Oklahoma	Kay Co	9.2	20.1	9.1	19.9	9.0	19.7	9.0	19.7	8.9	19.3
Oklahoma	Lincoln Co	8.4	22.7	8.3	22.3	8.2	21.9	8.2	21.9	8.0	21.1
Oklahoma	Mayes Co	10.9	23.7	10.7	23.2	10.6	23.0	10.6	22.9	10.4	22.3
Oklahoma	Muskogee Co	10.4	21.2	10.2	20.6	10.1	20.3	10.1	20.3	9.8	19.8
Oklahoma	Oklahoma Co	8.8	21.7	8.7	21.3	8.6	21.1	8.6	21.1	8.4	20.6
Oklahoma	Ottawa Co	9.9	23.0	9.7	22.5	9.6	22.3	9.6	22.3	9.4	21.7
Oklahoma	Pittsburg Co	9.8	21.3	9.6	20.6	9.4	20.3	9.4	20.2	9.1	19.6
Oklahoma	Seminole Co	7.9	16.6	7.7	16.2	7.6	15.9	7.6	15.8	7.4	15.0
Oklahoma	Tulsa Co	10.2	24.1	10.1	23.6	10.0	23.3	9.9	23.3	9.7	22.7
Oregon	Columbia Co	5.9	15.1	5.9	15.1	5.8	14.9	5.2	13.1	5.2	13.1
Oregon	Deschutes Co	7.1	21.6	7.0	21.5	7.0	21.4	6.3	20.3	6.3	20.3
Oregon	Jackson Co	10.9	37.6	10.8	37.2	10.8	37.1	9.1	32.6	9.1	32.6
Oregon	Klamath Co	10.1	39.1	10.0	38.7	9.9	38.5	8.9	35.0	8.9	35.0
Oregon	Lane Co	12.9	53.6	12.8	53.0	12.7	52.5	11.7	47.9	11.7	48.0
Oregon	Linn Co	8.1	30.4	8.0	30.2	8.0	30.2	7.4	27.7	7.4	27.7
Oregon	Multnomah Co	8.3	25.0	8.3	24.9	8.2	24.8	6.8	20.1	6.8	20.2
Oregon	Union Co	6.5	22.1	6.4	21.8	6.4	21.7	6.4	21.6	6.4	21.6
Oregon	Wasco Co	7.1	21.8	7.0	21.5	7.0	21.2	6.7	20.7	6.7	20.7
Oregon	Washington Co	9.0	32.0	8.9	31.8	8.9	31.6	7.4	25.7	7.4	25.7
Pennsylvania	Adams Co	9.3	29.3	9.2	29.1	9.1	29.0	9.0	28.7	8.8	28.3
Pennsylvania	Allegheny Co	16.5	53.4	16.2	52.7	15.8	51.5	14.2	46.9	14.1	46.7
Pennsylvania	Beaver Co	12.1	33.2	11.8	32.8	11.5	32.1	10.6	30.2	10.5	30.0
Pennsylvania	Berks Co	12.0	35.5	12.0	35.3	11.9	35.2	11.8	34.8	11.5	34.4
Pennsylvania	Bucks Co	10.6	30.5	10.5	30.4	10.4	30.3	10.4	30.1	10.2	29.8
Pennsylvania	Cambria Co	11.1	25.5	10.9	25.1	10.8	24.8	10.0	23.8	9.9	23.5
Pennsylvania	Centre Co	9.3	28.9	9.2	28.6	9.1	28.4	8.9	27.9	8.8	27.8

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Pennsylvania	Dauphin Co	11.0	33.3	10.9	33.0	10.8	32.8	10.6	32.5	10.5	32.2
Pennsylvania	Delaware Co	12.3	28.6	12.3	28.5	12.1	28.3	12.1	28.0	11.8	27.7
Pennsylvania	Erie Co	10.5	28.8	10.4	28.7	10.0	28.1	9.9	27.6	9.7	27.4
Pennsylvania	Lackawanna Co	9.1	28.2	9.0	28.0	8.9	27.9	8.8	27.7	8.7	27.5
Pennsylvania	Lancaster Co	12.2	33.7	12.0	33.3	11.9	33.2	11.8	32.9	11.6	32.5
Pennsylvania	Lehigh Co	10.5	34.7	10.4	34.5	10.3	34.4	10.2	34.1	10.1	33.8
Pennsylvania	Luzerne Co	9.7	29.1	9.5	29.0	9.5	28.9	9.4	28.8	9.2	28.6
Pennsylvania	Mercer Co	11.0	31.6	10.8	31.3	10.6	30.8	10.2	29.8	10.1	29.9
Pennsylvania	Montgomery Co	10.5	29.3	10.4	29.1	10.3	29.0	10.3	28.8	10.1	28.5
Pennsylvania	Northampton Co	10.9	35.0	10.8	34.8	10.7	34.8	10.6	34.5	10.4	34.3
Pennsylvania	Perry Co	9.4	25.0	9.3	24.9	9.2	24.8	9.1	24.5	8.9	24.1
Pennsylvania	Philadelphia Co	13.3	35.2	13.2	35.0	13.1	34.9	13.0	34.7	12.8	34.4
Pennsylvania	Washington Co	11.4	26.3	11.3	25.8	11.0	25.3	10.1	23.5	9.9	23.1
Pennsylvania	Westmoreland Co	10.9	29.6	10.7	29.4	10.5	29.0	9.6	27.4	9.5	27.2
Pennsylvania	York Co	12.3	35.9	12.1	35.5	12.0	35.4	11.9	35.0	11.7	34.7
Rhode Island	Kent Co	6.9	19.0	6.8	18.9	6.7	18.7	6.7	18.6	6.6	18.2
Rhode Island	Providence Co	9.3	26.6	9.2	26.4	9.2	26.3	9.1	26.2	9.0	26.0
South Carolina	Beaufort Co	8.7	19.9	8.8	19.9	8.6	19.6	8.6	19.5	8.1	18.5
South Carolina	Charleston Co	9.7	22.0	9.6	21.9	9.5	21.7	9.5	21.7	9.0	20.7
South Carolina	Chesterfield Co	9.4	18.8	9.2	18.4	9.2	18.2	9.1	18.2	8.7	17.5
South Carolina	Edgefield Co	9.9	20.2	9.7	19.7	9.6	19.6	9.6	19.5	8.9	18.4
South Carolina	Florence Co	10.5	21.1	10.3	20.6	10.2	20.5	10.2	20.4	9.8	19.8
South Carolina	Georgetown Co	10.7	23.2	10.6	22.9	10.5	22.8	10.4	22.7	10.1	21.9
South Carolina	Greenville Co	11.6	25.0	11.2	24.2	11.1	24.0	11.0	24.0	10.5	23.0
South Carolina	Greenwood Co	10.6	20.9	10.3	20.1	10.2	19.9	10.1	19.8	9.5	18.8
South Carolina	Horry Co	8.7	20.1	8.7	19.9	8.6	19.8	8.6	19.7	8.3	19.1
South Carolina	Lexington Co	11.2	22.0	11.0	21.4	10.9	21.2	10.9	21.2	10.3	20.3
South Carolina	Oconee Co	8.5	21.4	8.2	20.6	8.1	20.5	8.1	20.4	7.6	19.4
South Carolina	Richland Co	11.2	22.1	10.9	21.6	10.8	21.4	10.8	21.4	10.2	20.4
South Carolina	Spartanburg Co	10.9	23.1	10.5	22.4	10.4	22.2	10.4	22.2	9.8	21.2
South Dakota	Brookings Co	8.2	20.9	8.1	20.5	8.0	20.3	8.0	20.3	8.0	20.1
South Dakota	Brown Co	7.5	17.5	7.4	17.2	7.4	17.2	7.3	17.1	7.3	17.1
South Dakota	Jackson Co	5.2	12.5	5.1	12.5	5.1	12.4	5.1	12.4	5.1	12.3
South Dakota	Meade Co	6.0	14.7	5.9	14.6	5.9	14.5	5.9	14.5	5.9	14.5
South Dakota	Minnehaha Co	8.5	20.9	8.3	20.3	8.3	20.2	8.3	20.2	8.2	20.0
South Dakota	Pennington Co	7.4	20.1	7.4	20.0	7.4	19.9	7.4	19.9	7.4	19.9
Tennessee	Blount Co	10.6	24.6	10.2	23.5	10.1	23.2	10.0	23.2	9.6	22.3
Tennessee	Davidson Co	12.4	27.8	12.3	27.4	12.2	27.2	12.1	27.1	11.6	26.3
Tennessee	Dyer Co	10.1	22.4	10.0	22.0	9.8	21.6	9.8	21.6	9.4	20.7
Tennessee	Hamilton Co	13.5	27.3	13.4	26.7	13.3	26.4	13.2	26.4	12.4	25.2
Tennessee	Knox Co	13.6	29.6	13.1	28.6	12.9	28.4	12.9	28.3	12.3	27.5
Tennessee	Lawrence Co	9.7	21.5	9.7	21.3	9.6	21.0	9.6	20.9	8.9	18.9
Tennessee	McMinn Co	12.0	25.6	11.8	24.9	11.6	24.6	11.6	24.5	11.0	23.5
Tennessee	Maury Co	10.9	23.8	10.8	23.3	10.7	23.0	10.7	23.0	10.2	21.7

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Tennessee	Montgomery Co	11.0	21.7	10.9	21.5	10.8	21.2	10.8	21.1	10.3	20.1
Tennessee	Putnam Co	10.3	23.1	10.3	22.7	10.2	22.4	10.2	22.3	9.5	21.1
Tennessee	Roane Co	11.8	25.3	11.5	24.6	11.3	24.3	11.3	24.2	10.7	23.0
Tennessee	Shelby Co	12.4	28.4	12.4	28.2	12.2	27.8	12.1	27.6	11.8	26.9
Tennessee	Sullivan Co	12.5	27.4	12.2	26.5	12.1	26.3	12.1	26.2	11.6	25.3
Tennessee	Sumner Co	11.3	23.1	11.2	22.8	11.1	22.5	11.1	22.5	10.5	21.3
Texas	Bowie Co	12.2	26.8	12.0	26.4	11.8	26.1	11.8	26.1	11.6	25.6
Texas	Cameron Co	9.2	20.7	9.2	20.7	9.1	20.4	9.1	20.4	8.9	20.0
Texas	Dallas Co	11.4	27.6	11.2	26.9	11.1	26.7	11.1	26.7	10.6	25.9
Texas	Ector Co	7.3	15.3	7.3	15.3	7.3	15.2	7.3	15.2	7.2	15.1
Texas	Galveston Co	7.8	19.7	7.8	19.6	7.5	19.0	7.4	18.9	7.2	18.1
Texas	Gregg Co	10.6	26.6	10.4	26.0	10.2	25.7	10.2	25.6	9.9	25.0
Texas	Harris Co	12.9	27.2	13.3	27.7	12.7	26.9	12.7	26.8	12.5	26.3
Texas	Hidalgo Co	10.7	24.9	10.6	24.6	10.5	24.3	10.5	24.3	10.4	23.9
Texas	Jefferson Co	10.0	25.3	10.1	25.4	9.8	24.8	9.7	24.7	9.6	23.9
Texas	Lubbock Co	7.1	16.7	7.1	16.7	7.1	16.6	7.1	16.6	7.0	16.4
Texas	Nueces Co	9.6	20.3	9.9	20.9	9.5	19.9	9.4	19.8	9.3	19.5
Texas	Orange Co	10.1	25.2	10.3	25.3	9.9	24.6	9.9	24.6	9.7	23.7
Texas	Tarrant Co	10.1	23.1	9.9	22.6	9.8	22.4	9.7	22.3	9.4	21.7
Utah	Box Elder Co	8.6	39.0	8.5	38.4	8.5	38.3	8.3	36.9	8.3	36.9
Utah	Cache Co	12.5	51.9	12.3	51.4	12.3	51.3	12.0	50.0	12.0	50.0
Utah	Salt Lake Co	12.6	49.3	12.2	47.6	12.2	47.5	11.3	42.9	11.3	42.9
Utah	Utah Co	9.3	36.7	9.1	35.3	9.0	35.2	8.5	32.8	8.5	32.8
Utah	Weber Co	9.1	36.2	8.9	35.3	8.8	35.3	8.5	33.0	8.5	33.0
Vermont	Chittenden Co	7.7	21.6	7.7	21.4	7.6	21.3	7.6	21.3	7.5	21.1
Virginia	Arlington Co	10.5	28.5	10.3	28.2	10.2	28.0	10.1	27.8	9.9	27.4
Virginia	Charles City Co	9.4	21.8	9.2	21.5	9.1	21.4	9.1	21.3	8.8	20.7
Virginia	Chesterfield Co	9.9	24.2	9.8	23.8	9.7	23.6	9.6	23.6	9.4	23.0
Virginia	Fairfax Co	9.9	26.1	9.7	25.8	9.6	25.7	9.5	25.5	9.3	25.1
Virginia	Henrico Co	9.9	23.1	9.7	22.8	9.6	22.7	9.6	22.6	9.4	22.0
Virginia	Loudoun Co	9.4	26.4	9.2	26.2	9.1	26.0	9.1	25.8	8.9	25.3
Virginia	Page Co	9.1	23.2	8.9	22.7	8.8	22.6	8.8	22.4	8.6	21.8
Virginia	Bristol city	11.5	26.6	11.1	25.8	11.0	25.5	11.0	25.5	10.5	24.5
Virginia	Chesapeake city	10.1	23.9	9.8	23.5	9.7	23.3	9.7	23.2	9.5	22.8
Virginia	Hampton city	10.1	22.6	10.0	22.2	9.8	22.0	9.7	21.8	9.5	21.4
Virginia	Newport News city	9.2	20.9	9.1	20.5	9.0	20.3	8.9	20.2	8.7	19.8
Virginia	Norfolk city	10.5	23.3	10.4	23.1	10.2	22.9	10.1	22.8	9.9	22.4
Virginia	Richmond city	10.4	26.3	10.2	26.0	10.1	25.8	10.0	25.7	9.8	25.1
Virginia	Roanoke city	10.7	26.0	10.4	25.3	10.3	25.0	10.2	24.9	9.9	24.2
Virginia	Salem city	10.9	25.2	10.6	24.7	10.5	24.5	10.4	24.4	10.1	23.8
Virginia	Virginia Beach city	10.2	24.8	10.1	24.6	9.9	24.4	9.8	24.3	9.6	23.8
Washington	Benton Co	6.5	20.2	6.4	19.9	6.4	19.8	6.3	19.5	6.3	19.5
Washington	Clark Co	9.2	34.3	9.1	34.0	9.0	33.8	8.0	29.3	8.0	29.3
Washington	King Co	10.8	34.0	10.9	34.4	10.7	34.2	9.5	30.2	9.6	30.2

State	County	2015 Base Annual DV	2015 Base Daily DV	2020 Base Annual DV	2020 Base Daily DV	2020 15/65 Annual DV	2020 15/65 Daily DV	2020 15/35 Annual DV	2020 15/35 Daily DV	2020 14/35 Annual DV	2020 14/35 Daily DV
Washington	Pierce Co	11.1	43.0	11.6	44.9	11.5	44.7	9.9	38.0	10.0	38.0
Washington	Snohomish Co	11.3	40.1	11.4	40.5	11.4	40.2	10.4	37.0	10.4	37.0
Washington	Spokane Co	9.7	30.3	9.6	29.7	9.6	29.6	9.5	29.4	9.5	29.4
Washington	Thurston Co	8.9	34.9	8.8	35.0	8.8	34.8	8.2	32.0	8.2	32.1
Washington	Whatcom Co	7.6	20.9	7.6	21.0	7.6	21.0	7.5	20.7	7.5	20.7
Washington	Yakima Co	9.6	34.9	9.4	34.1	9.3	34.0	9.2	33.8	9.2	33.8
West Virginia	Berkeley Co	12.0	32.7	11.8	32.2	11.7	32.0	11.5	31.6	11.3	31.2
West Virginia	Brooke Co	12.9	30.1	12.7	29.7	12.5	29.3	11.4	27.6	11.3	27.3
West Virginia	Cabell Co	13.5	30.2	13.3	29.6	13.0	28.8	12.9	28.6	12.5	27.7
West Virginia	Hancock Co	13.4	32.7	13.2	32.3	13.0	31.9	11.9	29.8	11.8	29.6
West Virginia	Harrison Co	10.5	22.1	10.3	22.0	10.2	21.8	10.0	21.6	9.8	21.3
West Virginia	Kanawha Co	13.9	28.9	13.6	28.5	13.4	28.1	13.3	28.0	13.1	27.5
West Virginia	Marion Co	11.4	26.2	11.2	26.1	11.0	25.7	10.8	25.2	10.6	24.9
West Virginia	Marshall Co	11.8	25.8	11.6	25.7	11.3	25.2	10.7	24.4	10.6	24.1
West Virginia	Mercer Co	9.3	21.9	9.0	21.0	8.9	20.7	8.8	20.6	8.5	19.5
West Virginia	Monongalia Co	10.7	24.3	10.5	24.0	10.4	23.8	10.1	23.4	10.0	23.0
West Virginia	Ohio Co	11.1	24.8	11.0	24.7	10.7	24.3	10.1	23.5	10.0	23.2
West Virginia	Raleigh Co	9.8	23.4	9.5	22.8	9.4	22.5	9.3	22.5	9.0	21.7
West Virginia	Summers Co	7.4	20.1	7.2	19.4	7.1	19.2	7.0	19.1	6.8	18.3
West Virginia	Wood Co	12.8	29.8	12.6	29.7	12.4	29.3	12.2	29.1	12.0	28.5
Wisconsin	Brown Co	10.3	28.3	10.1	27.6	10.0	27.4	10.0	27.3	9.9	27.2
Wisconsin	Dane Co	11.1	30.1	10.8	29.3	10.7	29.1	10.7	29.0	10.6	28.7
Wisconsin	Dodge Co	9.7	26.6	9.5	25.8	9.4	25.4	9.4	25.4	9.2	24.8
Wisconsin	Grant Co	10.1	24.1	9.9	23.5	9.8	23.2	9.8	23.1	9.7	22.8
Wisconsin	Kenosha Co	10.2	28.0	10.1	27.6	9.7	26.9	9.7	26.9	9.5	26.5
Wisconsin	Manitowoc Co	8.7	24.3	8.5	23.8	8.4	23.4	8.4	23.4	8.2	22.7
Wisconsin	Milwaukee Co	12.1	32.1	11.9	31.5	11.8	31.1	11.7	30.9	11.5	30.5
Wisconsin	Outagamie Co	9.6	26.9	9.5	26.2	9.4	25.9	9.4	25.9	9.2	25.4
Wisconsin	Vilas Co	5.6	15.7	5.6	15.5	5.5	15.4	5.5	15.4	5.4	15.2
Wisconsin	Waukesha Co	11.8	32.4	11.6	31.9	11.4	31.6	11.4	31.6	11.3	31.3
Wyoming	Campbell Co	6.2	17.1	6.1	17.0	6.1	16.9	6.1	16.8	6.1	16.8
Wyoming	Laramie Co	4.9	12.0	4.8	11.8	4.8	11.8	4.8	11.7	4.8	11.7
Wyoming	Sheridan Co	10.5	31.8	10.4	31.6	10.4	31.4	10.4	31.3	10.4	31.3

Appendix 4-2b. Impacts on PM2.5 Annual and Daily Design Values (µg/m³) of Controls in the 2020 15/65 Scenario

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Alabama	Baldwin Co	9.1	8.9	-0.2	19.0	18.4	-0.6
Alabama	Clay Co	10.9	10.7	-0.2	22.3	21.9	-0.4
Alabama	Colbert Co	10.9	10.8	-0.1	22.2	21.9	-0.3
Alabama	DeKalb Co	12.0	11.9	-0.1	27.6	27.4	-0.2
Alabama	Escambia Co	10.6	10.5	-0.1	21.0	20.8	-0.2
Alabama	Houston Co	12.3	12.2	-0.1	24.8	24.6	-0.2
Alabama	Jefferson Co	15.7	15.1	-0.6	36.3	34.2	-2.1
Alabama	Madison Co	11.2	11.0	-0.2	23.0	22.8	-0.2
Alabama	Mobile Co	12.1	11.8	-0.3	24.3	23.9	-0.4
Alabama	Montgomery Co	12.8	12.6	-0.2	25.5	25.2	-0.3
Alabama	Morgan Co	12.8	12.7	-0.1	26.1	25.7	-0.4
Alabama	Russell Co	13.2	13.0	-0.2	29.6	29.4	-0.2
Alabama	Shelby Co	12.2	11.9	-0.3	25.8	25.1	-0.7
Alabama	Sumter Co	10.5	10.3	-0.2	23.0	22.7	-0.3
Alabama	Talladega Co	12.3	12.1	-0.2	26.9	26.4	-0.5
Arizona	Gila Co	9.1	9.1	0.0	22.4	22.3	-0.1
Arizona	Maricopa Co	10.2	10.1	-0.1	28.5	28.3	-0.2
Arizona	Pima Co	7.1	7.1	0.0	16.4	16.3	-0.1
Arizona	Pinal Co	8.0	8.0	0.0	18.6	18.5	-0.1
Arizona	Santa Cruz Co	12.0	11.9	-0.1	30.0	29.8	-0.2
Arkansas	Arkansas Co	10.0	9.8	-0.2	20.9	20.5	-0.4
Arkansas	Ashley Co	10.6	10.4	-0.2	23.6	23.3	-0.3
Arkansas	Craighead Co	9.9	9.7	-0.2	22.4	22.0	-0.4
Arkansas	Crittenden Co	11.1	10.9	-0.2	24.3	23.8	-0.5
Arkansas	Faulkner Co	10.4	10.3	-0.1	21.7	21.3	-0.4
Arkansas	Jefferson Co	11.3	11.2	-0.1	23.2	22.9	-0.3
Arkansas	Mississippi Co	9.7	9.5	-0.2	22.0	21.6	-0.4
Arkansas	Phillips Co	10.1	9.9	-0.2	22.0	21.6	-0.4
Arkansas	Polk Co	9.2	9.0	-0.2	18.6	18.3	-0.3
Arkansas	Pope Co	10.6	10.5	-0.1	22.4	22.2	-0.2
Arkansas	Pulaski Co	12.0	11.8	-0.2	26.2	25.9	-0.3
Arkansas	Sebastian Co	10.5	10.4	-0.1	21.0	20.8	-0.2
Arkansas	Union Co	11.8	11.7	-0.1	25.8	25.4	-0.4
Arkansas	White Co	9.7	9.5	-0.2	19.2	18.9	-0.3

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
California	Alameda Co	13.2	11.7	-1.5	58.7	50.7	-8.0
California	Butte Co	13.0	12.7	-0.3	48.6	46.3	-2.3
California	Calaveras Co	8.1	7.8	-0.3	21.1	19.8	-1.3
California	Colusa Co	9.3	9.0	-0.3	32.5	30.3	-2.2
California	Contra Costa Co	12.5	11.1	-1.4	61.1	52.6	-8.5
California	El Dorado Co	7.4	7.2	-0.2	18.0	17.7	-0.3
California	Fresno Co	19.6	17.3	-2.3	70.4	59.6	-10.8
California	Humboldt Co	8.1	8.0	-0.1	23.4	23.1	-0.3
California	Imperial Co	14.8	14.4	-0.4	44.9	43.0	-1.9
California	Inyo Co	6.0	5.9	-0.1	37.7	36.0	-1.7
California	Kern Co	20.8	18.6	-2.2	77.9	68.0	-9.9
California	Kings Co	16.8	15.6	-1.2	67.6	61.0	-6.6
California	Lake Co	4.7	4.6	-0.1	10.6	10.1	-0.5
California	Los Angeles Co	23.9	21.6	-2.3	62.7	58.1	-4.6
California	Mendocino Co	7.7	7.5	-0.2	25.2	24.2	-1.0
California	Merced Co	15.6	14.4	-1.2	53.1	47.7	-5.4
California	Monterey Co	8.5	7.9	-0.6	19.5	17.8	-1.7
California	Nevada Co	7.7	7.5	-0.2	22.9	22.2	-0.7
California	Orange Co	20.2	18.2	-2.0	40.7	35.6	-5.1
California	Placer Co	11.2	9.8	-1.4	36.5	30.6	-5.9
California	Riverside Co	27.5	22.7	-4.8	73.9	63.2	-10.7
California	Sacramento Co	12.1	10.9	-1.2	48.3	42.0	-6.3
California	San Bernardino Co	24.6	21.4	-3.2	65.8	58.1	-7.7
California	San Diego Co	15.7	13.7	-2.0	40.1	34.6	-5.5
California	San Francisco Co	11.4	9.6	-1.8	52.4	42.4	-10.0
California	San Joaquin Co	16.0	14.4	-1.6	52.0	45.3	-6.7
California	San Luis Obispo Co	9.4	8.6	-0.8	35.6	31.6	-4.0
California	San Mateo Co	10.5	9.6	-0.9	41.6	36.5	-5.1
California	Santa Barbara Co	9.5	8.7	-0.8	20.3	18.7	-1.6
California	Santa Clara Co	12.0	11.3	-0.7	52.3	48.2	-4.1
California	Santa Cruz Co	8.0	7.4	-0.6	19.0	17.3	-1.7
California	Shasta Co	8.7	8.6	-0.1	30.1	29.7	-0.4
California	Solano Co	11.7	10.2	-1.5	57.3	48.3	-9.0
California	Sonoma Co	9.8	9.4	-0.4	38.2	35.3	-2.9
California	Stanislaus Co	16.2	14.5	-1.7	59.2	51.5	-7.7
California	Sutter Co	10.9	10.5	-0.4	37.9	35.5	-2.4
California	Tulare Co	20.6	18.9	-1.7	73.6	65.4	-8.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
California	Ventura Co	14.0	12.0	-2.0	38.7	33.4	-5.3
California	Yolo Co	10.0	9.1	-0.9	31.8	27.5	-4.3
Colorado	Adams Co	9.0	9.0	0.0	22.6	22.6	0.0
Colorado	Arapahoe Co	8.0	7.9	-0.1	21.1	21.1	0.0
Colorado	Boulder Co	8.4	8.3	-0.1	20.6	20.5	-0.1
Colorado	Delta Co	7.8	7.8	0.0	16.5	16.4	-0.1
Colorado	Denver Co	9.5	9.5	0.0	25.9	26.0	0.1
Colorado	Elbert Co	4.0	4.0	0.0	9.9	9.8	-0.1
Colorado	El Paso Co	7.0	6.9	-0.1	16.4	16.4	0.0
Colorado	Gunnison Co	6.4	6.4	0.0	17.1	17.1	0.0
Colorado	La Plata Co	5.1	5.1	0.0	13.1	13.0	-0.1
Colorado	Larimer Co	7.4	7.4	0.0	18.4	18.4	0.0
Colorado	Mesa Co	7.1	7.1	0.0	17.6	17.5	-0.1
Colorado	Pueblo Co	7.5	7.4	-0.1	16.7	16.6	-0.1
Colorado	Routt Co	7.2	7.2	0.0	15.6	15.5	-0.1
Colorado	San Miguel Co	5.4	5.3	-0.1	11.2	11.2	0.0
Colorado	Weld Co	8.3	8.3	0.0	23.2	23.0	-0.2
Connecticut	Fairfield Co	10.9	10.7	-0.2	31.2	31.1	-0.1
Connecticut	Hartford Co	10.4	10.3	-0.1	28.7	28.6	-0.1
Connecticut	New Haven Co	11.1	10.9	-0.2	29.2	29.2	0.0
Connecticut	New London Co	9.3	9.2	-0.1	23.7	23.6	-0.1
Delaware	Kent Co	9.4	9.3	-0.1	0.0	0.0	0.0
Delaware	New Castle Co	13.0	12.9	-0.1	27.2	27.2	0.0
Delaware	Sussex Co	10.3	10.2	-0.1	0.0	0.0	0.0
District of Colun	District of Columbia	11.5	11.4	-0.1	30.7	30.6	-0.1
Florida	Alachua Co	8.2	8.1	-0.1	18.0	17.8	-0.2
Florida	Brevard Co	5.7	5.6	-0.1	14.2	14.1	-0.1
Florida	Broward Co	6.7	6.6	-0.1	16.7	16.4	-0.3
Florida	Citrus Co	6.9	6.8	-0.1	15.7	15.6	-0.1
Florida	Duval Co	8.8	8.7	-0.1	20.8	20.6	-0.2
Florida	Escambia Co	9.9	9.8	-0.1	19.9	19.7	-0.2
Florida	Hillsborough Co	8.6	8.5	-0.1	18.2	18.0	-0.2
Florida	Lee Co	6.3	6.3	0.0	14.3	14.1	-0.2
Florida	Leon Co	10.8	10.7	-0.1	22.3	22.1	-0.2
Florida	Manatee Co	7.0	6.9	-0.1	16.8	16.5	-0.3
Florida	Marion Co	7.9	7.9	0.0	16.5	16.4	-0.1
Florida	Miami-Dade Co	7.6	7.6	0.0	15.6	15.5	-0.1

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Florida	Orange Co	8.1	8.1	0.0	18.8	18.7	-0.1
Florida	Palm Beach Co	5.6	5.5	-0.1	14.4	14.3	-0.1
Florida	Pinellas Co	7.9	7.7	-0.2	17.0	16.8	-0.2
Florida	Polk Co	8.7	8.6	-0.1	19.4	19.2	-0.2
Florida	St. Lucie Co	6.6	6.5	-0.1	14.3	14.1	-0.2
Florida	Sarasota Co	7.1	6.9	-0.2	17.7	17.4	-0.3
Florida	Seminole Co	7.3	7.2	-0.1	15.6	15.5	-0.1
Florida	Volusia Co	7.2	7.1	-0.1	15.3	15.1	-0.2
Georgia	Bibb Co	13.6	13.5	-0.1	26.8	26.6	-0.2
Georgia	Chatham Co	12.3	12.1	-0.2	25.0	24.7	-0.3
Georgia	Clarke Co	12.6	12.5	-0.1	25.4	25.1	-0.3
Georgia	Clayton Co	13.7	13.5	-0.2	27.9	27.5	-0.4
Georgia	Cobb Co	13.4	13.1	-0.3	28.0	27.5	-0.5
Georgia	DeKalb Co	13.3	13.0	-0.3	30.7	30.1	-0.6
Georgia	Dougherty Co	12.6	12.5	-0.1	27.6	27.4	-0.2
Georgia	Floyd Co	14.0	13.8	-0.2	30.4	30.2	-0.2
Georgia	Fulton Co	15.3	14.9	-0.4	31.5	30.7	-0.8
Georgia	Glynn Co	10.0	9.9	-0.1	23.3	23.1	-0.2
Georgia	Gwinnett Co	12.5	12.2	-0.3	0.0	0.0	0.0
Georgia	Hall Co	12.0	11.9	-0.1	24.6	24.3	-0.3
Georgia	Houston Co	10.5	10.5	0.0	0.0	0.0	0.0
Georgia	Lowndes Co	10.0	9.9	-0.1	24.3	24.2	-0.1
Georgia	Muscogee Co	13.2	13.1	-0.1	33.8	33.5	-0.3
Georgia	Paulding Co	11.7	11.5	-0.2	29.8	29.3	-0.5
Georgia	Richmond Co	12.7	12.7	0.0	27.5	27.4	-0.1
Georgia	Walker Co	12.0	11.9	-0.1	24.1	23.8	-0.3
Georgia	Washington Co	12.6	12.5	-0.1	0.0	0.0	0.0
Georgia	Wilkinson Co	13.4	13.4	0.0	29.1	29.0	-0.1
Idaho	Ada Co	8.8	8.8	0.0	31.7	31.6	-0.1
Idaho	Bannock Co	9.1	9.1	0.0	40.0	39.9	-0.1
Idaho	Bonneville Co	6.6	6.5	-0.1	20.1	20.0	-0.1
Idaho	Canyon Co	9.1	9.1	0.0	31.9	31.7	-0.2
Idaho	Power Co	10.4	10.4	0.0	36.4	36.3	-0.1
Idaho	Shoshone Co	12.4	12.3	-0.1	36.0	35.9	-0.1
Illinois	Adams Co	11.1	10.9	-0.2	22.9	22.6	-0.3
Illinois	Champaign Co	10.5	10.3	-0.2	23.4	23.2	-0.2
Illinois	Cook Co	15.3	14.5	-0.8	36.5	35.3	-1.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Illinois	DuPage Co	12.4	12.0	-0.4	30.5	29.8	-0.7
Illinois	Kane Co	12.1	11.7	-0.4	29.3	28.9	-0.4
Illinois	Lake Co	11.1	10.6	-0.5	26.9	26.3	-0.6
Illinois	La Salle Co	0.0	0.0	0.0	28.0	27.6	-0.4
Illinois	McHenry Co	10.9	10.7	-0.2	28.7	28.2	-0.5
Illinois	McLean Co	11.5	11.3	-0.2	25.0	24.6	-0.4
Illinois	Macon Co	11.9	11.7	-0.2	29.7	29.4	-0.3
Illinois	Madison Co	15.1	14.6	-0.5	35.3	34.4	-0.9
Illinois	Peoria Co	12.1	11.6	-0.5	28.4	27.5	-0.9
Illinois	Randolph Co	10.5	10.4	-0.1	22.4	22.0	-0.4
Illinois	Rock Island Co	10.3	10.2	-0.1	22.8	22.5	-0.3
Illinois	St. Clair Co	14.5	14.1	-0.4	30.2	29.4	-0.8
Illinois	Sangamon Co	11.2	11.0	-0.2	25.8	25.4	-0.4
Illinois	Will Co	13.0	12.7	-0.3	31.7	31.0	-0.7
Indiana	Allen Co	11.7	11.6	-0.1	29.6	29.3	-0.3
Indiana	Clark Co	13.4	13.2	-0.2	30.4	30.0	-0.4
Indiana	Delaware Co	11.5	11.4	-0.1	26.4	26.2	-0.2
Indiana	Dubois Co	12.7	12.5	-0.2	0.0	0.0	0.0
Indiana	Elkhart Co	12.4	12.2	-0.2	29.2	28.6	-0.6
Indiana	Floyd Co	11.9	11.7	-0.2	26.5	26.1	-0.4
Indiana	Henry Co	10.5	10.4	-0.1	23.9	23.7	-0.2
Indiana	Howard Co	11.9	11.8	-0.1	29.4	29.1	-0.3
Indiana	Knox Co	10.6	10.4	-0.2	23.8	23.4	-0.4
Indiana	Lake Co	13.3	12.4	-0.9	40.4	36.9	-3.5
Indiana	La Porte Co	11.4	10.9	-0.5	27.3	26.1	-1.2
Indiana	Madison Co	11.5	11.4	-0.1	26.7	26.4	-0.3
Indiana	Marion Co	13.2	13.1	-0.1	32.5	32.3	-0.2
Indiana	Porter Co	12.3	10.9	-1.4	29.1	26.3	-2.8
Indiana	St. Joseph Co	11.9	11.6	-0.3	29.3	28.5	-0.8
Indiana	Spencer Co	11.1	10.9	-0.2	22.4	22.1	-0.3
Indiana	Vanderburgh Co	12.5	12.3	-0.2	28.7	28.4	-0.3
Indiana	Vigo Co	11.8	11.7	-0.1	28.3	28.0	-0.3
Iowa	Black Hawk Co	9.7	9.6	-0.1	24.2	23.9	-0.3
Iowa	Cerro Gordo Co	9.0	8.9	-0.1	23.8	23.6	-0.2
Iowa	Clinton Co	10.3	10.1	-0.2	26.6	26.2	-0.4
Iowa	Emmet Co	7.4	7.4	0.0	18.8	18.5	-0.3
Iowa	Johnson Co	9.8	9.7	-0.1	25.4	25.2	-0.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Iowa	Linn Co	9.8	9.7	-0.1	27.0	26.6	-0.4
Iowa	Muscatine Co	11.1	11.0	-0.1	28.4	28.0	-0.4
Iowa	Polk Co	8.9	8.8	-0.1	22.6	22.5	-0.1
Iowa	Pottawattamie Co	8.9	8.9	0.0	21.0	20.8	-0.2
Iowa	Scott Co	10.5	10.4	-0.1	25.6	25.3	-0.3
Iowa	Van Buren Co	8.7	8.6	-0.1	22.4	22.1	-0.3
Iowa	Woodbury Co	8.7	8.6	-0.1	21.8	21.6	-0.2
Kansas	Johnson Co	9.9	9.8	-0.1	23.1	22.9	-0.2
Kansas	Linn Co	8.9	8.7	-0.2	19.6	19.3	-0.3
Kansas	Sedgwick Co	9.6	9.5	-0.1	21.4	21.2	-0.2
Kansas	Shawnee Co	9.4	9.3	-0.1	20.8	20.5	-0.3
Kansas	Sumner Co	8.6	8.5	-0.1	18.4	18.2	-0.2
Kansas	Wyandotte Co	11.7	11.5	-0.2	25.9	25.7	-0.2
Kentucky	Bell Co	10.9	10.8	-0.1	23.9	23.6	-0.3
Kentucky	Boyd Co	11.4	11.0	-0.4	25.0	24.5	-0.5
Kentucky	Bullitt Co	11.7	11.5	-0.2	24.8	24.5	-0.3
Kentucky	Campbell Co	10.5	10.3	-0.2	26.8	26.3	-0.5
Kentucky	Carter Co	9.0	8.8	-0.2	19.3	18.9	-0.4
Kentucky	Christian Co	10.9	10.8	-0.1	22.6	22.4	-0.2
Kentucky	Daviess Co	11.3	11.1	-0.2	24.3	24.0	-0.3
Kentucky	Fayette Co	11.9	11.7	-0.2	25.5	25.2	-0.3
Kentucky	Franklin Co	10.2	10.0	-0.2	24.1	23.8	-0.3
Kentucky	Hardin Co	10.8	10.7	-0.1	23.5	23.2	-0.3
Kentucky	Jefferson Co	13.6	13.4	-0.2	32.9	32.6	-0.3
Kentucky	Kenton Co	11.3	11.1	-0.2	28.2	27.6	-0.6
Kentucky	McCracken Co	11.3	11.1	-0.2	23.5	23.2	-0.3
Kentucky	Madison Co	10.1	9.9	-0.2	20.6	20.3	-0.3
Kentucky	Perry Co	9.8	9.6	-0.2	0.0	0.0	0.0
Kentucky	Pike Co	10.4	10.2	-0.2	20.6	20.3	-0.3
Kentucky	Warren Co	11.1	10.9	-0.2	24.1	23.8	-0.3
Louisiana	Caddo Parish	11.3	11.1	-0.2	24.3	24.0	-0.3
Louisiana	Calcasieu Parish	10.2	9.9	-0.3	26.2	25.7	-0.5
Louisiana	East Baton Rouge Parish	12.9	12.6	-0.3	27.8	27.2	-0.6
Louisiana	Iberville Parish	12.2	11.8	-0.4	27.7	27.2	-0.5
Louisiana	Jefferson Parish	11.5	11.1	-0.4	25.1	24.4	-0.7
Louisiana	Lafayette Parish	9.8	9.6	-0.2	22.6	22.0	-0.6
Louisiana	Orleans Parish	11.7	11.3	-0.4	26.7	25.9	-0.8

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Louisiana	Ouachita Parish	10.8	10.7	-0.1	23.5	23.2	-0.3
Louisiana	St. Bernard Parish	8.8	8.4	-0.4	17.6	17.0	-0.6
Louisiana	Tangipahoa Parish	10.2	9.8	-0.4	21.4	20.5	-0.9
Louisiana	Terrebonne Parish	9.0	8.8	-0.2	20.8	20.5	-0.3
Louisiana	West Baton Rouge Parish	12.5	12.2	-0.3	26.7	26.1	-0.6
Maine	Androscoggin Co	9.2	9.2	0.0	24.7	24.6	-0.1
Maine	Aroostook Co	10.3	10.3	0.0	25.1	25.1	0.0
Maine	Cumberland Co	9.8	9.8	0.0	28.6	28.6	0.0
Maine	Hancock Co	5.3	5.2	-0.1	17.0	16.8	-0.2
Maine	Kennebec Co	9.2	9.2	0.0	24.4	24.3	-0.1
Maine	Oxford Co	9.1	9.1	0.0	22.6	22.5	-0.1
Maine	Penobscot Co	8.9	8.8	-0.1	24.5	24.5	0.0
Maine	York Co	8.2	8.2	0.0	23.1	23.0	-0.1
Maryland	Anne Arundel Co	11.0	10.9	-0.1	33.1	33.0	-0.1
Maryland	Baltimore Co	11.2	11.1	-0.1	32.3	32.1	-0.2
Maryland	Harford Co	9.8	9.7	-0.1	25.8	25.7	-0.1
Maryland	Montgomery Co	9.1	9.0	-0.1	27.1	26.9	-0.2
Maryland	Washington Co	9.9	9.8	-0.1	28.3	28.2	-0.1
Maryland	Baltimore city	12.9	12.7	-0.2	35.2	35.0	-0.2
Massachusetts	Berkshire Co	10.3	10.3	0.0	25.6	25.5	-0.1
Massachusetts	Hampden Co	11.4	11.3	-0.1	32.4	32.4	0.0
Massachusetts	Plymouth Co	9.0	8.9	-0.1	24.2	24.1	-0.1
Massachusetts	Suffolk Co	10.1	10.0	-0.1	25.1	25.0	-0.1
Michigan	Allegan Co	10.6	10.3	-0.3	30.6	29.9	-0.7
Michigan	Bay Co	10.2	9.9	-0.3	27.1	26.2	-0.9
Michigan	Berrien Co	10.7	10.4	-0.3	28.1	27.5	-0.6
Michigan	Chippewa Co	7.9	7.8	-0.1	24.4	24.0	-0.4
Michigan	Genesee Co	11.0	10.7	-0.3	28.7	28.0	-0.7
Michigan	Ingham Co	11.3	11.0	-0.3	29.4	28.8	-0.6
Michigan	Kalamazoo Co	12.6	12.3	-0.3	32.3	31.7	-0.6
Michigan	Kent Co	11.8	11.5	-0.3	31.3	30.7	-0.6
Michigan	Macomb Co	11.2	10.9	-0.3	29.1	28.7	-0.4
Michigan	Monroe Co	12.5	12.2	-0.3	29.4	28.9	-0.5
Michigan	Muskegon Co	10.6	10.4	-0.2	29.5	28.8	-0.7
Michigan	Oakland Co	12.9	12.6	-0.3	33.2	32.6	-0.6
Michigan	Ottawa Co	11.4	11.1	-0.3	27.8	27.2	-0.6
Michigan	Saginaw Co	9.5	8.9	-0.6	25.6	24.4	-1.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Michigan	St. Clair Co	12.6	12.3	-0.3	32.3	31.7	-0.6
Michigan	Washtenaw Co	12.1	11.7	-0.4	29.7	28.9	-0.8
Michigan	Wayne Co	17.3	16.9	-0.4	39.0	38.4	-0.6
Minnesota	Dakota Co	8.7	8.6	-0.1	23.6	23.3	-0.3
Minnesota	Hennepin Co	9.3	9.2	-0.1	25.1	24.9	-0.2
Minnesota	Mille Lacs Co	6.4	6.4	0.0	19.4	19.2	-0.2
Minnesota	Olmsted Co	9.4	9.3	-0.1	24.8	24.6	-0.2
Minnesota	Ramsey Co	10.5	10.4	-0.1	27.8	27.5	-0.3
Minnesota	St. Louis Co	8.0	7.8	-0.2	21.7	21.4	-0.3
Minnesota	Scott Co	8.8	8.8	0.0	21.9	21.8	-0.1
Minnesota	Stearns Co	8.3	8.3	0.0	22.9	22.7	-0.2
Mississippi	Adams Co	9.5	9.2	-0.3	24.1	23.6	-0.5
Mississippi	Bolivar Co	10.4	10.2	-0.2	25.1	24.7	-0.4
Mississippi	DeSoto Co	10.6	10.4	-0.2	21.5	21.0	-0.5
Mississippi	Forrest Co	11.1	10.9	-0.2	24.7	24.4	-0.3
Mississippi	Hancock Co	8.9	8.5	-0.4	18.4	17.8	-0.6
Mississippi	Harrison Co	9.3	9.1	-0.2	20.9	20.7	-0.2
Mississippi	Hinds Co	11.3	11.1	-0.2	24.0	23.7	-0.3
Mississippi	Jackson Co	10.4	10.1	-0.3	20.8	20.4	-0.4
Mississippi	Jones Co	12.5	12.3	-0.2	23.9	23.6	-0.3
Mississippi	Lauderdale Co	10.6	10.4	-0.2	24.3	23.9	-0.4
Mississippi	Lee Co	10.4	10.3	-0.1	19.5	19.2	-0.3
Mississippi	Lowndes Co	11.2	11.1	-0.1	24.5	24.2	-0.3
Mississippi	Pearl River Co	9.7	9.5	-0.2	20.9	20.6	-0.3
Mississippi	Rankin Co	10.7	10.5	-0.2	23.5	23.2	-0.3
Mississippi	Scott Co	9.3	9.2	-0.1	20.3	20.0	-0.3
Mississippi	Warren Co	10.3	10.0	-0.3	22.8	22.3	-0.5
Missouri	Buchanan Co	10.6	10.4	-0.2	23.9	23.7	-0.2
Missouri	Cass Co	9.4	9.3	-0.1	21.9	21.7	-0.2
Missouri	Cedar Co	9.5	9.4	-0.1	21.6	21.4	-0.2
Missouri	Clay Co	11.0	10.8	-0.2	25.7	25.5	-0.2
Missouri	Greene Co	10.2	10.1	-0.1	22.5	22.2	-0.3
Missouri	Jackson Co	10.4	10.3	-0.1	24.2	23.9	-0.3
Missouri	Jasper Co	11.6	11.5	-0.1	22.6	22.3	-0.3
Missouri	Jefferson Co	12.4	12.2	-0.2	27.7	27.3	-0.4
Missouri	Monroe Co	9.3	9.2	-0.1	23.8	23.5	-0.3
Missouri	St. Charles Co	12.1	11.9	-0.2	29.5	29.1	-0.4

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Missouri	Ste. Genevieve Co	11.7	11.5	-0.2	25.6	25.1	-0.5
Missouri	St. Louis Co	12.1	12.0	-0.1	27.5	27.2	-0.3
Missouri	St. Louis city	13.4	13.0	-0.4	30.3	29.6	-0.7
Montana	Cascade Co	5.8	5.8	0.0	17.8	17.8	0.0
Montana	Flathead Co	8.0	8.0	0.0	24.1	24.0	-0.1
Montana	Gallatin Co	8.4	8.3	-0.1	27.2	27.0	-0.2
Montana	Lake Co	9.2	9.2	0.0	27.8	27.7	-0.1
Montana	Lincoln Co	14.9	14.8	-0.1	42.2	41.8	-0.4
Montana	Missoula Co	10.5	10.4	-0.1	32.0	31.6	-0.4
Montana	Ravalli Co	8.9	8.9	0.0	27.3	27.2	-0.1
Montana	Rosebud Co	6.8	6.8	0.0	16.8	16.8	0.0
Montana	Sanders Co	6.3	6.2	-0.1	16.4	16.3	-0.1
Montana	Silver Bow Co	8.4	8.4	0.0	26.1	26.0	-0.1
Montana	Yellowstone Co	7.2	7.2	0.0	18.9	18.7	-0.2
Nebraska	Cass Co	8.8	8.7	-0.1	20.9	20.8	-0.1
Nebraska	Douglas Co	9.2	9.2	0.0	22.3	22.2	-0.1
Nebraska	Hall Co	7.5	7.4	-0.1	19.7	19.4	-0.3
Nebraska	Lancaster Co	8.6	8.5	-0.1	20.8	20.6	-0.2
Nebraska	Lincoln Co	6.3	6.2	-0.1	15.7	15.6	-0.1
Nebraska	Sarpy Co	8.8	8.7	-0.1	21.8	21.6	-0.2
Nebraska	Scotts Bluff Co	5.5	5.4	-0.1	14.3	14.1	-0.2
Nebraska	Washington Co	8.5	8.4	-0.1	21.1	20.9	-0.2
Nevada	Clark Co	9.8	9.7	-0.1	26.7	26.5	-0.2
Nevada	Washoe Co	8.7	8.6	-0.1	27.2	26.5	-0.7
New Hampshire	Cheshire Co	9.9	9.9	0.0	26.9	26.9	0.0
New Hampshire	Coos Co	8.9	8.9	0.0	20.8	20.7	-0.1
New Hampshire	Merrimack Co	7.9	7.9	0.0	23.9	23.9	0.0
New Hampshire	Sullivan Co	8.3	8.3	0.0	24.3	24.2	-0.1
New Jersey	Bergen Co	10.9	10.8	-0.1	27.0	26.9	-0.1
New Jersey	Camden Co	11.0	10.9	-0.1	31.9	31.8	-0.1
New Jersey	Gloucester Co	11.2	11.0	-0.2	28.9	28.8	-0.1
New Jersey	Hudson Co	11.8	11.7	-0.1	32.5	32.4	-0.1
New Jersey	Mercer Co	10.7	10.6	-0.1	28.6	28.6	0.0
New Jersey	Middlesex Co	9.5	9.4	-0.1	26.7	26.7	0.0
New Jersey	Morris Co	9.5	9.4	-0.1	28.2	28.1	-0.1
New Jersey	Union Co	12.0	11.9	-0.1	32.4	32.3	-0.1
New Jersey	Warren Co	10.2	10.1	-0.1	26.7	26.6	-0.1

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New Mexico	Bernalillo Co	6.4	6.4	0.0	18.7	18.6	-0.1
New Mexico	Chaves Co	6.4	6.3	-0.1	14.7	14.7	0.0
New Mexico	Dona Ana Co	10.3	10.3	0.0	29.6	29.4	-0.2
New Mexico	Grant Co	5.7	5.7	0.0	13.3	13.3	0.0
New Mexico	Lea Co	6.4	6.3	-0.1	14.3	14.3	0.0
New Mexico	Sandoval Co	9.9	9.8	-0.1	27.0	26.9	-0.1
New Mexico	San Juan Co	6.0	6.0	0.0	13.3	13.3	0.0
New Mexico	Santa Fe Co	4.6	4.6	0.0	10.3	10.2	-0.1
New York	Bronx Co	12.7	12.6	-0.1	32.9	32.9	0.0
New York	Chautauqua Co	8.2	8.0	-0.2	21.6	21.3	-0.3
New York	Erie Co	11.1	10.9	-0.2	28.3	28.0	-0.3
New York	Essex Co	5.3	5.3	0.0	14.9	14.8	-0.1
New York	Kings Co	11.8	11.6	-0.2	28.7	28.6	-0.1
New York	Monroe Co	9.1	9.0	-0.1	23.9	23.8	-0.1
New York	Nassau Co	9.7	9.5	-0.2	26.6	26.4	-0.2
New York	New York Co	13.8	13.7	-0.1	32.9	32.9	0.0
New York	Niagara Co	9.7	9.6	-0.1	24.2	23.8	-0.4
New York	Onondaga Co	8.6	8.5	-0.1	23.7	23.6	-0.1
New York	Orange Co	9.4	9.4	0.0	24.4	24.3	-0.1
New York	Queens Co	10.6	10.5	-0.1	29.7	29.7	0.0
New York	Richmond Co	9.3	9.2	-0.1	26.0	25.9	-0.1
New York	St. Lawrence Co	7.4	7.4	0.0	23.3	23.0	-0.3
New York	Steuben Co	7.3	7.2	-0.1	20.6	20.5	-0.1
New York	Suffolk Co	9.6	9.5	-0.1	25.4	25.3	-0.1
New York	Westchester Co	9.8	9.7	-0.1	24.9	24.8	-0.1
North Carolina	Alamance Co	10.2	10.1	-0.1	21.6	21.4	-0.2
North Carolina	Buncombe Co	10.2	10.1	-0.1	20.2	20.0	-0.2
North Carolina	Cabarrus Co	10.8	10.8	0.0	21.1	21.0	-0.1
North Carolina	Caswell Co	9.7	9.6	-0.1	20.5	20.3	-0.2
North Carolina	Catawba Co	11.8	11.7	-0.1	24.8	24.6	-0.2
North Carolina	Chatham Co	9.0	8.9	-0.1	18.2	18.0	-0.2
North Carolina	Cumberland Co	11.1	11.1	0.0	22.3	22.2	-0.1
North Carolina	Davidson Co	11.9	11.8	-0.1	23.7	23.5	-0.2
North Carolina	Duplin Co	9.5	9.5	0.0	19.8	19.7	-0.1
North Carolina	Durham Co	10.5	10.4	-0.1	24.4	24.2	-0.2
North Carolina	Forsyth Co	10.7	10.7	0.0	24.8	24.6	-0.2
North Carolina	Gaston Co	10.6	10.5	-0.1	20.5	20.3	-0.2

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North Carolina	Guilford Co	10.5	10.4	-0.1	24.5	24.3	-0.2
North Carolina	Haywood Co	11.0	10.9	-0.1	25.0	24.9	-0.1
North Carolina	Jackson Co	9.5	9.4	-0.1	21.2	21.0	-0.2
North Carolina	Lenoir Co	8.9	8.8	-0.1	18.5	18.3	-0.2
North Carolina	McDowell Co	11.2	11.1	-0.1	23.6	23.4	-0.2
North Carolina	Mecklenburg Co	11.5	11.4	-0.1	24.9	24.8	-0.1
North Carolina	Mitchell Co	10.6	10.5	-0.1	22.6	22.5	-0.1
North Carolina	Montgomery Co	9.0	8.9	-0.1	19.5	19.4	-0.1
North Carolina	Onslow Co	8.8	8.7	-0.1	19.6	19.4	-0.2
North Carolina	Orange Co	9.7	9.6	-0.1	19.4	19.3	-0.1
North Carolina	Pitt Co	9.6	9.5	-0.1	21.7	21.5	-0.2
North Carolina	Robeson Co	9.7	9.6	-0.1	18.7	18.5	-0.2
North Carolina	Swain Co	9.8	9.7	-0.1	21.1	20.9	-0.2
North Carolina	Wake Co	10.7	10.6	-0.1	24.4	24.3	-0.1
North Carolina	Wayne Co	11.1	11.0	-0.1	21.6	21.4	-0.2
North Dakota	Billings Co	4.3	4.2	-0.1	10.2	10.1	-0.1
North Dakota	Burke Co	5.3	5.3	0.0	14.1	14.0	-0.1
North Dakota	Burleigh Co	6.0	6.0	0.0	14.5	14.4	-0.1
North Dakota	Cass Co	7.1	7.1	0.0	20.0	19.8	-0.2
North Dakota	Mercer Co	5.7	5.7	0.0	14.7	14.7	0.0
Ohio	Athens Co	8.6	8.5	-0.1	20.2	19.9	-0.3
Ohio	Butler Co	12.3	12.1	-0.2	28.2	27.8	-0.4
Ohio	Clark Co	11.4	11.2	-0.2	27.4	27.0	-0.4
Ohio	Cuyahoga Co	15.2	14.7	-0.5	39.7	39.1	-0.6
Ohio	Franklin Co	13.4	13.1	-0.3	33.1	32.7	-0.4
Ohio	Hamilton Co	14.1	13.7	-0.4	33.6	33.0	-0.6
Ohio	Jefferson Co	14.0	13.7	-0.3	33.8	33.2	-0.6
Ohio	Lake Co	10.7	10.4	-0.3	26.8	25.9	-0.9
Ohio	Lawrence Co	12.8	12.5	-0.3	27.9	27.2	-0.7
Ohio	Lorain Co	11.0	10.7	-0.3	28.4	27.7	-0.7
Ohio	Lucas Co	12.3	11.9	-0.4	31.8	31.3	-0.5
Ohio	Mahoning Co	11.6	11.3	-0.3	31.2	30.7	-0.5
Ohio	Montgomery Co	12.1	11.7	-0.4	29.4	28.9	-0.5
Ohio	Portage Co	11.0	10.6	-0.4	28.6	28.0	-0.6
Ohio	Preble Co	10.2	10.1	-0.1	25.5	25.2	-0.3
Ohio	Scioto Co	15.4	15.1	-0.3	33.8	33.3	-0.5
Ohio	Stark Co	12.9	12.7	-0.2	27.3	27.0	-0.3

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Ohio	Summit Co	12.9	12.7	-0.2	30.4	29.9	-0.5
Ohio	Trumbull Co	11.8	11.6	-0.2	33.8	33.3	-0.5
Oklahoma	Caddo Co	7.6	7.5	-0.1	18.1	17.8	-0.3
Oklahoma	Canadian Co	7.3	7.2	-0.1	15.7	15.4	-0.3
Oklahoma	Carter Co	8.3	8.2	-0.1	17.8	17.5	-0.3
Oklahoma	Cherokee Co	9.7	9.5	-0.2	20.8	20.5	-0.3
Oklahoma	Garfield Co	8.5	8.4	-0.1	20.5	20.3	-0.2
Oklahoma	Kay Co	9.1	9.0	-0.1	19.9	19.7	-0.2
Oklahoma	Lincoln Co	8.3	8.2	-0.1	22.3	21.9	-0.4
Oklahoma	Mayes Co	10.7	10.6	-0.1	23.2	23.0	-0.2
Oklahoma	Muskogee Co	10.2	10.1	-0.1	20.6	20.3	-0.3
Oklahoma	Oklahoma Co	8.7	8.6	-0.1	21.3	21.1	-0.2
Oklahoma	Ottawa Co	9.7	9.6	-0.1	22.5	22.3	-0.2
Oklahoma	Pittsburg Co	9.6	9.4	-0.2	20.6	20.3	-0.3
Oklahoma	Seminole Co	7.7	7.6	-0.1	16.2	15.9	-0.3
Oklahoma	Tulsa Co	10.1	10.0	-0.1	23.6	23.3	-0.3
Oregon	Columbia Co	5.9	5.8	-0.1	15.1	14.9	-0.2
Oregon	Deschutes Co	7.0	7.0	0.0	21.5	21.4	-0.1
Oregon	Jackson Co	10.8	10.8	0.0	37.2	37.1	-0.1
Oregon	Klamath Co	10.0	9.9	-0.1	38.7	38.5	-0.2
Oregon	Lane Co	12.8	12.7	-0.1	53.0	52.5	-0.5
Oregon	Linn Co	8.0	8.0	0.0	30.2	30.2	0.0
Oregon	Multnomah Co	8.3	8.2	-0.1	24.9	24.8	-0.1
Oregon	Union Co	6.4	6.4	0.0	21.8	21.7	-0.1
Oregon	Wasco Co	7.0	7.0	0.0	21.5	21.2	-0.3
Oregon	Washington Co	8.9	8.9	0.0	31.8	31.6	-0.2
Pennsylvania	Adams Co	9.2	9.1	-0.1	29.1	29.0	-0.1
Pennsylvania	Allegheny Co	16.2	15.8	-0.4	52.7	51.5	-1.2
Pennsylvania	Beaver Co	11.8	11.5	-0.3	32.8	32.1	-0.7
Pennsylvania	Berks Co	12.0	11.9	-0.1	35.3	35.2	-0.1
Pennsylvania	Bucks Co	10.5	10.4	-0.1	30.4	30.3	-0.1
Pennsylvania	Cambria Co	10.9	10.8	-0.1	25.1	24.8	-0.3
Pennsylvania	Centre Co	9.2	9.1	-0.1	28.6	28.4	-0.2
Pennsylvania	Dauphin Co	10.9	10.8	-0.1	33.0	32.8	-0.2
Pennsylvania	Delaware Co	12.3	12.1	-0.2	28.5	28.3	-0.2
Pennsylvania	Erie Co	10.4	10.0	-0.4	28.7	28.1	-0.6
Pennsylvania	Lackawanna Co	9.0	8.9	-0.1	28.0	27.9	-0.1

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Pennsylvania	Lancaster Co	12.0	11.9	-0.1	33.3	33.2	-0.1
Pennsylvania	Lehigh Co	10.4	10.3	-0.1	34.5	34.4	-0.1
Pennsylvania	Luzerne Co	9.5	9.5	0.0	29.0	28.9	-0.1
Pennsylvania	Mercer Co	10.8	10.6	-0.2	31.3	30.8	-0.5
Pennsylvania	Montgomery Co	10.4	10.3	-0.1	29.1	29.0	-0.1
Pennsylvania	Northampton Co	10.8	10.7	-0.1	34.8	34.8	0.0
Pennsylvania	Perry Co	9.3	9.2	-0.1	24.9	24.8	-0.1
Pennsylvania	Philadelphia Co	13.2	13.1	-0.1	35.0	34.9	-0.1
Pennsylvania	Washington Co	11.3	11.0	-0.3	25.8	25.3	-0.5
Pennsylvania	Westmoreland Co	10.7	10.5	-0.2	29.4	29.0	-0.4
Pennsylvania	York Co	12.1	12.0	-0.1	35.5	35.4	-0.1
Rhode Island	Kent Co	6.8	6.7	-0.1	18.9	18.7	-0.2
Rhode Island	Providence Co	9.2	9.2	0.0	26.4	26.3	-0.1
South Carolina	Beaufort Co	8.8	8.6	-0.2	19.9	19.6	-0.3
South Carolina	Charleston Co	9.6	9.5	-0.1	21.9	21.7	-0.2
South Carolina	Chesterfield Co	9.2	9.2	0.0	18.4	18.2	-0.2
South Carolina	Edgefield Co	9.7	9.6	-0.1	19.7	19.6	-0.1
South Carolina	Florence Co	10.3	10.2	-0.1	20.6	20.5	-0.1
South Carolina	Georgetown Co	10.6	10.5	-0.1	22.9	22.8	-0.1
South Carolina	Greenville Co	11.2	11.1	-0.1	24.2	24.0	-0.2
South Carolina	Greenwood Co	10.3	10.2	-0.1	20.1	19.9	-0.2
South Carolina	Horry Co	8.7	8.6	-0.1	19.9	19.8	-0.1
South Carolina	Lexington Co	11.0	10.9	-0.1	21.4	21.2	-0.2
South Carolina	Oconee Co	8.2	8.1	-0.1	20.6	20.5	-0.1
South Carolina	Richland Co	10.9	10.8	-0.1	21.6	21.4	-0.2
South Carolina	Spartanburg Co	10.5	10.4	-0.1	22.4	22.2	-0.2
South Dakota	Brookings Co	8.1	8.0	-0.1	20.5	20.3	-0.2
South Dakota	Brown Co	7.4	7.4	0.0	17.2	17.2	0.0
South Dakota	Jackson Co	5.1	5.1	0.0	12.5	12.4	-0.1
South Dakota	Meade Co	5.9	5.9	0.0	14.6	14.5	-0.1
South Dakota	Minnehaha Co	8.3	8.3	0.0	20.3	20.2	-0.1
South Dakota	Pennington Co	7.4	7.4	0.0	20.0	19.9	-0.1
Tennessee	Blount Co	10.2	10.1	-0.1	23.5	23.2	-0.3
Tennessee	Davidson Co	12.3	12.2	-0.1	27.4	27.2	-0.2
Tennessee	Dyer Co	10.0	9.8	-0.2	22.0	21.6	-0.4
Tennessee	Hamilton Co	13.4	13.3	-0.1	26.7	26.4	-0.3
Tennessee	Knox Co	13.1	12.9	-0.2	28.6	28.4	-0.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Tennessee	Lawrence Co	9.7	9.6	-0.1	21.3	21.0	-0.3
Tennessee	McMinn Co	11.8	11.6	-0.2	24.9	24.6	-0.3
Tennessee	Maury Co	10.8	10.7	-0.1	23.3	23.0	-0.3
Tennessee	Montgomery Co	10.9	10.8	-0.1	21.5	21.2	-0.3
Tennessee	Putnam Co	10.3	10.2	-0.1	22.7	22.4	-0.3
Tennessee	Roane Co	11.5	11.3	-0.2	24.6	24.3	-0.3
Tennessee	Shelby Co	12.4	12.2	-0.2	28.2	27.8	-0.4
Tennessee	Sullivan Co	12.2	12.1	-0.1	26.5	26.3	-0.2
Tennessee	Sumner Co	11.2	11.1	-0.1	22.8	22.5	-0.3
Texas	Bowie Co	12.0	11.8	-0.2	26.4	26.1	-0.3
Texas	Cameron Co	9.2	9.1	-0.1	20.7	20.4	-0.3
Texas	Dallas Co	11.2	11.1	-0.1	26.9	26.7	-0.2
Texas	Ector Co	7.3	7.3	0.0	15.3	15.2	-0.1
Texas	Galveston Co	7.8	7.5	-0.3	19.6	19.0	-0.6
Texas	Gregg Co	10.4	10.2	-0.2	26.0	25.7	-0.3
Texas	Harris Co	13.3	12.7	-0.6	27.7	26.9	-0.8
Texas	Hidalgo Co	10.6	10.5	-0.1	24.6	24.3	-0.3
Texas	Jefferson Co	10.1	9.8	-0.3	25.4	24.8	-0.6
Texas	Lubbock Co	7.1	7.1	0.0	16.7	16.6	-0.1
Texas	Nueces Co	9.9	9.5	-0.4	20.9	19.9	-1.0
Texas	Orange Co	10.3	9.9	-0.4	25.3	24.6	-0.7
Texas	Tarrant Co	9.9	9.8	-0.1	22.6	22.4	-0.2
Utah	Box Elder Co	8.5	8.5	0.0	38.4	38.3	-0.1
Utah	Cache Co	12.3	12.3	0.0	51.4	51.3	-0.1
Utah	Salt Lake Co	12.2	12.2	0.0	47.6	47.5	-0.1
Utah	Utah Co	9.1	9.0	-0.1	35.3	35.2	-0.1
Utah	Weber Co	8.9	8.8	-0.1	35.3	35.3	0.0
Vermont	Chittenden Co	7.7	7.6	-0.1	21.4	21.3	-0.1
Virginia	Arlington Co	10.3	10.2	-0.1	28.2	28.0	-0.2
Virginia	Charles City Co	9.2	9.1	-0.1	21.5	21.4	-0.1
Virginia	Chesterfield Co	9.8	9.7	-0.1	23.8	23.6	-0.2
Virginia	Fairfax Co	9.7	9.6	-0.1	25.8	25.7	-0.1
Virginia	Henrico Co	9.7	9.6	-0.1	22.8	22.7	-0.1
Virginia	Loudoun Co	9.2	9.1	-0.1	26.2	26.0	-0.2
Virginia	Page Co	8.9	8.8	-0.1	22.7	22.6	-0.1
Virginia	Bristol city	11.1	11.0	-0.1	25.8	25.5	-0.3
Virginia	Chesapeake city	9.8	9.7	-0.1	23.5	23.3	-0.2

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Virginia	Hampton city	10.0	9.8	-0.2	22.2	22.0	-0.2
Virginia	Newport News city	9.1	9.0	-0.1	20.5	20.3	-0.2
Virginia	Norfolk city	10.4	10.2	-0.2	23.1	22.9	-0.2
Virginia	Richmond city	10.2	10.1	-0.1	26.0	25.8	-0.2
Virginia	Roanoke city	10.4	10.3	-0.1	25.3	25.0	-0.3
Virginia	Salem city	10.6	10.5	-0.1	24.7	24.5	-0.2
Virginia	Virginia Beach city	10.1	9.9	-0.2	24.6	24.4	-0.2
Washington	Benton Co	6.4	6.4	0.0	19.9	19.8	-0.1
Washington	Clark Co	9.1	9.0	-0.1	34.0	33.8	-0.2
Washington	King Co	10.9	10.7	-0.2	34.4	34.2	-0.2
Washington	Pierce Co	11.6	11.5	-0.1	44.9	44.7	-0.2
Washington	Snohomish Co	11.4	11.4	0.0	40.5	40.2	-0.3
Washington	Spokane Co	9.6	9.6	0.0	29.7	29.6	-0.1
Washington	Thurston Co	8.8	8.8	0.0	35.0	34.8	-0.2
Washington	Whatcom Co	7.6	7.6	0.0	21.0	21.0	0.0
Washington	Yakima Co	9.4	9.3	-0.1	34.1	34.0	-0.1
West Virginia	Berkeley Co	11.8	11.7	-0.1	32.2	32.0	-0.2
West Virginia	Brooke Co	12.7	12.5	-0.2	29.7	29.3	-0.4
West Virginia	Cabell Co	13.3	13.0	-0.3	29.6	28.8	-0.8
West Virginia	Hancock Co	13.2	13.0	-0.2	32.3	31.9	-0.4
West Virginia	Harrison Co	10.3	10.2	-0.1	22.0	21.8	-0.2
West Virginia	Kanawha Co	13.6	13.4	-0.2	28.5	28.1	-0.4
West Virginia	Marion Co	11.2	11.0	-0.2	26.1	25.7	-0.4
West Virginia	Marshall Co	11.6	11.3	-0.3	25.7	25.2	-0.5
West Virginia	Mercer Co	9.0	8.9	-0.1	21.0	20.7	-0.3
West Virginia	Monongalia Co	10.5	10.4	-0.1	24.0	23.8	-0.2
West Virginia	Ohio Co	11.0	10.7	-0.3	24.7	24.3	-0.4
West Virginia	Raleigh Co	9.5	9.4	-0.1	22.8	22.5	-0.3
West Virginia	Summers Co	7.2	7.1	-0.1	19.4	19.2	-0.2
West Virginia	Wood Co	12.6	12.4	-0.2	29.7	29.3	-0.4
Wisconsin	Brown Co	10.1	10.0	-0.1	27.6	27.4	-0.2
Wisconsin	Dane Co	10.8	10.7	-0.1	29.3	29.1	-0.2
Wisconsin	Dodge Co	9.5	9.4	-0.1	25.8	25.4	-0.4
Wisconsin	Grant Co	9.9	9.8	-0.1	23.5	23.2	-0.3
Wisconsin	Kenosha Co	10.1	9.7	-0.4	27.6	26.9	-0.7
Wisconsin	Manitowoc Co	8.5	8.4	-0.1	23.8	23.4	-0.4
Wisconsin	Milwaukee Co	11.9	11.8	-0.1	31.5	31.1	-0.4

State	County	2020 Base Annual DV	2020 15/65 Annual DV	Impact of 15/65 Controls on Annual DV	2020 Base Daily DV	2020 15/65 Daily DV	Impact of 15/65 Controls on Daily DV
Wisconsin	Outagamie Co	9.5	9.4	-0.1	26.2	25.9	-0.3
Wisconsin	Vilas Co	5.6	5.5	-0.1	15.5	15.4	-0.1
Wisconsin	Waukesha Co	11.6	11.4	-0.2	31.9	31.6	-0.3
Wyoming	Campbell Co	6.1	6.1	0.0	17.0	16.9	-0.1
Wyoming	Laramie Co	4.8	4.8	0.0	11.8	11.8	0.0
Wyoming	Sheridan Co	10.4	10.4	0.0	31.6	31.4	-0.2

Appendix 4-2c. Impacts on PM2.5 Annual and Daily Design Values (μg/m^3) of Controls in the 2020 15/35 and 14/35 Scenarios vs. the 2020 15/65 Scenario

State	County	2020 15/65 Annual DV	2020 15/35 Annual DV	Impact of 15/35 Controls on Annual DV	2020 14/35 Annual DV	Impact of 14/35 Controls on Annual DV	2020 15/65 Daily DV	2020 15/35 Daily DV	Impact of 15/35 Controls on Daily DV	2020 14/35 Daily DV	Impact of 14/35 Controls on Daily DV
Alabama	Baldwin Co	8.9	8.8	-0.1	8.5	-0.4	18.4	18.4	0.0	17.5	-0.9
Alabama	Clay Co	10.7	10.7	0.0	9.9	-0.8	21.9	21.9	0.0	20.5	-1.4
Alabama	Colbert Co	10.8	10.8	0.0	10.1	-0.7	21.9	21.9	0.0	20.4	-1.5
Alabama	DeKalb Co	11.9	11.9	0.0	11.2	-0.7	27.4	27.3	-0.1	26.2	-1.2
Alabama	Escambia Co	10.5	10.4	-0.1	10.1	-0.4	20.8	20.8	0.0	19.9	-0.9
Alabama	Houston Co	12.2	12.2	0.0	11.7	-0.5	24.6	24.6	0.0	23.7	-0.9
Alabama	Jefferson Co	15.1	15.1	0.0	14.5	-0.6	34.2	34.1	-0.1	33.0	-1.2
Alabama	Madison Co	11.0	11.0	0.0	10.3	-0.7	22.8	22.7	-0.1	21.3	-1.5
Alabama	Mobile Co	11.8	11.7	-0.1	11.5	-0.3	23.9	23.8	-0.1	23.2	-0.7
Alabama	Montgomery Co	12.6	12.6	0.0	12.0	-0.6	25.2	25.2	0.0	24.1	-1.1
Alabama	Morgan Co	12.7	12.6	-0.1	11.8	-0.9	25.7	25.7	0.0	23.6	-2.1
Alabama	Russell Co	13.0	13.0	0.0	12.4	-0.6	29.4	29.3	-0.1	28.5	-0.9
Alabama	Shelby Co	11.9	11.9	0.0	11.3	-0.6	25.1	25.1	0.0	23.9	-1.2
Alabama	Sumter Co	10.3	10.3	0.0	9.9	-0.4	22.7	22.7	0.0	21.6	-1.1
Alabama	Talladega Co	12.1	12.1	0.0	11.1	-1.0	26.4	26.4	0.0	24.8	-1.6
Arizona	Gila Co	9.1	9.0	-0.1	9.0	-0.1	22.3	22.2	-0.1	22.2	-0.1
Arizona	Maricopa Co	10.1	10.1	0.0	10.1	0.0	28.3	28.2	-0.1	28.2	-0.1
Arizona	Pima Co	7.1	7.1	0.0	7.1	0.0	16.3	16.3	0.0	16.3	0.0
Arizona	Pinal Co	8.0	8.0	0.0	7.9	-0.1	18.5	18.5	0.0	18.5	0.0
Arizona	Santa Cruz Co	11.9	11.9	0.0	11.9	0.0	29.8	29.7	-0.1	29.7	-0.1
Arkansas	Arkansas Co	9.8	9.8	0.0	9.5	-0.3	20.5	20.4	-0.1	19.5	-1.0
Arkansas	Ashley Co	10.4	10.4	0.0	10.1	-0.3	23.3	23.3	0.0	22.7	-0.6
Arkansas	Craighead Co	9.7	9.7	0.0	9.4	-0.3	22.0	21.9	-0.1	21.0	-1.0
Arkansas	Crittenden Co	10.9	10.9	0.0	10.6	-0.3	23.8	23.7	-0.1	22.9	-0.9
Arkansas	Faulkner Co	10.3	10.3	0.0	10.1	-0.2	21.3	21.3	0.0	20.5	-0.8
Arkansas	Jefferson Co	11.2	11.2	0.0	11.0	-0.2	22.9	22.8	-0.1	22.2	-0.7
Arkansas	Mississippi Co	9.5	9.5	0.0	9.2	-0.3	21.6	21.5	-0.1	20.7	-0.9
Arkansas	Phillips Co	9.9	9.8	-0.1	9.5	-0.4	21.6	21.6	0.0	20.8	-0.8
Arkansas	Polk Co	9.0	9.0	0.0	8.7	-0.3	18.3	18.2	-0.1	17.5	-0.8
Arkansas	Pope Co	10.5	10.5	0.0	10.3	-0.2	22.2	22.2	0.0	21.8	-0.4
Arkansas	Pulaski Co	11.8	11.8	0.0	11.5	-0.3	25.9	25.9	0.0	25.3	-0.6
Arkansas	Sebastian Co	10.4	10.4	0.0	10.1	-0.3	20.8	20.8	0.0	20.2	-0.6
Arkansas	Union Co	11.7	11.6	-0.1	11.4	-0.3	25.4	25.4	0.0	24.6	-0.8
Arkansas	White Co	9.5	9.5	0.0	9.2	-0.3	18.9	18.8	-0.1	18.1	-0.8
California	Alameda Co	11.7	11.4	-0.3	11.5	-0.2	50.7	49.5	-1.2	49.6	-1.1
California	Butte Co	12.7	11.8	-0.9	11.7	-1.0	46.3	42.2	-4.1	42.1	-4.2
California	Calaveras Co	7.8	7.7	-0.1	7.7	-0.1	19.8	19.5	-0.3	19.5	-0.3
California	Colusa Co	9.0	8.6	-0.4	8.6	-0.4	30.3	28.8	-1.5	28.8	-1.5
California	Contra Costa Co	11.1	10.9	-0.2	10.9	-0.2	52.6	51.5	-1.1	51.5	-1.1
California	El Dorado Co	7.2	6.8	-0.4	6.8	-0.4	17.7	16.9	-0.8	16.9	-0.8
California	Fresno Co	17.3	16.9	-0.4	17.0	-0.3	59.6	58.2	-1.4	58.3	-1.3
California	Humboldt Co	8.0	7.9	-0.1	7.9	-0.1	23.1	22.7	-0.4	22.7	-0.4
California	Imperial Co	14.4	13.8	-0.6	13.8	-0.6	43.0	41.5	-1.5	41.5	-1.5
California	Inyo Co	5.9	5.8	-0.1	5.8	-0.1	36.0	35.4	-0.6	35.4	-0.6
California	Kern Co	18.6	18.2	-0.4	18.2	-0.4	68.0	66.5	-1.5	66.6	-1.4
California	Kings Co	15.6	15.2	-0.4	15.2	-0.4	61.0	59.5	-1.5	59.6	-1.4
California	Lake Co	4.6	4.6	0.0	4.6	0.0	10.1	9.9	-0.2	9.9	-0.2
California	Los Angeles Co	21.6	21.3	-0.3	21.3	-0.3	58.1	56.8	-1.3	56.8	-1.3

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California	Mendocino Co	7.5	7.4	-0.1	7.4	-0.1	24.2	23.8	-0.4	23.8	-0.4
California	Merced Co	14.4	14.0	-0.4	14.0	-0.4	47.7	46.3	-1.4	46.3	-1.4
California	Monterey Co	7.9	7.7	-0.2	7.7	-0.2	17.8	17.3	-0.5	17.3	-0.5
California	Nevada Co	7.5	7.0	-0.5	7.0	-0.5	22.2	20.9	-1.3	20.9	-1.3
California	Orange Co	18.2	17.9	-0.3	17.9	-0.3	35.6	35.0	-0.6	35.0	-0.6
California	Placer Co	9.8	8.6	-1.2	8.6	-1.2	30.6	26.9	-3.7	26.9	-3.7
California	Riverside Co	22.7	22.3	-0.4	22.3	-0.4	63.2	61.1	-2.1	61.1	-2.1
California	Sacramento Co	10.9	10.5	-0.4	10.5	-0.4	42.0	40.0	-2.0	39.9	-2.1
California	San Bernardino Co	21.4	21.1	-0.3	21.1	-0.3	58.1	56.7	-1.4	56.7	-1.4
California	San Diego Co	13.7	13.5	-0.2	13.5	-0.2	34.6	34.0	-0.6	34.0	-0.6
California	San Francisco Co	9.6	9.4	-0.2	9.4	-0.2	42.4	41.5	-0.9	41.5	-0.9
California	San Joaquin Co	14.4	14.1	-0.3	14.1	-0.3	45.3	44.0	-1.3	44.0	-1.3
California	San Luis Obispo Co	8.6	8.4	-0.2	8.4	-0.2	31.6	30.6	-1.0	30.6	-1.0
California	San Mateo Co	9.6	9.4	-0.2	9.4	-0.2	36.5	35.7	-0.8	35.7	-0.8
California	Santa Barbara Co	8.7	8.5	-0.2	8.5	-0.2	18.7	18.0	-0.7	18.0	-0.7
California	Santa Clara Co	11.3	11.2	-0.1	11.2	-0.1	48.2	47.1	-1.1	47.1	-1.1
California	Santa Cruz Co	7.4	7.2	-0.2	7.2	-0.2	17.3	16.9	-0.4	16.9	-0.4
California	Shasta Co	8.6	8.5	-0.1	8.5	-0.1	29.7	29.3	-0.4	29.3	-0.4
California	Solano Co	10.2	9.9	-0.3	9.9	-0.3	48.3	46.6	-1.7	46.6	-1.7
California	Sonoma Co	9.4	9.2	-0.2	9.2	-0.2	35.3	34.1	-1.2	34.1	-1.2
California	Stanislaus Co	14.5	14.1	-0.4	14.1	-0.4	51.5	49.9	-1.6	49.9	-1.6
California	Sutter Co	10.5	9.6	-0.9	9.6	-0.9	35.5	32.0	-3.5	32.0	-3.5
California	Tulare Co	18.9	18.5	-0.4	18.6	-0.3	65.4	64.2	-1.2	64.3	-1.1
California	Ventura Co	12.0	11.8	-0.2	11.8	-0.2	33.4	32.7	-0.7	32.7	-0.7
California	Yolo Co	9.1	8.7	-0.4	8.7	-0.4	27.5	26.2	-1.3	26.2	-1.3
Colorado	Adams Co	9.0	9.0	0.0	9.0	0.0	22.6	22.3	-0.3	22.3	-0.3
Colorado	Arapahoe Co	7.9	7.9	0.0	7.9	0.0	21.1	20.9	-0.2	20.9	-0.2
Colorado	Boulder Co	8.3	8.3	0.0	8.3	0.0	20.5	20.4	-0.1	20.4	-0.1
Colorado	Delta Co	7.8	7.8	0.0	7.8	0.0	16.4	16.4	0.0	16.4	0.0
Colorado	Denver Co	9.5	9.5	0.0	9.5	0.0	26.0	25.6	-0.4	25.6	-0.4
Colorado	Elbert Co	4.0	3.9	-0.1	3.9	-0.1	9.8	9.8	0.0	9.8	0.0
Colorado	El Paso Co	6.9	6.9	0.0	6.9	0.0	16.4	16.2	-0.2	16.2	-0.2
Colorado	Gunnison Co	6.4	6.4	0.0	6.4	0.0	17.1	17.0	-0.1	17.0	-0.1
Colorado	La Plata Co	5.1	5.1	0.0	5.1	0.0	13.0	13.0	0.0	13.0	0.0
Colorado	Larimer Co	7.4	7.4	0.0	7.4	0.0	18.4	18.3	-0.1	18.3	-0.1
Colorado	Mesa Co	7.1	7.0	-0.1	7.0	-0.1	17.5	17.2	-0.3	17.2	-0.3
Colorado	Pueblo Co	7.4	7.4	0.0	7.4	0.0	16.6	16.6	0.0	16.6	0.0
Colorado	Routt Co	7.2	7.2	0.0	7.2	0.0	15.5	15.5	0.0	15.5	0.0
Colorado	San Miguel Co	5.3	5.3	0.0	5.3	0.0	11.2	11.1	-0.1	11.1	-0.1
Colorado	Weld Co	8.3	8.3	0.0	8.3	0.0	23.0	22.9	-0.1	22.9	-0.1
Connecticut	Fairfield Co	10.7	10.6	-0.1	10.5	-0.2	31.1	30.9	-0.2	30.6	-0.5
Connecticut	Hartford Co	10.3	10.3	0.0	10.2	-0.1	28.6	28.5	-0.1	28.3	-0.3
Connecticut	New Haven Co	10.9	10.9	0.0	10.8	-0.1	29.2	29.0	-0.2	28.8	-0.4
Connecticut	New London Co	9.2	9.2	0.0	9.1	-0.1	23.6	23.6	0.0	23.3	-0.3
Delaware	Kent Co	9.3	9.2	-0.1	9.0	-0.3	0.0	0.0	0.0	0.0	0.0
Delaware	New Castle Co	12.9	12.8	-0.1	12.5	-0.4	27.2	26.9	-0.3	26.7	-0.5
Delaware	Sussex Co	10.2	10.1	-0.1	9.9	-0.3	0.0	0.0	0.0	0.0	0.0
District of Columbia	District of Columbia	11.4	11.3	-0.1	11.1	-0.3	30.6	30.4	-0.2	29.9	-0.7
Florida	Alachua Co	8.1	8.1	0.0	7.9	-0.2	17.8	17.8	0.0	17.4	-0.4
Florida	Brevard Co	5.6	5.6	0.0	5.5	-0.1	14.1	14.1	0.0	13.6	-0.5
Florida	Broward Co	6.6	6.5	-0.1	6.5	-0.1	16.4	16.3	-0.1	16.2	-0.2
Florida	Citrus Co	6.8	6.8	0.0	6.7	-0.1	15.6	15.5	-0.1	15.0	-0.6
Florida	Duval Co	8.7	8.7	0.0	8.4	-0.3	20.6	20.5	-0.1	19.9	-0.7

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Florida	Escambia Co	9.8	9.8	0.0	9.5	-0.3	19.7	19.7	0.0	19.0	-0.7
Florida	Hillsborough Co	8.5	8.5	0.0	8.4	-0.1	18.0	18.0	0.0	17.4	-0.6
Florida	Lee Co	6.3	6.3	0.0	6.1	-0.2	14.1	14.1	0.0	13.7	-0.4
Florida	Leon Co	10.7	10.7	0.0	10.4	-0.3	22.1	22.1	0.0	21.4	-0.7
Florida	Manatee Co	6.9	6.8	-0.1	6.7	-0.2	16.5	16.5	0.0	16.0	-0.5
Florida	Marion Co	7.9	7.8	-0.1	7.7	-0.2	16.4	16.4	0.0	16.0	-0.4
Florida	Miami-Dade Co	7.6	7.5	-0.1	7.4	-0.2	15.5	15.4	-0.1	15.2	-0.3
Florida	Orange Co	8.1	8.1	0.0	7.9	-0.2	18.7	18.7	0.0	18.1	-0.6
Florida	Palm Beach Co	5.5	5.5	0.0	5.4	-0.1	14.3	14.3	0.0	13.9	-0.4
Florida	Pinellas Co	7.7	7.7	0.0	7.6	-0.1	16.8	16.8	0.0	16.4	-0.4
Florida	Polk Co	8.6	8.6	0.0	8.5	-0.1	19.2	19.2	0.0	18.6	-0.6
Florida	St. Lucie Co	6.5	6.5	0.0	6.3	-0.2	14.1	14.1	0.0	13.6	-0.5
Florida	Sarasota Co	6.9	6.9	0.0	6.8	-0.1	17.4	17.4	0.0	16.8	-0.6
Florida	Seminole Co	7.2	7.2	0.0	7.0	-0.2	15.5	15.4	-0.1	14.9	-0.6
Florida	Volusia Co	7.1	7.1	0.0	6.9	-0.2	15.1	15.1	0.0	14.7	-0.4
Georgia	Bibb Co	13.5	13.5	0.0	12.7	-0.8	26.6	26.5	-0.1	25.4	-1.2
Georgia	Chatham Co	12.1	12.1	0.0	11.4	-0.7	24.7	24.6	-0.1	23.4	-1.3
Georgia	Clarke Co	12.5	12.4	-0.1	11.4	-1.1	25.1	25.1	0.0	23.7	-1.4
Georgia	Clayton Co	13.5	13.5	0.0	12.8	-0.7	27.5	27.5	0.0	26.2	-1.3
Georgia	Cobb Co	13.1	13.1	0.0	12.5	-0.6	27.5	27.5	0.0	26.2	-1.3
Georgia	DeKalb Co	13.0	13.0	0.0	12.3	-0.7	30.1	30.0	-0.1	28.8	-1.3
Georgia	Dougherty Co	12.5	12.5	0.0	12.0	-0.5	27.4	27.4	0.0	26.6	-0.8
Georgia	Floyd Co	13.8	13.8	0.0	13.2	-0.6	30.2	30.1	-0.1	28.8	-1.4
Georgia	Fulton Co	14.9	14.9	0.0	14.2	-0.7	30.7	30.7	0.0	29.6	-1.1
Georgia	Glynn Co	9.9	9.9	0.0	9.4	-0.5	23.1	23.1	0.0	22.3	-0.8
Georgia	Gwinnett Co	12.2	12.2	0.0	11.5	-0.7	0.0	0.0	0.0	0.0	0.0
Georgia	Hall Co	11.9	11.8	-0.1	11.1	-0.8	24.3	24.3	0.0	23.1	-1.2
Georgia	Houston Co	10.5	10.4	-0.1	9.9	-0.6	0.0	0.0	0.0	0.0	0.0
Georgia	Lowndes Co	9.9	9.9	0.0	9.6	-0.3	24.2	24.2	0.0	23.3	-0.9
Georgia	Muscogee Co	13.1	13.0	-0.1	12.5	-0.6	33.5	33.4	-0.1	32.5	-1.0
Georgia	Paulding Co	11.5	11.5	0.0	10.8	-0.7	29.3	29.3	0.0	27.4	-1.9
Georgia	Richmond Co	12.7	12.6	-0.1	11.8	-0.9	27.4	27.3	-0.1	26.2	-1.2
Georgia	Walker Co	11.9	11.9	0.0	11.1	-0.8	23.8	23.7	-0.1	22.5	-1.3
Georgia	Washington Co	12.5	12.5	0.0	11.6	-0.9	0.0	0.0	0.0	0.0	0.0
Georgia	Wilkinson Co	13.4	13.3	-0.1	12.7	-0.7	29.0	28.9	-0.1	28.0	-1.0
Idaho	Ada Co	8.8	8.8	0.0	8.8	0.0	31.6	31.4	-0.2	31.4	-0.2
Idaho	Bannock Co	9.1	8.8	-0.3	8.8	-0.3	39.9	38.7	-1.2	38.7	-1.2
Idaho	Bonneville Co	6.5	6.5	0.0	6.5	0.0	20.0	19.9	-0.1	19.9	-0.1
Idaho	Canyon Co	9.1	9.0	-0.1	9.0	-0.1	31.7	31.5	-0.2	31.5	-0.2
Idaho	Power Co	10.4	10.1	-0.3	10.1	-0.3	36.3	35.1	-1.2	35.1	-1.2
Idaho	Shoshone Co	12.3	12.2	-0.1	12.2	-0.1	35.9	35.6	-0.3	35.6	-0.3
Illinois	Adams Co	10.9	10.9	0.0	10.4	-0.5	22.6	22.6	0.0	21.4	-1.2
Illinois	Champaign Co	10.3	10.3	0.0	9.9	-0.4	23.2	23.1	-0.1	22.6	-0.6
Illinois	Cook Co	14.5	14.5	0.0	14.2	-0.3	35.3	35.3	0.0	34.7	-0.6
Illinois	DuPage Co	12.0	12.0	0.0	11.7	-0.3	29.8	29.7	-0.1	29.4	-0.4
Illinois	Kane Co	11.7	11.8	0.1	11.5	-0.2	28.9	28.8	-0.1	28.4	-0.5
Illinois	Lake Co	10.6	10.6	0.0	10.4	-0.2	26.3	26.2	-0.1	26.0	-0.3
Illinois	La Salle Co	0.0	0.0	0.0	0.0	0.0	27.6	27.5	-0.1	27.1	-0.5
Illinois	McHenry Co	10.7	10.7	0.0	10.4	-0.3	28.2	28.1	-0.1	27.7	-0.5
Illinois	McLean Co	11.3	11.3	0.0	10.8	-0.5	24.6	24.5	-0.1	23.9	-0.7
Illinois	Macon Co	11.7	11.7	0.0	11.4	-0.3	29.4	29.4	0.0	28.6	-0.8
Illinois	Madison Co	14.6	14.6	0.0	14.0	-0.6	34.4	34.3	-0.1	33.2	-1.2
Illinois	Peoria Co	11.6	11.6	0.0	10.9	-0.7	27.5	27.5	0.0	26.0	-1.5

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Illinois	Randolph Co	10.4	10.3	-0.1	9.9	-0.5	22.0	21.9	-0.1	21.0	-1.0
Illinois	Rock Island Co	10.2	10.2	0.0	9.9	-0.3	22.5	22.5	0.0	21.8	-0.7
Illinois	St. Clair Co	14.1	14.0	-0.1	13.4	-0.7	29.4	29.3	-0.1	28.2	-1.2
Illinois	Sangamon Co	11.0	11.0	0.0	10.6	-0.4	25.4	25.4	0.0	24.4	-1.0
Illinois	Will Co	12.7	12.7	0.0	12.4	-0.3	31.0	31.0	0.0	30.5	-0.5
Indiana	Allen Co	11.6	11.6	0.0	11.2	-0.4	29.3	29.2	-0.1	28.8	-0.5
Indiana	Clark Co	13.2	13.2	0.0	12.7	-0.5	30.0	29.9	-0.1	28.7	-1.3
Indiana	Delaware Co	11.4	11.4	0.0	11.0	-0.4	26.2	26.1	-0.1	25.4	-0.8
Indiana	Dubois Co	12.5	12.5	0.0	12.1	-0.4	0.0	0.0	0.0	0.0	0.0
Indiana	Elkhart Co	12.2	12.2	0.0	11.9	-0.3	28.6	28.5	-0.1	28.0	-0.6
Indiana	Floyd Co	11.7	11.7	0.0	11.2	-0.5	26.1	26.0	-0.1	25.1	-1.0
Indiana	Henry Co	10.4	10.3	-0.1	10.0	-0.4	23.7	23.7	0.0	23.3	-0.4
Indiana	Howard Co	11.8	11.7	-0.1	11.4	-0.4	29.1	29.0	-0.1	28.4	-0.7
Indiana	Knox Co	10.4	10.4	0.0	10.1	-0.3	23.4	23.3	-0.1	22.3	-1.1
Indiana	Lake Co	12.4	12.4	0.0	12.2	-0.2	36.9	36.8	-0.1	36.5	-0.4
Indiana	La Porte Co	10.9	10.9	0.0	10.6	-0.3	26.1	26.0	-0.1	25.7	-0.4
Indiana	Madison Co	11.4	11.4	0.0	11.0	-0.4	26.4	26.4	0.0	25.9	-0.5
Indiana	Marion Co	13.1	13.1	0.0	12.7	-0.4	32.3	32.1	-0.2	31.5	-0.8
Indiana	Porter Co	10.9	10.9	0.0	10.6	-0.3	26.3	26.3	0.0	26.0	-0.3
Indiana	St. Joseph Co	11.6	11.6	0.0	11.3	-0.3	28.5	28.4	-0.1	28.0	-0.5
Indiana	Spencer Co	10.9	10.9	0.0	10.4	-0.5	22.1	22.0	-0.1	21.2	-0.9
Indiana	Vanderburgh Co	12.3	12.3	0.0	11.7	-0.6	28.4	28.3	-0.1	27.1	-1.3
Indiana	Vigo Co	11.7	11.7	0.0	11.3	-0.4	28.0	27.9	-0.1	27.1	-0.9
Iowa	Black Hawk Co	9.6	9.6	0.0	9.5	-0.1	23.9	23.9	0.0	23.0	-0.9
Iowa	Cerro Gordo Co	8.9	8.9	0.0	8.8	-0.1	23.6	23.6	0.0	23.3	-0.3
Iowa	Clinton Co	10.1	10.1	0.0	9.9	-0.2	26.2	26.2	0.0	25.9	-0.3
Iowa	Emmet Co	7.4	7.4	0.0	7.3	-0.1	18.5	18.5	0.0	18.1	-0.4
Iowa	Johnson Co	9.7	9.7	0.0	9.5	-0.2	25.2	25.1	-0.1	24.7	-0.5
Iowa	Linn Co	9.7	9.6	-0.1	9.5	-0.2	26.6	26.6	0.0	25.5	-1.1
Iowa	Muscatine Co	11.0	11.0	0.0	10.8	-0.2	28.0	28.0	0.0	26.9	-1.1
Iowa	Polk Co	8.8	8.8	0.0	8.7	-0.1	22.5	22.4	-0.1	22.3	-0.2
Iowa	Pottawattamie Co	8.9	8.8	-0.1	8.8	-0.1	20.8	20.8	0.0	20.5	-0.3
Iowa	Scott Co	10.4	10.4	0.0	10.1	-0.3	25.3	25.3	0.0	24.9	-0.4
Iowa	Van Buren Co	8.6	8.6	0.0	8.4	-0.2	22.1	22.1	0.0	21.3	-0.8
Iowa	Woodbury Co	8.6	8.6	0.0	8.5	-0.1	21.6	21.6	0.0	21.5	-0.1
Kansas	Johnson Co	9.8	9.8	0.0	9.6	-0.2	22.9	22.9	0.0	22.6	-0.3
Kansas	Linn Co	8.7	8.7	0.0	8.6	-0.1	19.3	19.3	0.0	18.7	-0.6
Kansas	Sedgwick Co	9.5	9.5	0.0	9.4	-0.1	21.2	21.1	-0.1	20.7	-0.5
Kansas	Shawnee Co	9.3	9.3	0.0	9.2	-0.1	20.5	20.5	0.0	20.0	-0.5
Kansas	Sumner Co	8.5	8.5	0.0	8.4	-0.1	18.2	18.2	0.0	17.9	-0.3
Kansas	Wyandotte Co	11.5	11.5	0.0	11.4	-0.1	25.7	25.6	-0.1	25.3	-0.4
Kentucky	Bell Co	10.8	10.8	0.0	10.3	-0.5	23.6	23.6	0.0	22.7	-0.9
Kentucky	Boyd Co	11.0	11.0	0.0	10.6	-0.4	24.5	24.4	-0.1	23.9	-0.6
Kentucky	Bullitt Co	11.5	11.5	0.0	11.0	-0.5	24.5	24.5	0.0	23.6	-0.9
Kentucky	Campbell Co	10.3	10.3	0.0	9.8	-0.5	26.3	26.2	-0.1	25.2	-1.1
Kentucky	Carter Co	8.8	8.8	0.0	8.4	-0.4	18.9	18.8	-0.1	18.1	-0.8
Kentucky	Christian Co	10.8	10.8	0.0	10.3	-0.5	22.4	22.3	-0.1	21.6	-0.8
Kentucky	Daviess Co	11.1	11.1	0.0	10.6	-0.5	24.0	23.9	-0.1	22.9	-1.1
Kentucky	Fayette Co	11.7	11.7	0.0	11.2	-0.5	25.2	25.1	-0.1	24.4	-0.8
Kentucky	Franklin Co	10.0	10.0	0.0	9.5	-0.5	23.8	23.7	-0.1	23.0	-0.8
Kentucky	Hardin Co	10.7	10.6	-0.1	10.1	-0.6	23.2	23.2	0.0	22.2	-1.0
Kentucky	Jefferson Co	13.4	13.4	0.0	12.9	-0.5	32.6	32.5	-0.1	31.6	-1.0
Kentucky	Kenton Co	11.1	11.0	-0.1	10.5	-0.6	27.6	27.5	-0.1	26.5	-1.1

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Kentucky	McCracken Co	11.1	11.1	0.0	10.6	-0.5	23.2	23.1	-0.1	22.1	-1.1
Kentucky	Madison Co	9.9	9.9	0.0	9.5	-0.4	20.3	20.2	-0.1	19.4	-0.9
Kentucky	Perry Co	9.6	9.6	0.0	9.2	-0.4	0.0	0.0	0.0	0.0	0.0
Kentucky	Pike Co	10.2	10.2	0.0	9.8	-0.4	20.3	20.2	-0.1	19.4	-0.9
Kentucky	Warren Co	10.9	10.9	0.0	10.4	-0.5	23.8	23.7	-0.1	22.7	-1.1
Louisiana	Caddo Parish	11.1	11.1	0.0	10.9	-0.2	24.0	24.0	0.0	23.3	-0.7
Louisiana	Calcasieu Parish	9.9	9.9	0.0	9.7	-0.2	25.7	25.6	-0.1	24.7	-1.0
Louisiana	East Baton Rouge Parish	12.6	12.5	-0.1	12.4	-0.2	27.2	27.1	-0.1	26.8	-0.4
Louisiana	Iberville Parish	11.8	11.7	-0.1	11.5	-0.3	27.2	27.1	-0.1	26.7	-0.5
Louisiana	Jefferson Parish	11.1	11.0	-0.1	10.8	-0.3	24.4	24.3	-0.1	24.0	-0.4
Louisiana	Lafayette Parish	9.6	9.6	0.0	9.4	-0.2	22.0	21.9	-0.1	21.1	-0.9
Louisiana	Orleans Parish	11.3	11.2	-0.1	11.0	-0.3	25.9	25.8	-0.1	25.3	-0.6
Louisiana	Ouachita Parish	10.7	10.7	0.0	10.6	-0.1	23.2	23.2	0.0	22.6	-0.6
Louisiana	St. Bernard Parish	8.4	8.4	0.0	8.1	-0.3	17.0	16.9	-0.1	16.2	-0.8
Louisiana	Tangipahoa Parish	9.8	9.8	0.0	9.6	-0.2	20.5	20.5	0.0	19.8	-0.7
Louisiana	Terrebonne Parish	8.8	8.8	0.0	8.6	-0.2	20.5	20.5	0.0	20.0	-0.5
Louisiana	West Baton Rouge Parish	12.2	12.1	-0.1	12.0	-0.2	26.1	26.0	-0.1	25.7	-0.4
Maine	Androscoggin Co	9.2	9.2	0.0	9.1	-0.1	24.6	24.5	-0.1	24.4	-0.2
Maine	Aroostook Co	10.3	10.3	0.0	10.3	0.0	25.1	25.0	-0.1	25.0	-0.1
Maine	Cumberland Co	9.8	9.7	-0.1	9.7	-0.1	28.6	28.5	-0.1	28.4	-0.2
Maine	Hancock Co	5.2	5.2	0.0	5.2	0.0	16.8	16.8	0.0	16.5	-0.3
Maine	Kennebec Co	9.2	9.2	0.0	9.1	-0.1	24.3	24.3	0.0	24.2	-0.1
Maine	Oxford Co	9.1	9.1	0.0	9.0	-0.1	22.5	22.5	0.0	22.3	-0.2
Maine	Penobscot Co	8.8	8.8	0.0	8.8	0.0	24.5	24.4	-0.1	24.2	-0.3
Maine	York Co	8.2	8.2	0.0	8.1	-0.1	23.0	22.9	-0.1	22.7	-0.3
Maryland	Anne Arundel Co	10.9	10.8	-0.1	10.6	-0.3	33.0	32.7	-0.3	32.3	-0.7
Maryland	Baltimore Co	11.1	11.0	-0.1	10.8	-0.3	32.1	31.9	-0.2	31.5	-0.6
Maryland	Harford Co	9.7	9.6	-0.1	9.5	-0.2	25.7	25.5	-0.2	25.2	-0.5
Maryland	Montgomery Co	9.0	8.9	-0.1	8.7	-0.3	26.9	26.7	-0.2	26.3	-0.6
Maryland	Washington Co	9.8	9.6	-0.2	9.5	-0.3	28.2	27.9	-0.3	27.6	-0.6
Maryland	Baltimore city	12.7	12.6	-0.1	12.4	-0.3	35.0	34.7	-0.3	34.4	-0.6
Massachusetts	Berkshire Co	10.3	10.2	-0.1	10.2	-0.1	25.5	25.4	-0.1	25.2	-0.3
Massachusetts	Hampden Co	11.3	11.3	0.0	11.2	-0.1	32.4	32.3	-0.1	32.1	-0.3
Massachusetts	Plymouth Co	8.9	8.9	0.0	8.8	-0.1	24.1	24.1	0.0	23.9	-0.2
Massachusetts	Suffolk Co	10.0	10.0	0.0	9.9	-0.1	25.0	24.9	-0.1	24.7	-0.3
Michigan	Allegan Co	10.3	10.3	0.0	10.1	-0.2	29.9	29.8	-0.1	29.4	-0.5
Michigan	Bay Co	9.9	9.9	0.0	9.7	-0.2	26.2	26.1	-0.1	25.7	-0.5
Michigan	Berrien Co	10.4	10.4	0.0	10.1	-0.3	27.5	27.4	-0.1	27.1	-0.4
Michigan	Chippewa Co	7.8	7.8	0.0	7.7	-0.1	24.0	24.0	0.0	23.6	-0.4
Michigan	Genesee Co	10.7	10.6	-0.1	10.4	-0.3	28.0	27.9	-0.1	27.2	-0.8
Michigan	Ingham Co	11.0	11.0	0.0	10.7	-0.3	28.8	28.6	-0.2	28.1	-0.7
Michigan	Kalamazoo Co	12.3	12.3	0.0	12.0	-0.3	31.7	31.6	-0.1	31.1	-0.6
Michigan	Kent Co	11.5	11.5	0.0	11.3	-0.2	30.7	30.6	-0.1	30.2	-0.5
Michigan	Macomb Co	10.9	10.9	0.0	10.6	-0.3	28.7	28.5	-0.2	28.1	-0.6
Michigan	Monroe Co	12.2	12.1	-0.1	11.8	-0.4	28.9	28.7	-0.2	28.1	-0.8
Michigan	Muskegon Co	10.4	10.4	0.0	10.2	-0.2	28.8	28.7	-0.1	28.0	-0.8
Michigan	Oakland Co	12.6	12.5	-0.1	12.2	-0.4	32.6	32.3	-0.3	31.8	-0.8
Michigan	Ottawa Co	11.1	11.1	0.0	10.9	-0.2	27.2	27.1	-0.1	26.5	-0.7
Michigan	Saginaw Co	8.9	8.8	-0.1	8.6	-0.3	24.4	24.3	-0.1	24.0	-0.4
Michigan	St. Clair Co	12.3	12.3	0.0	11.9	-0.4	31.7	31.5	-0.2	30.8	-0.9
Michigan	Washtenaw Co	11.7	11.7	0.0	11.3	-0.4	28.9	28.7	-0.2	28.1	-0.8
Michigan	Wayne Co	16.9	16.8	-0.1	16.4	-0.5	38.4	38.1	-0.3	37.5	-0.9
Minnesota	Dakota Co	8.6	8.6	0.0	8.5	-0.1	23.3	23.3	0.0	23.0	-0.3

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Minnesota	Hennepin Co	9.2	9.2	0.0	9.1	-0.1	24.9	24.9	0.0	24.6	-0.3
Minnesota	Mille Lacs Co	6.4	6.4	0.0	6.3	-0.1	19.2	19.2	0.0	19.0	-0.2
Minnesota	Olmsted Co	9.3	9.3	0.0	9.2	-0.1	24.6	24.6	0.0	23.9	-0.7
Minnesota	Ramsey Co	10.4	10.4	0.0	10.3	-0.1	27.5	27.5	0.0	27.1	-0.4
Minnesota	St. Louis Co	7.8	7.8	0.0	7.8	0.0	21.4	21.3	-0.1	21.0	-0.4
Minnesota	Scott Co	8.8	8.8	0.0	8.7	-0.1	21.8	21.7	-0.1	21.6	-0.2
Minnesota	Stearns Co	8.3	8.3	0.0	8.2	-0.1	22.7	22.7	0.0	22.4	-0.3
Mississippi	Adams Co	9.2	9.2	0.0	9.0	-0.2	23.6	23.5	-0.1	22.6	-1.0
Mississippi	Bolivar Co	10.2	10.2	0.0	9.9	-0.3	24.7	24.7	0.0	23.7	-1.0
Mississippi	DeSoto Co	10.4	10.4	0.0	10.0	-0.4	21.0	20.9	-0.1	19.6	-1.4
Mississippi	Forrest Co	10.9	10.9	0.0	10.6	-0.3	24.4	24.4	0.0	23.7	-0.7
Mississippi	Hancock Co	8.5	8.5	0.0	8.3	-0.2	17.8	17.7	-0.1	17.2	-0.6
Mississippi	Harrison Co	9.1	9.1	0.0	8.8	-0.3	20.7	20.6	-0.1	20.0	-0.7
Mississippi	Hinds Co	11.1	11.1	0.0	10.9	-0.2	23.7	23.6	-0.1	22.9	-0.8
Mississippi	Jackson Co	10.1	10.1	0.0	9.8	-0.3	20.4	20.3	-0.1	19.4	-1.0
Mississippi	Jones Co	12.3	12.3	0.0	11.9	-0.4	23.6	23.5	-0.1	22.6	-1.0
Mississippi	Lauderdale Co	10.4	10.4	0.0	10.0	-0.4	23.9	23.9	0.0	23.0	-0.9
Mississippi	Lee Co	10.3	10.3	0.0	9.8	-0.5	19.2	19.2	0.0	18.1	-1.1
Mississippi	Lowndes Co	11.1	11.1	0.0	10.6	-0.5	24.2	24.1	-0.1	22.5	-1.7
Mississippi	Pearl River Co	9.5	9.4	-0.1	9.2	-0.3	20.6	20.5	-0.1	19.8	-0.8
Mississippi	Rankin Co	10.5	10.5	0.0	10.3	-0.2	23.2	23.1	-0.1	22.5	-0.7
Mississippi	Scott Co	9.2	9.2	0.0	8.9	-0.3	20.0	20.0	0.0	19.1	-0.9
Mississippi	Warren Co	10.0	9.9	-0.1	9.7	-0.3	22.3	22.2	-0.1	21.3	-1.0
Missouri	Buchanan Co	10.4	10.4	0.0	10.3	-0.1	23.7	23.6	-0.1	23.3	-0.4
Missouri	Cass Co	9.3	9.3	0.0	9.2	-0.1	21.7	21.7	0.0	21.3	-0.4
Missouri	Cedar Co	9.4	9.3	-0.1	9.1	-0.3	21.4	21.4	0.0	20.8	-0.6
Missouri	Clay Co	10.8	10.8	0.0	10.7	-0.1	25.5	25.4	-0.1	25.3	-0.2
Missouri	Greene Co	10.1	10.1	0.0	9.8	-0.3	22.2	22.2	0.0	21.5	-0.7
Missouri	Jackson Co	10.3	10.3	0.0	10.1	-0.2	23.9	23.9	0.0	23.6	-0.3
Missouri	Jasper Co	11.5	11.5	0.0	11.3	-0.2	22.3	22.3	0.0	21.5	-0.8
Missouri	Jefferson Co	12.2	12.2	0.0	11.7	-0.5	27.3	27.3	0.0	25.9	-1.4
Missouri	Monroe Co	9.2	9.2	0.0	8.9	-0.3	23.5	23.5	0.0	22.7	-0.8
Missouri	St. Charles Co	11.9	11.9	0.0	11.2	-0.7	29.1	29.0	-0.1	27.7	-1.4
Missouri	Ste. Genevieve Co	11.5	11.4	-0.1	11.0	-0.5	25.1	25.1	0.0	23.6	-1.5
Missouri	St. Louis Co	12.0	11.9	-0.1	11.5	-0.5	27.2	27.1	-0.1	26.3	-0.9
Missouri	St. Louis city	13.0	12.9	-0.1	12.4	-0.6	29.6	29.5	-0.1	28.8	-0.8
Montana	Cascade Co	5.8	5.7	-0.1	5.7	-0.1	17.8	17.6	-0.2	17.6	-0.2
Montana	Flathead Co	8.0	7.8	-0.2	7.8	-0.2	24.0	23.3	-0.7	23.3	-0.7
Montana	Gallatin Co	8.3	8.3	0.0	8.3	0.0	27.0	26.9	-0.1	26.9	-0.1
Montana	Lake Co	9.2	9.0	-0.2	9.0	-0.2	27.7	26.9	-0.8	26.9	-0.8
Montana	Lincoln Co	14.8	14.5	-0.3	14.6	-0.2	41.8	41.3	-0.5	41.3	-0.5
Montana	Missoula Co	10.4	9.4	-1.0	9.4	-1.0	31.6	28.6	-3.0	28.6	-3.0
Montana	Ravalli Co	8.9	8.8	-0.1	8.8	-0.1	27.2	26.9	-0.3	26.9	-0.3
Montana	Rosebud Co	6.8	6.8	0.0	6.8	0.0	16.8	16.8	0.0	16.7	-0.1
Montana	Sanders Co	6.2	6.2	0.0	6.2	0.0	16.3	16.2	-0.1	16.2	-0.1
Montana	Silver Bow Co	8.4	8.3	-0.1	8.3	-0.1	26.0	25.8	-0.2	25.8	-0.2
Montana	Yellowstone Co	7.2	7.1	-0.1	7.1	-0.1	18.7	18.7	0.0	18.7	0.0
Nebraska	Cass Co	8.7	8.7	0.0	8.6	-0.1	20.8	20.7	-0.1	20.5	-0.3
Nebraska	Douglas Co	9.2	9.2	0.0	9.1	-0.1	22.2	22.1	-0.1	21.9	-0.3
Nebraska	Hall Co	7.4	7.4	0.0	7.3	-0.1	19.4	19.4	0.0	19.1	-0.3
Nebraska	Lancaster Co	8.5	8.5	0.0	8.4	-0.1	20.6	20.6	0.0	20.3	-0.3
Nebraska	Lincoln Co	6.2	6.2	0.0	6.2	0.0	15.6	15.6	0.0	15.5	-0.1
Nebraska	Sarpy Co	8.7	8.7	0.0	8.6	-0.1	21.6	21.6	0.0	21.4	-0.2

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Nebraska	Scotts Bluff Co	5.4	5.4	0.0	5.4	0.0	14.1	14.1	0.0	14.0	-0.1
Nebraska	Washington Co	8.4	8.4	0.0	8.3	-0.1	20.9	20.9	0.0	20.7	-0.2
Nevada	Clark Co	9.7	9.7	0.0	9.7	0.0	26.5	26.4	-0.1	26.4	-0.1
Nevada	Washoe Co	8.6	8.4	-0.2	8.4	-0.2	26.5	26.0	-0.5	26.0	-0.5
New Hampshire	Cheshire Co	9.9	9.8	-0.1	9.8	-0.1	26.9	26.8	-0.1	26.7	-0.2
New Hampshire	Coos Co	8.9	8.9	0.0	8.8	-0.1	20.7	20.6	-0.1	20.3	-0.4
New Hampshire	Merrimack Co	7.9	7.9	0.0	7.8	-0.1	23.9	23.8	-0.1	23.6	-0.3
New Hampshire	Sullivan Co	8.3	8.3	0.0	8.2	-0.1	24.2	24.2	0.0	24.0	-0.2
New Jersey	Bergen Co	10.8	10.7	-0.1	10.6	-0.2	26.9	26.7	-0.2	26.5	-0.4
New Jersey	Camden Co	10.9	10.8	-0.1	10.6	-0.3	31.8	31.6	-0.2	31.3	-0.5
New Jersey	Gloucester Co	11.0	10.9	-0.1	10.7	-0.3	28.8	28.6	-0.2	28.3	-0.5
New Jersey	Hudson Co	11.7	11.6	-0.1	11.5	-0.2	32.4	32.2	-0.2	32.0	-0.4
New Jersey	Mercer Co	10.6	10.6	0.0	10.4	-0.2	28.6	28.4	-0.2	28.0	-0.6
New Jersey	Middlesex Co	9.4	9.4	0.0	9.2	-0.2	26.7	26.5	-0.2	26.2	-0.5
New Jersey	Morris Co	9.4	9.3	-0.1	9.2	-0.2	28.1	27.9	-0.2	27.5	-0.6
New Jersey	Union Co	11.9	11.8	-0.1	11.7	-0.2	32.3	32.1	-0.2	31.8	-0.5
New Jersey	Warren Co	10.1	10.0	-0.1	9.9	-0.2	26.6	26.5	-0.1	26.2	-0.4
New Mexico	Bernalillo Co	6.4	6.4	0.0	6.4	0.0	18.6	18.6	0.0	18.6	0.0
New Mexico	Chaves Co	6.3	6.3	0.0	6.3	0.0	14.7	14.6	-0.1	14.5	-0.2
New Mexico	Dona Ana Co	10.3	10.3	0.0	10.2	-0.1	29.4	29.4	0.0	29.3	-0.1
New Mexico	Grant Co	5.7	5.7	0.0	5.7	0.0	13.3	13.3	0.0	13.2	-0.1
New Mexico	Lea Co	6.3	6.3	0.0	6.3	0.0	14.3	14.3	0.0	14.2	-0.1
New Mexico	Sandoval Co	9.8	9.8	0.0	9.8	0.0	26.9	26.9	0.0	26.9	0.0
New Mexico	San Juan Co	6.0	6.0	0.0	6.0	0.0	13.3	13.3	0.0	13.3	0.0
New Mexico	Santa Fe Co	4.6	4.6	0.0	4.6	0.0	10.2	10.2	0.0	10.2	0.0
New York	Bronx Co	12.6	12.5	-0.1	12.4	-0.2	32.9	32.7	-0.2	32.5	-0.4
New York	Chautauqua Co	8.0	7.9	-0.1	7.7	-0.3	21.3	20.9	-0.4	20.7	-0.6
New York	Erie Co	10.9	10.8	-0.1	10.7	-0.2	28.0	27.7	-0.3	27.4	-0.6
New York	Essex Co	5.3	5.3	0.0	5.2	-0.1	14.8	14.6	-0.2	14.3	-0.5
New York	Kings Co	11.6	11.5	-0.1	11.4	-0.2	28.6	28.4	-0.2	28.2	-0.4
New York	Monroe Co	9.0	8.9	-0.1	8.8	-0.2	23.8	23.6	-0.2	23.4	-0.4
New York	Nassau Co	9.5	9.5	0.0	9.3	-0.2	26.4	26.2	-0.2	26.0	-0.4
New York	New York Co	13.7	13.7	0.0	13.5	-0.2	32.9	32.6	-0.3	32.4	-0.5
New York	Niagara Co	9.6	9.6	0.0	9.4	-0.2	23.8	23.5	-0.3	23.1	-0.7
New York	Onondaga Co	8.5	8.5	0.0	8.4	-0.1	23.6	23.4	-0.2	23.1	-0.5
New York	Orange Co	9.4	9.3	-0.1	9.2	-0.2	24.3	24.2	-0.1	23.9	-0.4
New York	Queens Co	10.5	10.5	0.0	10.4	-0.1	29.7	29.5	-0.2	29.3	-0.4
New York	Richmond Co	9.2	9.2	0.0	9.0	-0.2	25.9	25.7	-0.2	25.6	-0.3
New York	St. Lawrence Co	7.4	7.4	0.0	7.3	-0.1	23.0	22.9	-0.1	22.7	-0.3
New York	Steuben Co	7.2	7.2	0.0	7.0	-0.2	20.5	20.3	-0.2	19.9	-0.6
New York	Suffolk Co	9.5	9.5	0.0	9.3	-0.2	25.3	25.1	-0.2	24.8	-0.5
New York	Westchester Co	9.7	9.7	0.0	9.6	-0.1	24.8	24.7	-0.1	24.5	-0.3
North Carolina	Alamance Co	10.1	10.1	0.0	9.8	-0.3	21.4	21.3	-0.1	20.6	-0.8
North Carolina	Buncombe Co	10.1	10.1	0.0	9.7	-0.4	20.0	20.0	0.0	19.1	-0.9
North Carolina	Cabarrus Co	10.8	10.7	-0.1	10.4	-0.4	21.0	21.0	0.0	20.2	-0.8
North Carolina	Caswell Co	9.6	9.5	-0.1	9.2	-0.4	20.3	20.2	-0.1	19.5	-0.8
North Carolina	Catawba Co	11.7	11.7	0.0	11.3	-0.4	24.6	24.6	0.0	23.8	-0.8
North Carolina	Chatham Co	8.9	8.9	0.0	8.6	-0.3	18.0	17.9	-0.1	17.4	-0.6
North Carolina	Cumberland Co	11.1	11.0	-0.1	10.7	-0.4	22.2	22.1	-0.1	21.5	-0.7
North Carolina	Davidson Co	11.8	11.8	0.0	11.4	-0.4	23.5	23.5	0.0	22.7	-0.8
North Carolina	Duplin Co	9.5	9.4	-0.1	9.1	-0.4	19.7	19.6	-0.1	19.1	-0.6
North Carolina	Durham Co	10.4	10.4	0.0	10.1	-0.3	24.2	24.2	0.0	23.3	-0.9
North Carolina	Forsyth Co	10.7	10.6	-0.1	10.3	-0.4	24.6	24.6	0.0	23.7	-0.9

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North Carolina	Gaston Co	10.5	10.5	0.0	10.1	-0.4	20.3	20.3	0.0	19.5	-0.8
North Carolina	Guilford Co	10.4	10.3	-0.1	10.0	-0.4	24.3	24.3	0.0	23.4	-0.9
North Carolina	Haywood Co	10.9	10.9	0.0	10.5	-0.4	24.9	24.8	-0.1	24.2	-0.7
North Carolina	Jackson Co	9.4	9.4	0.0	9.0	-0.4	21.0	21.0	0.0	20.5	-0.5
North Carolina	Lenoir Co	8.8	8.8	0.0	8.5	-0.3	18.3	18.2	-0.1	17.5	-0.8
North Carolina	McDowell Co	11.1	11.1	0.0	10.7	-0.4	23.4	23.4	0.0	22.6	-0.8
North Carolina	Mecklenburg Co	11.4	11.4	0.0	11.0	-0.4	24.8	24.7	-0.1	24.0	-0.8
North Carolina	Mitchell Co	10.5	10.5	0.0	10.1	-0.4	22.5	22.4	-0.1	21.6	-0.9
North Carolina	Montgomery Co	8.9	8.9	0.0	8.5	-0.4	19.4	19.3	-0.1	18.6	-0.8
North Carolina	Onslow Co	8.7	8.7	0.0	8.4	-0.3	19.4	19.4	0.0	18.8	-0.6
North Carolina	Orange Co	9.6	9.6	0.0	9.3	-0.3	19.3	19.2	-0.1	18.6	-0.7
North Carolina	Pitt Co	9.5	9.5	0.0	9.2	-0.3	21.5	21.4	-0.1	20.7	-0.8
North Carolina	Robeson Co	9.6	9.6	0.0	9.3	-0.3	18.5	18.5	0.0	17.9	-0.6
North Carolina	Swain Co	9.7	9.7	0.0	9.2	-0.5	20.9	20.9	0.0	20.2	-0.7
North Carolina	Wake Co	10.6	10.6	0.0	10.3	-0.3	24.3	24.2	-0.1	23.5	-0.8
North Carolina	Wayne Co	11.0	10.9	-0.1	10.6	-0.4	21.4	21.4	0.0	20.7	-0.7
North Dakota	Billings Co	4.2	4.2	0.0	4.2	0.0	10.1	10.1	0.0	10.1	0.0
North Dakota	Burke Co	5.3	5.3	0.0	5.3	0.0	14.0	14.0	0.0	14.0	0.0
North Dakota	Burleigh Co	6.0	6.0	0.0	6.0	0.0	14.4	14.4	0.0	14.4	0.0
North Dakota	Cass Co	7.1	7.1	0.0	7.1	0.0	19.8	19.8	0.0	19.7	-0.1
North Dakota	Mercer Co	5.7	5.7	0.0	5.7	0.0	14.7	14.6	-0.1	14.6	-0.1
Ohio	Athens Co	8.5	8.4	-0.1	8.1	-0.4	19.9	19.8	-0.1	19.1	-0.8
Ohio	Butler Co	12.1	12.1	0.0	11.6	-0.5	27.8	27.7	-0.1	26.7	-1.1
Ohio	Clark Co	11.2	11.1	-0.1	10.7	-0.5	27.0	26.9	-0.1	26.1	-0.9
Ohio	Cuyahoga Co	14.7	14.4	-0.3	14.1	-0.6	39.1	38.3	-0.8	38.0	-1.1
Ohio	Franklin Co	13.1	13.1	0.0	12.7	-0.4	32.7	32.5	-0.2	32.0	-0.7
Ohio	Hamilton Co	13.7	13.7	0.0	13.1	-0.6	33.0	32.9	-0.1	31.9	-1.1
Ohio	Jefferson Co	13.7	12.5	-1.2	12.4	-1.3	33.2	31.0	-2.2	30.8	-2.4
Ohio	Lake Co	10.4	10.2	-0.2	10.0	-0.4	25.9	25.3	-0.6	24.7	-1.2
Ohio	Lawrence Co	12.5	12.4	-0.1	12.1	-0.4	27.2	27.0	-0.2	26.2	-1.0
Ohio	Lorain Co	10.7	10.5	-0.2	10.2	-0.5	27.7	27.3	-0.4	26.6	-1.1
Ohio	Lucas Co	11.9	11.9	0.0	11.6	-0.3	31.3	31.1	-0.2	30.6	-0.7
Ohio	Mahoning Co	11.3	11.0	-0.3	10.8	-0.5	30.7	29.7	-1.0	29.9	-0.8
Ohio	Montgomery Co	11.7	11.7	0.0	11.2	-0.5	28.9	28.7	-0.2	28.1	-0.8
Ohio	Portage Co	10.6	10.4	-0.2	10.2	-0.4	28.0	27.3	-0.7	27.3	-0.7
Ohio	Preble Co	10.1	10.1	0.0	9.7	-0.4	25.2	25.1	-0.1	24.4	-0.8
Ohio	Scioto Co	15.1	15.0	-0.1	14.5	-0.6	33.3	33.2	-0.1	32.4	-0.9
Ohio	Stark Co	12.7	12.4	-0.3	12.2	-0.5	27.0	26.3	-0.7	26.3	-0.7
Ohio	Summit Co	12.7	12.4	-0.3	12.0	-0.7	29.9	29.3	-0.6	28.9	-1.0
Ohio	Trumbull Co	11.6	11.2	-0.4	11.0	-0.6	33.3	32.1	-1.2	32.3	-1.0
Oklahoma	Caddo Co	7.5	7.5	0.0	7.4	-0.1	17.8	17.8	0.0	17.5	-0.3
Oklahoma	Canadian Co	7.2	7.2	0.0	7.0	-0.2	15.4	15.4	0.0	14.9	-0.5
Oklahoma	Carter Co	8.2	8.2	0.0	7.9	-0.3	17.5	17.4	-0.1	16.7	-0.8
Oklahoma	Cherokee Co	9.5	9.5	0.0	9.3	-0.2	20.5	20.5	0.0	19.8	-0.7
Oklahoma	Garfield Co	8.4	8.4	0.0	8.2	-0.2	20.3	20.2	-0.1	19.8	-0.5
Oklahoma	Kay Co	9.0	9.0	0.0	8.9	-0.1	19.7	19.7	0.0	19.3	-0.4
Oklahoma	Lincoln Co	8.2	8.2	0.0	8.0	-0.2	21.9	21.9	0.0	21.1	-0.8
Oklahoma	Mayes Co	10.6	10.6	0.0	10.4	-0.2	23.0	22.9	-0.1	22.3	-0.7
Oklahoma	Muskogee Co	10.1	10.1	0.0	9.8	-0.3	20.3	20.3	0.0	19.8	-0.5
Oklahoma	Oklahoma Co	8.6	8.6	0.0	8.4	-0.2	21.1	21.1	0.0	20.6	-0.5
Oklahoma	Ottawa Co	9.6	9.6	0.0	9.4	-0.2	22.3	22.3	0.0	21.7	-0.6
Oklahoma	Pittsburg Co	9.4	9.4	0.0	9.1	-0.3	20.3	20.2	-0.1	19.6	-0.7
Oklahoma	Seminole Co	7.6	7.6	0.0	7.4	-0.2	15.9	15.8	-0.1	15.0	-0.9

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Oklahoma	Tulsa Co	10.0	9.9	-0.1	9.7	-0.3	23.3	23.3	0.0	22.7	-0.6
Oregon	Columbia Co	5.8	5.2	-0.6	5.2	-0.6	14.9	13.1	-1.8	13.1	-1.8
Oregon	Deschutes Co	7.0	6.3	-0.7	6.3	-0.7	21.4	20.3	-1.1	20.3	-1.1
Oregon	Jackson Co	10.8	9.1	-1.7	9.1	-1.7	37.1	32.6	-4.5	32.6	-4.5
Oregon	Klamath Co	9.9	8.9	-1.0	8.9	-1.0	38.5	35.0	-3.5	35.0	-3.5
Oregon	Lane Co	12.7	11.7	-1.0	11.7	-1.0	52.5	47.9	-4.6	48.0	-4.5
Oregon	Linn Co	8.0	7.4	-0.6	7.4	-0.6	30.2	27.7	-2.5	27.7	-2.5
Oregon	Multnomah Co	8.2	6.8	-1.4	6.8	-1.4	24.8	20.1	-4.7	20.2	-4.6
Oregon	Union Co	6.4	6.4	0.0	6.4	0.0	21.7	21.6	-0.1	21.6	-0.1
Oregon	Wasco Co	7.0	6.7	-0.3	6.7	-0.3	21.2	20.7	-0.5	20.7	-0.5
Oregon	Washington Co	8.9	7.4	-1.5	7.4	-1.5	31.6	25.7	-5.9	25.7	-5.9
Pennsylvania	Adams Co	9.1	9.0	-0.1	8.8	-0.3	29.0	28.7	-0.3	28.3	-0.7
Pennsylvania	Allegheny Co	15.8	14.2	-1.6	14.1	-1.7	51.5	46.9	-4.6	46.7	-4.8
Pennsylvania	Beaver Co	11.5	10.6	-0.9	10.5	-1.0	32.1	30.2	-1.9	30.0	-2.1
Pennsylvania	Berks Co	11.9	11.8	-0.1	11.5	-0.4	35.2	34.8	-0.4	34.4	-0.8
Pennsylvania	Bucks Co	10.4	10.4	0.0	10.2	-0.2	30.3	30.1	-0.2	29.8	-0.5
Pennsylvania	Cambria Co	10.8	10.0	-0.8	9.9	-0.9	24.8	23.8	-1.0	23.5	-1.3
Pennsylvania	Centre Co	9.1	8.9	-0.2	8.8	-0.3	28.4	27.9	-0.5	27.8	-0.6
Pennsylvania	Dauphin Co	10.8	10.6	-0.2	10.5	-0.3	32.8	32.5	-0.3	32.2	-0.6
Pennsylvania	Delaware Co	12.1	12.1	0.0	11.8	-0.3	28.3	28.0	-0.3	27.7	-0.6
Pennsylvania	Erie Co	10.0	9.9	-0.1	9.7	-0.3	28.1	27.6	-0.5	27.4	-0.7
Pennsylvania	Lackawanna Co	8.9	8.8	-0.1	8.7	-0.2	27.9	27.7	-0.2	27.5	-0.4
Pennsylvania	Lancaster Co	11.9	11.8	-0.1	11.6	-0.3	33.2	32.9	-0.3	32.5	-0.7
Pennsylvania	Lehigh Co	10.3	10.2	-0.1	10.1	-0.2	34.4	34.1	-0.3	33.8	-0.6
Pennsylvania	Luzerne Co	9.5	9.4	-0.1	9.2	-0.3	28.9	28.8	-0.1	28.6	-0.3
Pennsylvania	Mercer Co	10.6	10.2	-0.4	10.1	-0.5	30.8	29.8	-1.0	29.9	-0.9
Pennsylvania	Montgomery Co	10.3	10.3	0.0	10.1	-0.2	29.0	28.8	-0.2	28.5	-0.5
Pennsylvania	Northampton Co	10.7	10.6	-0.1	10.4	-0.3	34.8	34.5	-0.3	34.3	-0.5
Pennsylvania	Perry Co	9.2	9.1	-0.1	8.9	-0.3	24.8	24.5	-0.3	24.1	-0.7
Pennsylvania	Philadelphia Co	13.1	13.0	-0.1	12.8	-0.3	34.9	34.7	-0.2	34.4	-0.5
Pennsylvania	Washington Co	11.0	10.1	-0.9	9.9	-1.1	25.3	23.5	-1.8	23.1	-2.2
Pennsylvania	Westmoreland Co	10.5	9.6	-0.9	9.5	-1.0	29.0	27.4	-1.6	27.2	-1.8
Pennsylvania	York Co	12.0	11.9	-0.1	11.7	-0.3	35.4	35.0	-0.4	34.7	-0.7
Rhode Island	Kent Co	6.7	6.7	0.0	6.6	-0.1	18.7	18.6	-0.1	18.2	-0.5
Rhode Island	Providence Co	9.2	9.1	-0.1	9.0	-0.2	26.3	26.2	-0.1	26.0	-0.3
South Carolina	Beaufort Co	8.6	8.6	0.0	8.1	-0.5	19.6	19.5	-0.1	18.5	-1.1
South Carolina	Charleston Co	9.5	9.5	0.0	9.0	-0.5	21.7	21.7	0.0	20.7	-1.0
South Carolina	Chesterfield Co	9.2	9.1	-0.1	8.7	-0.5	18.2	18.2	0.0	17.5	-0.7
South Carolina	Edgefield Co	9.6	9.6	0.0	8.9	-0.7	19.6	19.5	-0.1	18.4	-1.2
South Carolina	Florence Co	10.2	10.2	0.0	9.8	-0.4	20.5	20.4	-0.1	19.8	-0.7
South Carolina	Georgetown Co	10.5	10.4	-0.1	10.1	-0.4	22.8	22.7	-0.1	21.9	-0.9
South Carolina	Greenville Co	11.1	11.0	-0.1	10.5	-0.6	24.0	24.0	0.0	23.0	-1.0
South Carolina	Greenwood Co	10.2	10.1	-0.1	9.5	-0.7	19.9	19.8	-0.1	18.8	-1.1
South Carolina	Horry Co	8.6	8.6	0.0	8.3	-0.3	19.8	19.7	-0.1	19.1	-0.7
South Carolina	Lexington Co	10.9	10.9	0.0	10.3	-0.6	21.2	21.2	0.0	20.3	-0.9
South Carolina	Oconee Co	8.1	8.1	0.0	7.6	-0.5	20.5	20.4	-0.1	19.4	-1.1
South Carolina	Richland Co	10.8	10.8	0.0	10.2	-0.6	21.4	21.4	0.0	20.4	-1.0
South Carolina	Spartanburg Co	10.4	10.4	0.0	9.8	-0.6	22.2	22.2	0.0	21.2	-1.0
South Dakota	Brookings Co	8.0	8.0	0.0	8.0	0.0	20.3	20.3	0.0	20.1	-0.2
South Dakota	Brown Co	7.4	7.3	-0.1	7.3	-0.1	17.2	17.1	-0.1	17.1	-0.1
South Dakota	Jackson Co	5.1	5.1	0.0	5.1	0.0	12.4	12.4	0.0	12.3	-0.1
South Dakota	Meade Co	5.9	5.9	0.0	5.9	0.0	14.5	14.5	0.0	14.5	0.0
South Dakota	Minnehaha Co	8.3	8.3	0.0	8.2	-0.1	20.2	20.2	0.0	20.0	-0.2

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South Dakota	Pennington Co	7.4	7.4	0.0	7.4	0.0	19.9	19.9	0.0	19.9	0.0
Tennessee	Blount Co	10.1	10.0	-0.1	9.6	-0.5	23.2	23.2	0.0	22.3	-0.9
Tennessee	Davidson Co	12.2	12.1	-0.1	11.6	-0.6	27.2	27.1	-0.1	26.3	-0.9
Tennessee	Dyer Co	9.8	9.8	0.0	9.4	-0.4	21.6	21.6	0.0	20.7	-0.9
Tennessee	Hamilton Co	13.3	13.2	-0.1	12.4	-0.9	26.4	26.4	0.0	25.2	-1.2
Tennessee	Knox Co	12.9	12.9	0.0	12.3	-0.6	28.4	28.3	-0.1	27.5	-0.9
Tennessee	Lawrence Co	9.6	9.6	0.0	8.9	-0.7	21.0	20.9	-0.1	18.9	-2.1
Tennessee	McMinn Co	11.6	11.6	0.0	11.0	-0.6	24.6	24.5	-0.1	23.5	-1.1
Tennessee	Maury Co	10.7	10.7	0.0	10.2	-0.5	23.0	23.0	0.0	21.7	-1.3
Tennessee	Montgomery Co	10.8	10.8	0.0	10.3	-0.5	21.2	21.1	-0.1	20.1	-1.1
Tennessee	Putnam Co	10.2	10.2	0.0	9.5	-0.7	22.4	22.3	-0.1	21.1	-1.3
Tennessee	Roane Co	11.3	11.3	0.0	10.7	-0.6	24.3	24.2	-0.1	23.0	-1.3
Tennessee	Shelby Co	12.2	12.1	-0.1	11.8	-0.4	27.8	27.6	-0.2	26.9	-0.9
Tennessee	Sullivan Co	12.1	12.1	0.0	11.6	-0.5	26.3	26.2	-0.1	25.3	-1.0
Tennessee	Sumner Co	11.1	11.1	0.0	10.5	-0.6	22.5	22.5	0.0	21.3	-1.2
Texas	Bowie Co	11.8	11.8	0.0	11.6	-0.2	26.1	26.1	0.0	25.6	-0.5
Texas	Cameron Co	9.1	9.1	0.0	8.9	-0.2	20.4	20.4	0.0	20.0	-0.4
Texas	Dallas Co	11.1	11.1	0.0	10.6	-0.5	26.7	26.7	0.0	25.9	-0.8
Texas	Ector Co	7.3	7.3	0.0	7.2	-0.1	15.2	15.2	0.0	15.1	-0.1
Texas	Galveston Co	7.5	7.4	-0.1	7.2	-0.3	19.0	18.9	-0.1	18.1	-0.9
Texas	Gregg Co	10.2	10.2	0.0	9.9	-0.3	25.7	25.6	-0.1	25.0	-0.7
Texas	Harris Co	12.7	12.7	0.0	12.5	-0.2	26.9	26.8	-0.1	26.3	-0.6
Texas	Hidalgo Co	10.5	10.5	0.0	10.4	-0.1	24.3	24.3	0.0	23.9	-0.4
Texas	Jefferson Co	9.8	9.7	-0.1	9.6	-0.2	24.8	24.7	-0.1	23.9	-0.9
Texas	Lubbock Co	7.1	7.1	0.0	7.0	-0.1	16.6	16.6	0.0	16.4	-0.2
Texas	Nueces Co	9.5	9.4	-0.1	9.3	-0.2	19.9	19.8	-0.1	19.5	-0.4
Texas	Orange Co	9.9	9.9	0.0	9.7	-0.2	24.6	24.6	0.0	23.7	-0.9
Texas	Tarrant Co	9.8	9.7	-0.1	9.4	-0.4	22.4	22.3	-0.1	21.7	-0.7
Utah	Box Elder Co	8.5	8.3	-0.2	8.3	-0.2	38.3	36.9	-1.4	36.9	-1.4
Utah	Cache Co	12.3	12.0	-0.3	12.0	-0.3	51.3	50.0	-1.3	50.0	-1.3
Utah	Salt Lake Co	12.2	11.3	-0.9	11.3	-0.9	47.5	42.9	-4.6	42.9	-4.6
Utah	Utah Co	9.0	8.5	-0.5	8.5	-0.5	35.2	32.8	-2.4	32.8	-2.4
Utah	Weber Co	8.8	8.5	-0.3	8.5	-0.3	35.3	33.0	-2.3	33.0	-2.3
Vermont	Chittenden Co	7.6	7.6	0.0	7.5	-0.1	21.3	21.3	0.0	21.1	-0.2
Virginia	Arlington Co	10.2	10.1	-0.1	9.9	-0.3	28.0	27.8	-0.2	27.4	-0.6
Virginia	Charles City Co	9.1	9.1	0.0	8.8	-0.3	21.4	21.3	-0.1	20.7	-0.7
Virginia	Chesterfield Co	9.7	9.6	-0.1	9.4	-0.3	23.6	23.6	0.0	23.0	-0.6
Virginia	Fairfax Co	9.6	9.5	-0.1	9.3	-0.3	25.7	25.5	-0.2	25.1	-0.6
Virginia	Henrico Co	9.6	9.6	0.0	9.4	-0.2	22.7	22.6	-0.1	22.0	-0.7
Virginia	Loudoun Co	9.1	9.1	0.0	8.9	-0.2	26.0	25.8	-0.2	25.3	-0.7
Virginia	Page Co	8.8	8.8	0.0	8.6	-0.2	22.6	22.4	-0.2	21.8	-0.8
Virginia	Bristol city	11.0	11.0	0.0	10.5	-0.5	25.5	25.5	0.0	24.5	-1.0
Virginia	Chesapeake city	9.7	9.7	0.0	9.5	-0.2	23.3	23.2	-0.1	22.8	-0.5
Virginia	Hampton city	9.8	9.7	-0.1	9.5	-0.3	22.0	21.8	-0.2	21.4	-0.6
Virginia	Newport News city	9.0	8.9	-0.1	8.7	-0.3	20.3	20.2	-0.1	19.8	-0.5
Virginia	Norfolk city	10.2	10.1	-0.1	9.9	-0.3	22.9	22.8	-0.1	22.4	-0.5
Virginia	Richmond city	10.1	10.0	-0.1	9.8	-0.3	25.8	25.7	-0.1	25.1	-0.7
Virginia	Roanoke city	10.3	10.2	-0.1	9.9	-0.4	25.0	24.9	-0.1	24.2	-0.8
Virginia	Salem city	10.5	10.4	-0.1	10.1	-0.4	24.5	24.4	-0.1	23.8	-0.7
Virginia	Virginia Beach city	9.9	9.8	-0.1	9.6	-0.3	24.4	24.3	-0.1	23.8	-0.6
Washington	Benton Co	6.4	6.3	-0.1	6.3	-0.1	19.8	19.5	-0.3	19.5	-0.3
Washington	Clark Co	9.0	8.0	-1.0	8.0	-1.0	33.8	29.3	-4.5	29.3	-4.5
Washington	King Co	10.7	9.5	-1.2	9.6	-1.1	34.2	30.2	-4.0	30.2	-4.0

State	County	2020 15/65 Annual DV	2020 15/35 Annual DV	Impact of 15/35 Controls on Annual DV	2020 14/35 Annual DV	Impact of 14/35 Controls on Annual DV	2020 15/65 Daily DV	2020 15/35 Daily DV	Impact of 15/35 Controls on Daily DV	2020 14/35 Daily DV	Impact of 14/35 Controls on Daily DV
Washington	Pierce Co	11.5	9.9	-1.6	10.0	-1.5	44.7	38.0	-6.7	38.0	-6.7
Washington	Snohomish Co	11.4	10.4	-1.0	10.4	-1.0	40.2	37.0	-3.2	37.0	-3.2
Washington	Spokane Co	9.6	9.5	-0.1	9.5	-0.1	29.6	29.4	-0.2	29.4	-0.2
Washington	Thurston Co	8.8	8.2	-0.6	8.2	-0.6	34.8	32.0	-2.8	32.1	-2.7
Washington	Whatcom Co	7.6	7.5	-0.1	7.5	-0.1	21.0	20.7	-0.3	20.7	-0.3
Washington	Yakima Co	9.3	9.2	-0.1	9.2	-0.1	34.0	33.8	-0.2	33.8	-0.2
West Virginia	Berkeley Co	11.7	11.5	-0.2	11.3	-0.4	32.0	31.6	-0.4	31.2	-0.8
West Virginia	Brooke Co	12.5	11.4	-1.1	11.3	-1.2	29.3	27.6	-1.7	27.3	-2.0
West Virginia	Cabell Co	13.0	12.9	-0.1	12.5	-0.5	28.8	28.6	-0.2	27.7	-1.1
West Virginia	Hancock Co	13.0	11.9	-1.1	11.8	-1.2	31.9	29.8	-2.1	29.6	-2.3
West Virginia	Harrison Co	10.2	10.0	-0.2	9.8	-0.4	21.8	21.6	-0.2	21.3	-0.5
West Virginia	Kanawha Co	13.4	13.3	-0.1	13.1	-0.3	28.1	28.0	-0.1	27.5	-0.6
West Virginia	Marion Co	11.0	10.8	-0.2	10.6	-0.4	25.7	25.2	-0.5	24.9	-0.8
West Virginia	Marshall Co	11.3	10.7	-0.6	10.6	-0.7	25.2	24.4	-0.8	24.1	-1.1
West Virginia	Mercer Co	8.9	8.8	-0.1	8.5	-0.4	20.7	20.6	-0.1	19.5	-1.2
West Virginia	Monongalia Co	10.4	10.1	-0.3	10.0	-0.4	23.8	23.4	-0.4	23.0	-0.8
West Virginia	Ohio Co	10.7	10.1	-0.6	10.0	-0.7	24.3	23.5	-0.8	23.2	-1.1
West Virginia	Raleigh Co	9.4	9.3	-0.1	9.0	-0.4	22.5	22.5	0.0	21.7	-0.8
West Virginia	Summers Co	7.1	7.0	-0.1	6.8	-0.3	19.2	19.1	-0.1	18.3	-0.9
West Virginia	Wood Co	12.4	12.2	-0.2	12.0	-0.4	29.3	29.1	-0.2	28.5	-0.8
Wisconsin	Brown Co	10.0	10.0	0.0	9.9	-0.1	27.4	27.3	-0.1	27.2	-0.2
Wisconsin	Dane Co	10.7	10.7	0.0	10.6	-0.1	29.1	29.0	-0.1	28.7	-0.4
Wisconsin	Dodge Co	9.4	9.4	0.0	9.2	-0.2	25.4	25.4	0.0	24.8	-0.6
Wisconsin	Grant Co	9.8	9.8	0.0	9.7	-0.1	23.2	23.1	-0.1	22.8	-0.4
Wisconsin	Kenosha Co	9.7	9.7	0.0	9.5	-0.2	26.9	26.9	0.0	26.5	-0.4
Wisconsin	Manitowoc Co	8.4	8.4	0.0	8.2	-0.2	23.4	23.4	0.0	22.7	-0.7
Wisconsin	Milwaukee Co	11.8	11.7	-0.1	11.5	-0.3	31.1	30.9	-0.2	30.5	-0.6
Wisconsin	Outagamie Co	9.4	9.4	0.0	9.2	-0.2	25.9	25.9	0.0	25.4	-0.5
Wisconsin	Vilas Co	5.5	5.5	0.0	5.4	-0.1	15.4	15.4	0.0	15.2	-0.2
Wisconsin	Waukesha Co	11.4	11.4	0.0	11.3	-0.1	31.6	31.6	0.0	31.3	-0.3
Wyoming	Campbell Co	6.1	6.1	0.0	6.1	0.0	16.9	16.8	-0.1	16.8	-0.1
Wyoming	Laramie Co	4.8	4.8	0.0	4.8	0.0	11.8	11.7	-0.1	11.7	-0.1
Wyoming	Sheridan Co	10.4	10.4	0.0	10.4	0.0	31.4	31.3	-0.1	31.3	-0.1

Appendix N. Comparison of Projected PM2.5 Concentrations Using 36 km vs 12 km Modeling

The air quality modeling performed for the PM NAAQS RIA included CMAQ model runs with a horizontal grid resolution of approximately 36 x 36 km (as fully described in Chapter 4). Ambient measurements indicate that $PM_{2.5}$ species, especially directly emitted species like crustal material and carbon (elemental and primary organic carbon) can exhibit large spatial gradients in urban areas. The magnitude and extent of these gradients depends on the type and distribution of local emissions sources within the urban area. Being able to adequately represent in our modeling the large observed gradients is important when trying to assess the impacts of changes in emissions at such sources on monitors in the general vicinity of the source. It is likely that 36 km resolution will understate the impacts of controls on primary emissions from local sources since this relatively coarse resolution smoothes out the emissions from such sources. In view of this issue, we initiated a sensitivity analysis to explore the difference in annual PM2.5 design values calculated using 36 km modeling versus modeling at a 12 x 12 km resolution. We chose to use 12 km modeling for this analysis because of the availability of meteorological data and other inputs at this resolution that are consistent with our 36 km modeling platform. These 12 km inputs cover an Eastern U.S. modeling domain that extends from east Texas to Maine. This domain is shown in Figure 1 (figure is provided on the last page of this appendix).

Ideally, we would want to perform the grid resolution comparison modeling using an control scenario that focused on the effectiveness of local source control measures. However, due to the large computational requirements for 12 km modeling and the time constraints for completing the analysis, we elected to use the 2015 base case scenario since this was one of the initial scenarios developed for the PM NAAQS analysis. The emissions reductions in this base case run are derived mostly from national control programs (e.g., onroad and nonroad engine rules) and regional programs (i.e., CAIR), and thus, the effects of grid resolution are likely to be less than if we analyzed a scenario reflecting more local controls.

The 2015 base case 12 km run was performed in a similar manner to the corresponding 36 km run and the CMAQ outputs were post-processed using the same SMAT technique to project $PM_{2.5}$ design values (as described in Chapter 4). Table 1 shows the 36 km and 12 km modeling results for counties in the Eastern U.S. 12 km modeling domain and with projected annual design values at or above 14 $\mu g/m^3$, which covers the range of annual concentrations of interest for the PM NAAQS analysis.

Table 1. Projected Annual $PM_{2.5}$ Design Values in Eastern US Based on 36 km and 12 km CMAQ Modeling: 2015 Base Case

State	County	Annual DV @ 36 km	Annual DV @ 12 km	Difference (12 km - 36 km)
Alabama	Jefferson Co	16.11	16.15	0.04
Georgia	Clayton Co	14.20	14.61	0.41
Georgia	DeKalb Co	13.95	14.06	0.11
Georgia	Floyd Co	14.43	14.31	-0.12
Georgia	Fulton Co	15.88	16.41	0.53
Illinois	Cook Co	15.50	15.41	-0.09
Illinois	Madison Co	15.26	15.18	-0.08
Illinois	St. Clair Co	14.71	14.61	-0.10
Michigan	Wayne Co	17.57	17.22	-0.35
New York	New York Co	14.10	14.45	0.35
Ohio	Cuyahoga Co	15.55	15.51	-0.04
Ohio	Hamilton Co	14.41	14.64	0.23
Ohio	Jefferson Co	14.20	14.28	0.08
Ohio	Scioto Co	15.63	15.49	-0.14
Pennsylvania	Allegheny Co	16.48	16.42	-0.06
Tennessee	Knox Co	13.88	14.08	0.20

The data in Table 1 indicate that the predicted annual DV for $PM_{2.5}$ is higher in some counties and lower in others across these modeling resolutions. In both runs, the same eight counties are projected to exceed the 1997 annual standard of 15 $\mu g/m^3$. The 12 km concentrations in six of these eight counties are lower than in the 36 km run. On average, the 12 km concentrations are lower by 0.02 $\mu g/m^3$ in the eight nonattainment counties, but the range is -0.35 to + 0.53 $\mu g/m^3$. Excluding the data for Fulton County in the calculation, since this appears to be somewhat of an outlier across these counties, on average the 12 km concentrations in the nonattainment counties are 0.10 $\mu g/m^3$ lower than in the 36 km modeling. However, in counties with concentrations between 14 and 15 $\mu g/m^3$, the concentrations tend to be higher in the 12 km run.

The results of this limited sensitivity analysis indicate that grid resolution can be an important factor in modeling to project future year concentrations. The sensitivity results shown here reflect the national, regional nature of control programs that are part of the 2015 base case scenario. As indicated above, we would expect the differences between the use of 36 km and 12 km modeling to be greater than found in this limited sensitivity analysis if the control scenario used in the comparison emphasized more local controls.

Figure 1. The 12 km modeling domain (area within the box shown in this figure).

Appendix O: CMAQ Model Performance Evaluation for 2001

An operational model performance evaluation for $PM_{2.5}$ and its related speciated components was conducted using the 2001 data in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for 36-km continental United States domain[1].[2] The PM2.5 components covered in this evaluation include sulfate (SO_4), nitrate (NO_3), total nitrate (TNO_3=NO_3+HNO_3), ammonium (NH_4), elemental carbon (EC), and organic carbon (OC). This evaluation principally comprises statistical assessments of model versus observed pairs that were paired in time and space on a daily or weekly basis, depending on the sampling frequency of each network (measured data). It should be noted when pairing model and observed data that each CMAQ concentration represents a grid-cell volume-averaged value, while the ambient network measurements are made at specific locations. Performance statistics were calculated for each month and season individually and for the entire year, as a whole. Seasons were defined as: winter (December-January-February), spring (March-April-May), summer (June-July-August), and fall (September-October-November). Ambient measurements for 2001 were obtained from the following networks for model evaluation: **S**peciation **T**rends **N**etwork (STN), **I**nteragency **M**onitoring of **PRO**tected **V**isual **E**nvironments (IMPROVE), and **C**lean **A**ir **S**tatus and **T**rends **Net**work (CASTNet). The pollutant species included in the evaluation for each network are listed in Table A-1. For PM2.5 species that are measured by more than one network, we calculated separate sets of statistics for each network. Statistics were generated for the following geographic groupings: 36-km domainwide, and Eastern vs. Western (divided along the 100th meridian).

Table A-1. Monitoring networks and pollutants species included in the CMAQ performance evaluation.

Ambient Monitoring Networks	Particulate Species						
	$PM_{2.5}$ Mass	SO_4	NO_3	TNO_3	NH_4	EC	OC
IMPROVE	X	X	X		X	X	X
CASTNet		X		X	X		
STN	X	X	X		X	X	X

Note that TNO_3 = (NO_3 + HNO_3)

There are various statistical metrics available for model performance evaluation. For this evaluation, the principal evaluation statistics used to evaluate CMAQ performance were two bias metrics, fractional bias and normalized mean bias; and two error metrics, fractional error and normalized mean error. Fractional bias is defined as:

[1] See Chapter 4, Section 4.1.2 of the PM NAAQS RIA for the map of the CMAQ modeling domain.
[2] This evaluation includes updates to the CMAQ Model Performance Evaluation Report for 2001 updated March 2005 (CAIR Docket OAR-2005-0053-2149).

$$\text{FB} = \frac{1}{n}\left(\frac{\sum_{1}^{n}(P-O)}{\sum_{1}^{n}\left(\frac{(P+O)}{2}\right)}\right)*100,$$ where P = predicted concentrations and O = observed concentrations. FB is a useful model performance indicator because it has the advantage of equally weighting positive and negative bias estimates. The single largest disadvantage in this estimate of model performance is that the estimated concentration (i.e., prediction, P) is found in both the numerator and denominator. Fractional error (FE) is similar to fractional bias except the absolute value of the difference is used so that the error is always positive. Fractional error is defined as:

$$\text{FE} = \frac{1}{n}\left(\frac{\sum_{1}^{n}|P-O|}{\sum_{1}^{n}\left(\frac{(P+O)}{2}\right)}\right)*100$$

Normalized mean bias (NMB) is used as a normalization to facilitate a range of concentration magnitudes. This statistic averages the difference (model - observed) over the sum of observed values. NMB is a useful model performance indicator because it avoids over inflating the observed range of values, especially at low concentrations. Normalized mean bias is defined as:

$$\text{NMB} = \frac{\sum_{1}^{n}(P-O)}{\sum_{1}^{n}(O)}*100$$

Normalized mean error (NME) is also similar to NMB, where the performance statistic is used as a normalization of the mean error. NME calculates the absolute value of the difference (model - observed) over the sum of observed values. Normalized mean error is defined as:

$$\text{NME} = \frac{\sum_{1}^{n}|P-O|}{\sum_{1}^{n}(O)}*100$$

The “acceptability” of model performance was judged by comparing our CMAQ 2001 performance results to the range of performance found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies[3]. Overall, the FB, FE, NMB, and NME statistics shown in Tables A-2 – A-8 below for CMAQ in 2001 are within the range or close to that found by other groups in recent applications. The CMAQ model performance results give us confidence that our applications of CMAQ using this modeling platform provide a scientifically credible

[3] See Appendix C of the CMAQ Model Performance Evaluation Report for 2001 updated March 2005 (CAIR Docket OAR-2005-0053-2149). These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

approach for assessing $PM_{2.5}$ concentrations for the purposes of the PM NAAQS assessment. We discuss in the following sections the bias and error results for the annual and seasonal $PM_{2.5}$ and its related speciated components.

Annual PM2.5 Species Evaluation

Table A-2 provides annual model performance statistics for PM2.5 and its component species for the 36-km national domain and the East and West domains. Nationally, annual total PM2.5 mass is under-predicted, with a NMB of -8%, FB of -10%, NME of 39%, and FE of 42% for STN sites and a NMB of -11%, FB of -11%, NME of 47%, and FE of 51% for IMPROVE sites. PM2.5 model performance compared at STN network sites is better in the East than in the West, whereas the comparison at East and West IMPROVE sites are similar. Although not shown here, the mean observed concentrations of PM2.5 are approximately twice as high at the STN sites (~6µg m^{-3}) as the IMPROVE sites (~13µg m^{-3}), thus illustrating the statistical differences between the urban STN and rural IMPROVE networks. Sulfate is consistently under-predicted at STN, IMPROVE, and CASTNet sites, with NMB values ranging from -51% to -9%. Overall, sulfate performance is best in the East at urban STN sites (NMB=-9%, FB= -8%, NME=34%, and FE=41%). Nitrate is under-predicted both nationally and in the West, while nitrate is over-predicted in the East at both STN and IMPROVE networks. Model performance of total nitrate at CASTNet sites shows an over-prediction domainwide (NMB= 9%; FB=4%) and in the East (NMB=14%; FB=13%). Total nitrate performance was slightly worse in the West, with a NMB of -27% and FB of -21%. Ammonium model performance varies across STN and CASTNet, with STN showing an over-prediction in the national and Eastern domains and CASTNet showing an under-prediction in the national, East and West domains. Elemental carbon is over-predicted at STN sites in the East with a NMB of 34%, FB of 26%, NME of 71% and FE=59%. Although, EC is under-predicted at IMPROVE sites in the East with a NMB of -18%, FB of -26%, NME of 46% and FE=53%. In the West, EC model performance is similar between the STN and IMPROVE networks when comparing FB statistics (STN: FB=-8%; IMPROVE: FB=-7), however NMB statistics are significantly different (STN: NMB=-13%; IMPROVE: NMB=19%). Organic carbon is moderately under-predicted for all domains in the STN network. For the IMPROVE network, OC is under-predicted in the East and over-predicted in the West. Differences in model predictions between IMPROVE and STN networks could be attributed to both the rural versus urban characteristics as well as differences in the measurement methodology between the two networks (e.g. blank correction factors, and filter technology used).

Table A-2. Annual model performance statistics for PM NAAQS CMAQ 2001

PM NAAQS CMAQ 2001 Annual			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
$PM_{2.5}$ Total Mass	STN	National	6356	-10	42	-8	39
		East	5124	-5	39	-2	35
		West	1232	-29	53	-36	54
	IMPROVE	National	13218	-11	51	-11	47
		East	5606	-11	47	-11	41

		West	7612	-10	54	-12	55
Sulfate	STN	National	6723	-16	45	-13	36
		East	5478	-8	41	-9	34
		West	1245	-52	64	-51	58
	IMPROVE	National	13477	-21	50	-20	39
		East	5657	-15	41	-16	34
		West	7790	-26	57	-33	52
	CASTNet	National	3791	-29	37	-21	27
		East	2784	-22	29	-19	25
		West	1007	-47	59	-45	51
Nitrate	STN	National	5883	-39	89	-15	74
		East	4673	-23	81	14	70
		West	1210	-103	116	-76	82
	IMPROVE	National	13398	-72	116	-10	86
		East	5636	-53	109	16	90
		West	7762	-85	121	-42	82
Total Nitrate (NO3 + HNO3)	CASTNet	National	3788	4	38	9	35
		East	2781	13	34	14	33
		West	1007	-21	51	-27	47
Ammonium	STN	National	6723	20	63	6	54
		East	5478	27	59	16	51
		West	1245	13	78	-53	75
	CASTNet	National	3791	-17	38	-11	31
		East	2784	-8	32	-10	29
		West	1007	-39	57	-37	51
Elemental Carbon	STN	National	6842	19	60	22	69
		East	5551	26	59	34	71
		West	1291	-8	65	-13	63
	IMPROVE	National	13441	-15	60	-2	63
		East	5646	-26	53	-18	46
		West	7795	-7	66	19	85
Organic Carbon	STN	National	6685	-46	65	-43	54
		East	5401	-45	65	-41	51
		West	1284	-46	68	-47	61
	IMPROVE	National	13428	6	63	4	68
		East	5658	-28	60	-24	51
		West	7770	31	64	38	88

Seasonal PM2.5 Total Mass Performance

Seasonal model performance statistics for PM2.5 total mass are shown in Table A-3. Total PM2.5 mass is generally over-predicted in the cooler seasons (winter and fall) in the East for both STN and IMPROVE networks. In the winter season, in the West, PM2.5 is moderately under-predicted for urban STN sites with a NMB of -47% and FB of -42%, and over-predicted for rural IMPROVE sites with a NMB of 24% and FB of 15%. Note that for comparison of West versus East STN sites, the total number of Western sites is usually less than a quarter of the Eastern sites. In the fall season, PM2.5 is slightly over-predicted for Eastern STN and IMPROVE networks with NMB values ranging from 6% to 8% and FB values ranging from 2% to 6%. In the west, PM2.5 performance shows an under-prediction for STN (NMB=-42%, FB=-37%, NME=57%, and FE=58%) and IMPROVE (NMB=-7%, FB=-5%, NME=50%, and FE=47%) in the fall. In the spring and summer seasons, CMAQ under-predicts PM2.5 in the East and West for STN and IMPROVE. Better PM2.5 performance is achieved during the spring season in the East, with STN showing a slight under-prediction (NMB=-3%, FB=-8%) and IMPROVE showing a moderate under-prediction (NMB=-15%, FB=-20%).

Table A-3. Seasonal model performance statistics for PM2.5 total mass

PM2.5 total mass - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Winter	STN	National	1179	-4	46	19	54
		East	947	7	42	12	42
		West	232	-42	63	-47	59
	IMPROVE	National	2869	19	54	21	59
		East	1140	15	47	20	50
		West	1729	22	59	24	74
Spring	STN	National	1292	-10	42	-6	38
		East	1033	-8	41	-3	36
		West	259	-18	46	-17	46
	IMPROVE	National	3271	-26	52	-22	46
		East	1394	-15	46	-15	41
		West	1877	-33	57	-33	54
Summer	STN	National	1901	-20	40	-17	34
		East	1547	-20	38	-15	32
		West	354	-20	46	-27	48
	IMPROVE	National	3378	-30	52	-26	44
		East	1471	-42	51	-34	40
		West	1907	-21	52	-13	52
Fall	STN	National	1984	-4	41	-4	40
		East	1597	4	37	8	35
		West	387	-37	58	-42	57
	IMPROVE	National	3700	-2	45	1	44
		East	1601	2	43	6	39
		West	2099	-5	47	-7	50

Seasonal Sulfate Performance

As seen in Table A-4, CMAQ generally under-predicts sulfate nationally throughout the entire year. Sulfate predictions during the winter season show NMB values ranging from -15% to -27% and FB values ranging from -9% to -29% in the East and with NMB values ranging from -10% to -40% and FB values ranging from 0.1% to -32% in the West. Sulfate predictions during the fall seasons are nearly unbiased in the East, with NMB values ranging from 2% to -6% across STN, IMPROVE, and CASTNet networks. Sulfate is moderately under-predicted in the West during the fall season. In the spring, sulfate predictions are moderately under-predicted in the East and West, with NMB values ranging from -22% to -43% and FB values ranging from -29% to -53%. Sulfate predictions during the summer season are somewhat under-predicted in the East across the available monitoring data, while sulfate predictions in the West were moderately under-predicted.

Table A-4. Seasonal model performance statistics for sulfate

Sulfate - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Winter	STN	National	1292	-14	48	-17	43
		East	1030	-9	47	-15	42
		West	262	-32	51	-40	52
	IMPROVE	National	2979	-5	49	-14	41
		East	1143	-12	43	-16	39
		West	1836	0.1	52	-10	48
	CASTNet	National	878	-23	35	-26	30
		East	656	-29	34	-27	30
		West	222	-6	37	-11	36
Spring	STN	National	1345	-26	55	-23	37
		East	1083	-22	42	-22	36
		West	262	-46	56	-42	49
	IMPROVE	National	3372	-26	48	-24	38
		East	1422	-22	40	-22	34
		West	1950	-29	54	-30	49
	CASTNet	National	963	-36	41	-29	32
		East	713	-30	34	-27	30
		West	250	-53	60	-43	49
Summer	STN	National	2005	-20	46	-11	35
		East	1672	-9	40	-8	33
		West	333	-72	78	-60	64
	IMPROVE	National	3385	-38	58	-26	40
		East	1483	-21	45	-20	35
		West	1902	-51	67	-46	57
	CASTNet	National	952	-37	42	-21	25
		East	689	-22	28	-19	23
		West	263	-77	79	-58	59
Fall	STN	National	2081	-8	42	-4	36
		East	1693	2	37	2	33

		West	388	-51	65	-52	60
	IMPROVE	National	3711	-14	47	-12	36
		East	1609	-4	37	-4	31
		West	2102	-22	55	-31	51
	CASTNet	National	990	-19	31	-9	21
		East	721	-9	21	-6	19
		West	269	-48	57	-44	49

Seasonal Nitrate Performance

Table A-5 provides the seasonal model performance statistics for nitrate and total nitrate for the national domain and the East and West domains. Typically, nitrate and total nitrate performance for all of the seasonal assessments tend to be better in the East (NMB range of 51% to -11%) as compared to the West (NMB range of 37% to -80%). Nitrate is generally under-predicted domainwide during the winter season when nitrate is most abundant. In the East, during the winter, nitrate (NMB ~-5%) and total nitrate (NMB ~2%) performance is slightly under-predicted. Nitrate and total nitrate performance is mixed for the fall, spring and summer seasons, with moderate under-predictions occurring in the West and moderate over-predictions occurring in the East.

Table A-5. Seasonal model performance statistics for nitrate

Nitrate - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Nitrate (Winter)	STN	National	1196	-39	79	-27	62
		East	939	-25	73	-6	55
		West	257	-91	103	-74	78
	IMPROVE	National	2957	-64	108	-25	74
		East	1137	-39	92	-5	70
		West	1820	79	118	-50	79
Total Nitrate (Winter)	CASTNet	National	877	6	37	1	31
		East	655	7	33	2	30
		West	222	4	48	-9	46
Nitrate (Spring)	STN	National	1344	-32	85	4	69
		East	1082	-21	83	15	68
		West	262	-77	95	-54	70
	IMPROVE	National	3356	-55	104	3	81
		East	1415	-39	102	25	87
		West	1941	-66	105	-28	73
Total Nitrate (Spring)	CASTNet	National	962	-1	33	1	29
		East	712	5	30	4	27
		West	250	-18	43	-21	43
Nitrate (Summer)	STN	National	1561	-62	103	-26	87
		East	1243	-45	93	6	86
		West	318	-129	139	-82	89

	IMPROVE	National	3379	-111	138	-35	97
		East	1475	-94	129	-11	105
		West	1904	-125	145	-55	90
Total Nitrate (Summer)	CASTNet	National	952	-2	42	13	40
		East	689	17	34	26	37
		West	263	-51	65	-41	52
Nitrate (Fall)	STN	National	1782	-25	85	-11	83
		East	1409	-4	76	41	81
		West	373	107	121	-80	85
	IMPROVE	National	3706	-58	115	13	105
		East	1609	-39	110	51	116
		West	2097	-74	119	37	90
Total Nitrate (Fall)	CASTNet	National	989	13	42	23	43
		East	720	25	39	31	43
		West	269	-18	49	-25	46

Seasonal Ammonium Performance

Table A-5 lists the performance statistics for ammonium PM at the STN and CASTNet sites. In the winter, ammonium performance varies across the STN and CASTNet networks, with STN showing an over-prediction in the East (NMB=10%) and the West (NMB=58%) and CASTNet showing an under-prediction in the East (NMB=-13) and West (NMB=-15%). Likewise, ammonium performance for the spring season in the East is similar to that of the winter season, with NMB of 11% for STN and NMB of -7% for CASTNet. However, in the West, model predictions in the spring are generally under-predicted for the West. Ammonium predictions in the summer are moderately under-predicted for the East and West in both the rural and urban sites. In the fall, ammonium predictions are over-predicted in the East (STN: NMB=54%, CASTNet: NMB=8%), whereas in the ammonium predictions are under-predicted in the West (STN: NMB=-58%, CASTNet: NMB=-38%).

Table A-6. Seasonal model performance statistics for ammonium

Ammonium - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Winter	STN	National	1292	13	64	-4	53
		East	1030	20	58	10	48
		West	262	-13	87	58	75
	CASTNet	National	878	-12	37	-13	31
		East	656	-12	34	-13	30
		West	222	-13	48	-15	48
Spring	STN	National	1345	15	51	8	47
		East	1083	19	51	11	45
		West	262	-3	55	-19	59
	CASTNet	National	963	-11	34	-8	28
		East	713	-4	29	-7	27

		West	250	-32	51	-28	48
Summer	STN	National	2005	-1	53	-6	43
		East	1672	6	49	-0.4	39
		West	333	-40	73	-59	73
	CASTNet	National	952	-37	44	-23	29
		East	689	-25	33	-20	27
		West	263	-70	72	-52	55
Fall	STN	National	2081	47	79	30	78
		East	1693	57	77	54	77
		West	388	2	91	-58	81
	CASTNet	National	990	-6	39	3	35
		East	721	7	33	8	34
		West	269	-40	55	-38	50

Seasonal Elemental Carbon Performance

Table A-7 presents the seasonal performance statistics of elemental carbon for the urban and rural 2001 monitoring data. In the winter, elemental carbon performance is mixed across the STN and IMPROVE networks, with a slight under-prediction in the East (NMB=-3%) and slight over-prediction (NMB=10%) in the West for IMPROVE and a moderate over-prediction in the East (NMB=44%) and a moderate under-prediction in the West (NMB=-31%). Nationally, elemental carbon predictions are moderately over-predicted for the spring and summer seasons for STN, however, elemental carbon is generally under-predicted for the East and West at IMPROVE. Fall elemental carbon predictions are similar to that of the winter predictions, with an under-prediction in the East and slight over-prediction in the West for IMPROVE and an over-prediction in the East and a moderate under-prediction in the West. These biases and errors are not unexpected since there are known uncertainties among the scientific community in carbonaceous emissions/measurements, transport, and deposition processes.

Table A-7. Seasonal model performance statistics for elemental carbon

Elemental Carbon - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Winter	STN	National	1292	19	67	16	75
		East	1025	31	66	44	83
		West	267	-28	69	-31	61
	IMPROVE	National	2953	-18	68	3	71
		East	1144	-16	52	-3	52
		West	1809	-19	78	10	96
Spring	STN	National	1390	31	63	47	82
		East	1117	37	64	55	86
		West	273	11	62	20	67
	IMPROVE	National	3363	-25	55	-13	53
		East	1416	-26	51	-20	45
		West	1947	-23	58	-3	65

Summer	STN	National	2042	31	60	46	76
		East	1694	34	60	51	77
		West	348	19	61	27	72
	IMPROVE	National	3385	-2	62	9	73
		East	1471	-37	56	-32	44
		West	1914	26	67	61	110
Fall	STN	National	2118	-0.2	55	0.2	56
		East	1715	7	52	10	55
		West	403	-30	68	-27	59
	IMPROVE	National	3740	-17	58	-7	56
		East	1615	-24	52	-15	45
		West	2125	-12	63	2	70

Seasonal Organic Carbon Performance

Seasonal organic carbon performance statistics are provided in Table A-8. The model predictions show moderate under-predictions for all Eastern sites located in the urban STN sites (NMB values range from -28% to -51%) and rural IMPROVE sites (NMB values range from -2% to -45%). For STN, organic carbon performance in the West shows under-predictions, with the largest underestimations during the colder months, winter and fall. For IMPROVE, organic carbon performance in the West shows a positive bias and error with moderate over-predictions. These biases and errors reflect sampling artifacts among each monitoring network. In addition, uncertainties exist for primary organic mass emissions and secondary organic aerosol formation. Research efforts are ongoing to improve fire emission estimates and understand the formation of semi-volatile compounds, and the partitioning of SOA between the gas and particulate phases.

Table A-8. Seasonal model performance statistics for organic carbon

Organic Carbon - PM NAAQS 2001			No. of Obs.	FB (%)	FE (%)	NMB (%)	NME (%)
Winter	STN	National	1251	-36	66	-41	58
		East	986	-27	59	-28	50
		West	265	-72	90	-61	70
	IMPROVE	National	2945	18	65	20	76
		East	1144	-6	53	-2	53
		West	1801	33	72	52	109
Spring	STN	National	1363	-42	61	-38	50
		East	1092	-43	62	-39	49
		West	271	-37	59	-35	51
	IMPROVE	National	3360	0.4	55	-5	56
		East	1417	-23	56	-22	50
		West	1943	17	54	18	63
Summer	STN	National	2013	-57	69	-47	54
		East	1665	-63	73	-51	54
		West	348	-26	52	-31	51

	IMPROVE	National	3396	-5	68	2	74
		East	1483	-62	74	-45	54
		West	1913	39	64	54	97
Fall	STN	National	2058	-43	64	-43	53
		East	1658	-40	62	-41	50
		West	400	-53	73	-47	62
	IMPROVE	National	3727	11	63	4	66
		East	1614	-19	56	-18	49
		West	2113	34	68	28	85