Final Regulatory Impact Analysis (RIA) for the SO_2 National Ambient Air Quality Standards (NAAQS)

June 2010

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Executive Summary

ES.1 Overview

This Regulatory Impact Analysis (RIA) provides illustrative estimates of the incremental costs and monetized human health benefits of attaining a revised short-term Sulfur Dioxide (SO_2) National Ambient Air Quality Standard (NAAQS) within the current monitoring network of 488 SO_2 monitors. Because this analysis only considers counties with an SO_2 monitor, the possibility exists that there may be many more potential nonattainment areas than have been analyzed in this RIA.

This RIA chiefly serves two purposes. First, it provides the public with an estimate of the costs and benefits of attaining a new SO_2 NAAQS. Second, it fulfills the requirements of Executive Order 12866 and the guidelines of OMB Circular A-4. [1] These documents present guidelines for EPA to assess the benefits and costs of the selected regulatory option, as well as one less stringent and one more stringent option. The RIA analyzes the new short-term SO_2 NAAQS of 75 parts per billion (ppb), based on the 3-year average of the 99th percentile of 1-hour daily maximum concentrations. This RIA also analyzes alternative primary standards of 50 and 100 ppb.

This analysis does not estimate the projected attainment status of areas of the country other than those counties currently served by one of the approximately 488 monitors in the current network. It is important to note that the final rule requires a monitoring network comprised of monitors sited at locations of expected maximum hourly concentrations, and also provides for nonattainment designations using air quality modeling near large stationary sources. Only about one third of the existing SO_2 network may be source-oriented and/or in the locations of maximum concentration required by the final rule because the current network is focused on population areas and community-wide ambient levels of SO_2. Actual monitored levels using the new monitoring network and/or air quality modeling results near large stationary sources may be higher than levels measured using the existing network. We recognize that once the new requirements are put in place, more areas could find themselves exceeding the new SO_2 NAAQS. However for this RIA analysis, we lack sufficient data to predict which counties might exceed the new NAAQS after implementation of the new monitoring network and modeling requirements. Therefore we lack a credible analytic path to estimating costs and benefits for such a future scenario.

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[1] U.S. Office of Management and Budget. Circular A-4, September 17, 2003. Available at http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf.

In setting primary ambient air quality standards, EPA's responsibility under the law is to establish standards that protect public health, regardless of the costs of implementing a new standard. The Clean Air 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 create standards based on health considerations only.

The 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 is essential to making efficient, cost effective decisions for implementation of these standards. The impacts of cost and efficiency are considered by states during this process, as they decide what timelines, strategies, and policies are most appropriate. This RIA is intended to inform the public about the potential costs and benefits associated with a hypothetical scenario that may result when a new SO_2 standard is implemented, but is not relevant to establishing the standards themselves.

ES.2 Summary of Analytic Approach

This RIA includes several key elements, including specification of baseline SO_2 emissions and concentrations; development of illustrative control strategies to attain the standard in 2020; and analyses of the control costs and health benefits of reaching the various alternative standards. Additional information on the methods employed by the Agency for this RIA is presented below.

Overview of Baseline Emissions Forecast and Baseline SO_2 Concentrations

The baseline emissions and concentrations for this RIA are emissions data from the 2005 National Emissions Inventory (NEI), and baseline SO_2 concentration values from 2005-2007 across the community-wide monitoring network. We used results from community multi-scale air quality model (CMAQ) simulations to calculate the expected reduction in ambient SO_2 concentrations between the 2005 base year and 2020. More specifically, design values (i.e. air quality concentrations at each monitor) were calculated for 2020 using monitored air quality concentrations from 2005 and modeled air quality projections for 2020, countywide emissions inventory data for 2005 and 2006-8, and emissions inventory projections for 2020. These data were used to create ratios between emissions and air quality, and those ratios (relative response factors, or RRFs) were used to estimate air quality monitor design values for 2020. The 2020 baseline air quality estimates revealed that 27 monitors in 24 counties were projected to exceed the 75 ppb NAAQS in 2020.

Development of Illustrative Control Strategies

For each alternative standard, we analyzed the impact that additional emissions controls applied to numerous sectors would have on predicted ambient SO_2 concentrations, incremental to the baseline set of controls. Thus the modeled analysis for a revised standard focuses specifically on incremental improvements beyond the current standards, and uses control options that might be available to states for application by 2020. The hypothetical modeled control strategy presented in this RIA is one illustrative option for achieving emissions reductions to move towards a national attainment of a tighter standard. It is not a recommendation for how a tighter SO_2 standard should be implemented, and states will make decisions regarding implementation strategies once a final NAAQS has been set.

The baseline for this analysis is complicated by the expected issuance of additional air quality regulations. The SO_2 NAAQS is only one of several regulatory programs that are likely to affect EGU emissions nationally in the next several years. We thus expect that EGUs will apply controls in the coming years in response to multiple rules. These include the maximum achievable control technology (MACT) rule for utility boilers, revisions to the Clean Air Interstate Rule, and reconsideration of the Clean Air Mercury Rule. Therefore controls and costs attributed solely to the SO_2 NAAQS in this analysis will likely be needed for compliance with other future rules as well.

The 2020 baseline air quality estimates revealed that 27 monitors in 24 counties were projected to exceed the 75 ppb NAAQS in 2020. We then developed hypothetical control strategies that could be adopted to bring the current highest emitting monitor in each of those counties into attainment with 75 ppb by 2020, as well as hypothetical control strategies for counties exceeding the lower bound analytic target of 50 ppb, and the upper bound analytic target of 100 ppb. Controls for three emissions sectors were included in the control analysis: non-electricity generating unit point sources (nonEGU), area sources (area), and electricity generating unit point sources (EGU). Finally, we note it was not possible, in this analysis, to bring all areas into attainment with alternative standards in all areas using identified engineering controls. For these monitor areas we estimated the cost of unspecified emission reductions.

Analysis of Costs and Benefits

We estimated the benefits and costs for the final NAAQS of 75 ppb, as well as alternative SO_2 NAAQS levels of 50 ppb and 100 ppb (99^{th} percentile). These costs and benefits are associated with an incremental difference in ambient concentrations between a baseline scenario and a pollution control strategy. As indicated in Chapter 4, several areas of the country may not be able to attain some alternative standard using known pollution control methods. Because some areas require substantial emission reductions from unknown sources to attain the various standards, the results are very sensitive to assumptions about the costs of full attainment. For this reason, we provide the full attainment results and the partial attainment results for both benefits and costs.

Benefits

Our benefits analysis estimates the human health benefits for each of the alternative standard levels including benefits related to reducing SO_2 concentrations and the co-benefits of reducing concentrations of fine particulate matter ($PM_{2.5}$). For the SO_2 benefits analysis, we use the Environmental Benefits Mapping and Analysis Program (BenMAP) to estimate the health benefits occurring as a result of implementing alternative SO_2 NAAQS levels. BenMAP has been used extensively in previous RIAs to estimate the health benefits of reducing exposure to various pollutants.

The primary input to the benefits assessment for SO_2 effects is the estimated changes in ambient air quality expected to result from a simulated control strategy or attainment of a particular standard. CMAQ projects both design values at SO_2 monitors and air quality concentrations at 12 km by 12 km grid cells nationwide. To estimate the benefits of fully attaining the standards in all areas, EPA employed the “monitor rollback” approach to approximate the air quality change resulting from just attaining alternative SO_2 NAAQS at each design value monitor. Under this approach, we use data from the existing SO_2 monitoring network and the inverse distance-squared variant of the Veronoi Neighborhood Averaging (VNA) interpolation method to adjust the air quality modeled concentrations such that each area just attains the target NAAQS levels.

We quantified SO_2-related health endpoints for which the SO_2 ISA provides the strongest evidence of an effect. In this analysis, we only estimated the benefits for those endpoints with sufficient evidence to support a quantified concentration-response relationship using the information presented in the SO_2 ISA, which contains an extensive literature review for several health endpoints related to SO_2 exposure. Based on our review of this information, we quantified three short-term morbidity endpoints that the SO_2 ISA identified as “sufficient to infer a likely causal relationship”: asthma exacerbation, respiratory-related emergency department visits, and respiratory-related hospitalizations. We then selected concentration-response functions and valuation functions based on criteria detailed in chapter 5. The valuation functions, ambient concentrations, and population data in the monitor areas are combined in BenMAP to provide the benefits estimates for this analysis. In this analysis, we decided not to quantify the premature mortality from SO_2 exposure in this analysis despite evidence suggesting a positive association. As the literature continues to evolve, we may revisit this decision in future benefits assessment for SO_2.

In addition, because SO_2 is also a precursor to $PM_{2.5,}$ reducing SO_2 emissions in the projected non-attainment areas will also reduce $PM_{2.5}$ formation, human exposure, and the incidence of $PM_{2.5}$-related health effects. In this analysis, we estimated the co-benefits of reducing $PM_{2.5}$ exposure for the alternative standards. Due to analytical limitations, it was not possible to provide a comprehensive estimate of $PM_{2.5}$-related benefits. Instead, we used the "benefit-per-ton" method to estimate these benefits. The $PM_{2.5}$ benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of $PM_{2.5}$ from a specified source. EPA has used these estimates in previous RIAs, including the recent NO_2 NAAQS RIA.

These estimates reflect EPA's most current interpretation of the scientific literature and are consistent with the methodology used for the proposal RIA. These benefits are incremental to an air quality baseline that reflects attainment with the 2008 ozone and 2006 $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). More than 99% of the total dollar benefits are attributable to reductions in $PM_{2.5}$ exposure resulting from SO_2 emission controls. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided in Figure 5.1 for the selected standard of 75 ppb. Methodological limitations prevented EPA from quantifying the impacts to, or monetizing the benefits from several important benefit categories, including ecosystem effects from sulfur deposition, improvements in visibility, and materials damage. Other direct benefits from reduced SO_2 exposure have not been quantified, including reductions in premature mortality.

Costs

Consistent with our development of the illustrative control strategies described above, our analysis of the costs associated with the range of alternative NAAQS focuses on SO_2 emission controls for electric generating units (EGU) and nonEGU stationary and area sources. EGU, nonEGU and area source controls largely include measures from the Control Strategy Tool (CoST), and the AirControlNET control technology database. For these sources, we estimated costs based on the cost equations included in AirControlNET.

As indicated in the above discussion on illustrative control strategies, implementation of the SO_2 control measures identified from AirControlNET and other sources does not result in attainment with the selected NAAQS in several areas. In these areas, additional unspecified emission reductions might be necessary to reach some alternative standard levels. In order to bring these monitor areas into attainment, we calculated controls costs using a fixed cost per ton approach similar to that used in the ozone RIA analysis. We recognize that a single fixed cost of control of $15,000 per ton of emissions reductions does not account for the significant emissions cuts that are necessary in some areas, and so its use provides an estimate that is likely to differ from actual future costs.

ES.3 Results of Analysis

Air Quality

Table ES.1 presents the number of monitors and counties exceeding the various target NAAQS levels in 2020 prior to control, out of 229 monitors from which a full set of data were available for this analysis.

Table ES.1. Number of monitors and counties projected to exceed 50, 75, and 100 ppb alternative NAAQS target levels in 2020.

Alternative standard (ppb)	Number of monitors	Number of counties
50	71	56
75	27	24
100	11	9

Table ES.2 presents the emission reductions achieved through applying identical control measures, both by sector and in total. As this table reveals, a majority of the emission reductions would be achieved through EGU emission controls.

Table ES.2: Emission Reductions from Identified Controls in 2020 in Total and by Sector (Tons) [a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb
Total Emission Reductions from Identified Controls [b]	800,000	370,000	190,000
EGUs	540,000	260,000	110,000
Non-EGUs	250,000	110,000	79,000
Area Sources	15,000	200	100

[a] All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b] These values represent emission reductions for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

Table ES.3 shows the emission reductions needed beyond identified controls for counties to attain the alternative standards being analyzed.

Table ES.3: Total Emission Reductions and those from Extrapolated Controls in 2020 in Total and by Sector (Tons) [a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb
Total Emission Reductions from Identified and Unidentified Controls	920,000	350,000	170,000
Total Emission Reductions from Unidentified Controls	110,000	33,000	18,000
Unidentified Reductions from EGUs	33,000	5,000	-
Unidentified Reductions from non-EGUs	54,000	22,000	15,000
Unidentified Reductions from Area Sources	19,000	6,400	3,000

[a] All estimates rounded to two significant figures.

Benefit and Cost Estimates

When estimating the SO_2- and $PM_{2.5}$-related human health benefits and compliance costs in Table ES.4 below, EPA applied methods and assumptions consistent with the state-of-the-science for human health impact assessment, economics and air quality analysis. EPA applied its best professional judgment in performing this analysis and believes that these estimates provide a reasonable indication of the expected benefits and costs to the nation of the selected SO_2 standard and alternatives considered by the Agency. The Regulatory Impacts Analysis (RIA) available in the docket describes in detail the empirical basis for EPA's assumptions and characterizes the various sources of uncertainties affecting the estimates below.

EPA's 2009 Integrated Science Assessment for Particulate Matter concluded, based on the scientific literature, that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship. Nonetheless, consistent with historical practice and our commitment to characterizing the uncertainty in our benefits estimates, EPA has included a sensitivity analysis with an assumed threshold in the PM-mortality health impact function in the RIA. EPA has included a sensitivity analysis in the RIA to help inform our understanding of the health benefits which can be achieved at lower air quality concentration levels. While the primary estimate and the sensitivity analysis are not directly comparable, due to differences in population data and use of different analysis years, as well as the difference in the assumption of a threshold in the sensitivity analysis, comparison of the two results provide a rough sense of the proportion of the health benefits that occur at lower $PM_{2.5}$ air quality levels. Using a threshold of 10 $\mu g/m^3$ is an arbitrary choice (EPA could have assumed 6, 8, or 12 µg/m3 for the sensitivity analysis). Assuming a threshold of 10 $\mu g/m^3$, the sensitivity analysis shows that roughly one-third of the benefits occur at air quality levels below that threshold. Because the primary estimates reflect EPA's current methods and data, EPA notes that caution should be exercised when comparing the results of the primary and sensitivity analyses. EPA appreciates the value of sensitivity analyses in highlighting the uncertainty in the benefits estimates and will continue to work to refine these analyses, particularly in those instances in which air quality modeling data are available.

Table ES.4 shows the results of the cost and benefits analysis for each standard alternative. As indicated above, implementation of the SO_2 control measures identified from AirControlNET and other sources does not result in attainment with the all target NAAQS levels in several areas. In these areas, additional unspecified emission reductions might be necessary to reach some alternative standard levels. The first part of the table, labeled *Partial attainment (identified controls)*, shows only those benefits and costs from control measures we were able to identify. The second part of the table, labeled *Unidentified Controls*, shows only additional benefits and costs resulting from unidentified controls. The third part of the table, labeled *Full attainment*, shows total benefits and costs resulting from both identified and unidentified controls. It is important to emphasize that we were able to identify control measures for a significant portion of attainment for many of those counties that would not fully attain the target NAAQS level with identified controls. Note also that in addition to separating full and partial attainment, the table also separates the portion of benefits associated with reduced SO_2 exposure (i.e., SO_2 benefits) from the additional benefits associated with reducing SO_2 emissions, which are precursors to $PM_{2.5}$ formation – (i.e., the $PM_{2.5}$ co-benefits). For instance, for the selected standard of 75 ppb, \$2.2 million in benefits are associated with reduced SO_2 exposure while \$15 billion to \$37 billion are associated with reduced $PM_{2.5}$ exposure.

Table ES.4: Monetized Benefits and Costs to Attain Alternate Standard Levels in 2020 (millions of 2006\$)[a]

		# Counties Fully Controlled	Discount Rate	Monetized SO_2 Benefits	Monetized $PM_{2.5}$ Co-Benefits [c,d]	Costs	Net Benefits
Partial Attainment (identified controls)	50 ppb	40	3%	-[b]	\$30,000 to \$74,000	\$2,600	\$27,000 to \$71,000
			7%		\$28,000 to \$67,000		\$25,000 to \$64,000
	75 ppb	20	3%	-[b]	\$14,000 to \$35,000	\$960	\$13,000 to \$34,000
			7%		\$13,000 to \$31,000		\$12,000 to \$30,000
	100 ppb	6	3%	-[b]	\$6,900 to \$17,000	\$470	\$6,400 to \$17,000
			7%		\$6,200 to \$15,000		\$5,700 to \$15,000
Unidentified Controls	50 ppb	16	3%	-[b]	\$4,000 to \$9,000	\$1,800	\$2,200 to \$7,200
			7%		\$3,000 to \$8,000		\$1,200 to \$6,200
	75 ppb	4	3%	-[b]	\$1,000 to \$3,000	\$500	\$500 to \$1,500
			7%		\$1,000 to \$3,000		\$500 to \$2,500
	100 ppb	3	3%	-[b]	\$500 to \$1,000	\$260	\$240 to \$740
			7%		\$500 to \$1,000		\$240 to \$740
Full Attainment	50 ppb	56	3%	\$8.50	\$34,000 to \$83,000	\$4,400	\$30,000 to \$79,000
			7%		\$31,000 to \$75,000		\$27,000 to \$71,000
	75 ppb	24	3%	\$2.20	\$15,000 to \$37,000	\$1,500	\$14,000 to \$36,000
			7%		\$14,000 to \$34,000		\$13,000 to \$33,000
	100 ppb	9	3%	\$0.60	\$7,400 to \$18,000	\$730	\$6,700 to \$17,000
			7%		\$6,700 to \$16,000		\$6,000 to \$15,000

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates.
[b] The approach used to simulate air quality changes for SO_2 did not provide the data needed to distinguish partial attainment benefits from full attainment benefits from reduced SO_2 exposure. Therefore, a portion of the SO_2 benefits is attributable to the known controls and a portion of the SO_2 benefits are attributable to the unidentified controls. Because all SO_2-related benefits are short-term effects, the results are identical for all discount rates.
[c] Benefits are shown as a range from Pope et al (2002) to Laden et al. (2006). Monetized benefits do not include unquantified benefits, such as other health effects, reduced sulfur deposition, or improvements in visibility.
[d] These models assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality because there is no clear scientific evidence that would support the development of differential effects estimates by particle type. Reductions in SO_2 emissions from multiple sectors to meet the SO_2 NAAQS would primarily reduce the sulfate fraction of $PM_{2.5}$. Because this rule targets a specific particle precursor (i.e., SO_2), this introduces some uncertainty into the results of the analysis.

ES.4. Caveats and Limitations

Air Quality, Emissions, and Control Strategies

The estimates of emission reductions associated with the control strategies described above are subject to important limitations and uncertainties. We summarize these limitations as follows:

- *Actual State Implementation Plans May Differ from our Simulation*: In order to reach attainment with the proposed NAAQS, each state will develop its own implementation plan implementing a combination of emissions controls that may differ from those simulated in this analysis. This analysis therefore represents an approximation of the emissions reductions that would be required to reach attainment and should not be treated as a precise estimate.

- *Use of Existing CMAQ Model Runs*: This analysis represents a screening level analysis. We did not conduct new regional scale modeling specifically targets to SO_2; instead we relied upon impact ratios developed from model runs used in the analysis underlying the $PM_{2.5}$ NAAQS.

- *Unidentified controls*: We have limited information on available controls for some of the monitor areas included in this analysis. For a number of small non-EGU and area sources, there is little or no information available on SO_2 controls.

Costs

- We do not have sufficient information for all of our known control measures to calculate cost estimates that vary with an interest rate. We are able to calculate annualized costs at an interest rate other than 7% (e.g., 3% interest rate) where there is sufficient information—available capital cost data, and equipment life—to annualize the costs for individual control measures. For the vast majority of nonEGU point source control measures, we do have sufficient capital cost and equipment life data for individual control measures to prepare annualized capital costs using the standard capital recovery factor. Hence, we are able to provide annualized cost estimates at different interest rates for the point source control measures.

- There are some unquantified costs that are not adequately captured in this illustrative analysis. These costs include the costs of federal and State administration of control programs, which we believe are less than the alternative of States developing approvable SIPs, securing EPA approval of those SIPs, and Federal/State enforcement. Additionally, control measure costs referred to as “no cost” may require limited government agency resources for administration and oversight of the program not included in this analysis; those costs are generally outweighed by the saving to the industrial, commercial, or private sector. The Agency also did not consider transactional costs and/or effects on labor supply in the illustrative analysis.

Benefits

Although we strive to incorporate as many quantitative assessments of uncertainty, there are several aspects for which we are only able to address qualitatively. These aspects are important factors to consider when evaluating the relative benefits of the attainment strategies for each of the alternative standards:

- The 12 km CMAQ grid, which is the air quality modeling resolution, may be too coarse to accurately estimate the potential near-field health benefits of reducing SO_2 emissions. These uncertainties may under- or over-estimate benefits.
- The interpolation techniques used to estimate the full attainment benefits of the alternative standards contributed some uncertainty to the analysis. The great majority of benefits estimated for the various standard alternatives were derived through interpolation. As noted previously in this chapter, these benefits are likely to be more uncertain than if we had modeled the air quality scenario for both SO_2 and $PM_{2.5}$. In general, the VNA interpolation approach may under-estimate benefits because it does not account for the broader spatial distribution of air quality changes that may occur due to the implementation of a regional emission control program.
- There are many uncertainties associated with the health impact functions used in this modeling effort. These include: within study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of C-R functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the C-R function,

including causality and thresholds. These uncertainties may under- or over-estimate benefits.

- Co-pollutants present in the ambient air may have contributed to the health effects attributed to SO_2 in single pollutant models. Risks attributed to SO_2 might be overestimated where concentration-response functions are based on single pollutant models. If co-pollutants are highly correlated with SO_2, their inclusion in an SO_2 health effects model can lead to misleading conclusions in identifying a specific causal pollutant. Because this collinearity exists, many of the studies reported statistically insignificant effect estimates for both SO_2 and the co-pollutants; this is due in part to the loss of statistical power as these models control for co-pollutants. Where available, we have selected multipollutant effect estimates to control for the potential confounding effects of co-pollutants; these include NYDOH (2006), Schwartz et al. (1994) and O'Connor et al. (2008). The remaining studies include single pollutant models.
- This analysis is for the year 2020, and projecting key variables introduces uncertainty. 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.
- This analysis omits certain unquantified effects due to lack of data, time and resources. These unquantified endpoints include other health effects, ecosystem effects, and visibility. EPA will continue to evaluate new methods and models and select those most appropriate for estimating the benefits of reductions in air pollution. Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, ecologists, and economists should result in a more tightly integrated analytical framework for measuring benefits of air pollution policies.
- $PM_{2.5}$ co-benefits represent a substantial proportion of total monetized benefits (over 99% of total monetized benefits), and these estimates are subject to a number of assumptions and uncertainties.
    a. $PM_{2.5}$ co-benefits were derived through benefit per-ton estimates, which do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an over-estimate or under-estimate of the actual benefits of controlling directly emitted fine particulates.
    b. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.

c. We assume that the health impact function for fine particles is linear down to the lowest air quality levels modeled in this analysis. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.

d. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality (which typically accounts for 85% to 95% of total monetized benefits), we include a set of twelve estimates based on results of the expert elicitation study in addition to our core estimates. Even these multiple characterizations omit the uncertainty in air quality estimates, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the $PM_{2.5}$ estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis. For more information on the uncertainties associated with $PM_{2.5}$ co-benefits, please consult the $PM_{2.5}$ NAAQS RIA (Table 5.5).

While the monetized benefits of reduced SO_2 exposure appear small when compared to the monetized benefits of reduced $PM_{2.5}$ exposure, readers should not necessarily infer that the total monetized benefits of attaining a new SO_2 standard are minimal. For this rule, the monetized $PM_{2.5}$ co-benefits represent over 99% of the total monetized benefits. This result is consistent with other recent RIAs, where the $PM_{2.5}$ co-benefits represent a large proportion of total monetized benefits. This result is amplified in this RIA by the decision not to quantify SO_2-related premature mortality and other morbidity endpoints due to the uncertainties associated with estimating those endpoints. Studies have shown that there is a relationship between SO_2 exposure and premature mortality, but that relationship is limited by potential confounding. Because premature mortality generally comprises over 90% of the total monetized benefits, this decision may substantially underestimate the monetized health benefits of reduced SO_2 exposure.

In addition, we were unable to quantify the benefits from several welfare benefit categories. We lacked the necessary air quality data to quantify the benefits from improvements in visibility from reducing light-scattering particles. Previous RIAs for ozone (U.S. EPA, 2008a) and $PM_{2.5}$ (U.S. EPA, 2006a) indicate that visibility is an important benefit category, and previous efforts to monetize those benefits have only included a subset of visibility benefits, excluding benefits in urban areas and many national and state parks. Even this subset accounted for up to 5% of total monetized benefits in the Ozone NAAQS RIA (U.S. EPA, 2008a).

We were also unable to quantify the ecosystem benefits of reduced sulfur deposition because we lacked the necessary air quality data, and the methodology to estimate ecosystem benefits is still being developed. Previous assessments (U.S. EPA, 1999; U.S. EPA, 2005; U.S. EPA, 2009e) indicate that ecosystem benefits are also an important benefits category, but those efforts were only able to monetize a tiny subset of ecosystem benefits in specific geographic locations, such as recreational fishing effects from lake acidification in the Adirondacks. We were also unable to quantify the benefits of decreased mercury methylation from sulfate deposition. Quantifying the relationship between sulfate and mercury methylation in natural settings is difficult, but some studies have shown that decreasing sulfate deposition can also decrease methylmercury.

ES.5. References

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. "Reduction in Fine Particulate Air Pollution and Mortality." American Journal of Respiratory and Critical Care Medicine 173:667-672. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132-1141.

U.S. Environmental Protection Agency (U.S. EPA). 1999a. The Benefits and Costs of the Clean Air Act 1990 to 2010: EPA Report to Congress. EPA-410-R-99-001. Office of Air and Radiation, Office of Policy, Washington, DC. November. Available on the Internet at < http://www.epa.gov/air/sect812/1990-2010/fullrept.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2005. Regulatory Impact Analysis for the Final Clean Air Interstate Rule. Office of Air and Radiation. March. Available on the Internet at < http://www.epa.gov/cair/pdfs/finaltech08.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2006a. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for Particulate Matter, Chapter 5. Office of Air Quality Planning and Standards, Research Triangle Park, NC. October. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2008a. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air

Quality Planning and Standards, Research Triangle Park, NC. March. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2009e. Risk and Exposure Assessment for Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur (Final). EPA-452/R-09-008a. Office of Air Quality Planning and Standards, Research Triangle Park, NC. September. Available on the Internet at <http://www.epa.gov/ttn/naaqs/standards/no2so2sec/data/NOxSOxREASep2009MainContent.pdf>.

Chapter 1: Introduction and Background

Synopsis

This document estimates the incremental costs and monetized human health benefits of attaining a revised primary sulfur dioxide (SO_2) National Ambient Air Quality Standard (NAAQS) nationwide. This document contains illustrative analyses that consider limited emission control scenarios that states, tribes and regional planning organizations might implement to achieve a revised SO_2 NAAQS. EPA weighed the available empirical data and photochemical modeling to make judgments regarding the proposed attainment status of certain urban areas in the future. According to the Clean Air Act, EPA must use health-based criteria in setting the NAAQS and cannot consider estimates of compliance cost. This Regulatory Impact Analysis (RIA) is intended to provide the public a sense of the benefits and costs of meeting new alternative SO_2 NAAQS, and to meet the requirements of Executive Order 12866 and OMB Circular A-4 (described below in Section 1.2.2).

This RIA provides illustrative estimates of the incremental costs and monetized human health benefits of attaining a revised primary SO_2 National Ambient Air Quality Standard (NAAQS) in 2020 within the current monitoring network[1]. This proposal would add a new short-term (1-hour exposure) standard, in addition to the current annual average standard.

This analysis does not estimate the projected attainment status of areas of the country other than those counties currently served by one of the approximately 488 monitors in the current network. It is important to note that the final rule requires a monitoring network comprised of monitors sited at locations of expected maximum hourly concentrations, and also provides for nonattainment designations using air quality modeling near large stationary sources. Only about one third of the existing SO_2 network may be source-oriented and/or in the locations of maximum concentration required by the final rule because the current network is focused on population areas and community-wide ambient levels of SO_2. Actual monitored levels using the new monitoring network and/or air quality modeling results near large stationary sources may be higher than levels measured using the existing network. We recognize that once the new requirements are put in place, more areas could find themselves exceeding the new SO_2 NAAQS. However for this RIA analysis, we lack sufficient data to predict which counties might exceed the new NAAQS after implementation of the new monitoring network and modeling requirements. Therefore we lack a credible analytic path to estimating costs and benefits for such a future scenario.

[1] There are 488 monitors. Currently xx monitors (representing xx counties) exceed the final NAAQS in this analysis (75 ppb, 99th percentile daily 1-hour maximum SO_2 concentration).

1.1 Background

Two sections of the Clean Air Act ("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." SO_2 is one of six pollutants for which EPA has developed air quality criteria.

Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants identified under section 108. Section 109(b)(1) defines a primary standard as "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." 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 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 retain or revise the NAAQS. After promulgation or revision of the NAAQS, the standards are implemented by the States.

1.2 Role of the Regulatory Impact Analysis in the NAAQS Setting Process

1.2.1 Legislative Roles

In setting primary ambient air quality standards, EPA's responsibility under the law is to establish standards that protect public health, regardless of the costs of implementing a new standard. The Clean Air 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 create standards based on health considerations only.

The 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 states during this process, as they decide 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 SO_2 standard is implemented, but is not relevant to establishing the standards themselves.

1.2.2 Role of Statutory and Executive Orders

There are several statutory and executive orders that dictate the manner in which EPA considers rulemaking and public documents. This document is separate from the NAAQS decision making process, but there are several statutes and executive orders that still apply to any public documentation. The analysis required by these statutes and executive orders is presented in Chapter 8.

EPA presents this RIA 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 option, as well as one less stringent and one more stringent option. OMB circular A-4 also requires both a benefit-cost, and a cost-effectiveness analysis for rules where health is the primary effect. Within this RIA we provide a benefit-cost analysis. Methodological and data limitations prevent us from performing a cost-effectiveness analysis and a meaningful more formal uncertainty analysis for this RIA.

The proposal would set a new short-term SO_2 standard based on the 3-year average of the 99th percentile of 1-hour daily maximum concentrations, establishing a new standard within the range of 75 parts per billion (ppb). This RIA analyzes alternative primary standards of 50 ppb, and 100 ppb.

1.2.3 Market Failure or Other Social Purpose

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

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[2] U.S. Office of Management and Budget. Circular A-4, September 17, 2003, available at <http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf>.

improving the function of government, removing distributional unfairness, or promoting privacy and personal freedom.

An externality occurs when one party's actions impose uncompensated benefits or costs on another party. Environmental problems are a classic case of externality. For example, the smoke from a factory may adversely affect the health of local residents while soiling the property in nearby neighborhoods. If bargaining was costless and all property rights were well defined, people would eliminate externalities through bargaining without the need for government regulation. From this perspective, externalities arise from high transaction costs and/or poorly defined property rights that prevent people from reaching efficient outcomes through market transactions.

Firms exercise market power when they reduce output below what would be offered in a competitive industry in order to obtain higher prices. They may exercise market power collectively or unilaterally. Government action can be a source of market power, such as when regulatory actions exclude low-cost imports. Generally, regulations that increase market power for selected entities should be avoided. However, there are some circumstances in which government may choose to validate a monopoly. If a market can be served at lowest cost only when production is limited to a single producer of local gas and electricity distribution services, a natural monopoly is said to exist. In such cases, the government may choose to approve the monopoly and to regulate its prices and/or production decisions. Nevertheless, it should be noted that technological advances often affect economies of scale. This can, in turn, transform what was once considered a natural monopoly into a market where competition can flourish.

Market failures may also result from inadequate or asymmetric information. Because information, like other goods, is costly to produce and disseminate, an evaluation will need to do more than demonstrate the possible existence of incomplete or asymmetric information. Even though the market may supply less than the full amount of information, the amount it does supply may be reasonably adequate and therefore not require government regulation. Sellers have an incentive to provide information through advertising that can increase sales by highlighting distinctive characteristics of their products. Buyers may also obtain reasonably adequate information about product characteristics through other channels, such as a seller offering a warranty or a third party providing information.

There are justifications for regulations in addition to correcting market failures. A regulation may be appropriate when there are clearly identified measures that can make government operate more efficiently. In addition, Congress establishes some regulatory programs to redistribute resources to select groups. Such regulations should be examined to ensure that they are both effective and cost-effective. Congress also authorizes some regulations to prohibit discrimination that conflicts with generally accepted norms within our society. Rulemaking may also be appropriate to protect privacy, permit more personal freedom or promote other democratic aspirations.

From an economics perspective, setting an air quality standard is a straightforward case of addressing an externality, in this case where entities are emitting pollutants, which cause health and environmental problems without compensation for those suffering the problems. Setting a standard with a reasonable margin of safety attempts to place the cost of control on those who emit the pollutants and lessens the impact on those who suffer the health and environmental problems from higher levels of pollution.

1.2.4 Illustrative Nature of the Analysis

This SO_2 NAAQS RIA is an illustrative analysis that provides useful insights into a limited number of emissions control scenarios that states might implement to achieve a revised SO_2 NAAQS. Because states are ultimately responsible for implementing strategies to meet any revised standard, the control scenarios in this RIA are necessarily hypothetical in nature. They are not forecasts of expected future outcomes. Important uncertainties and limitations are documented in the relevant portions of the analysis.

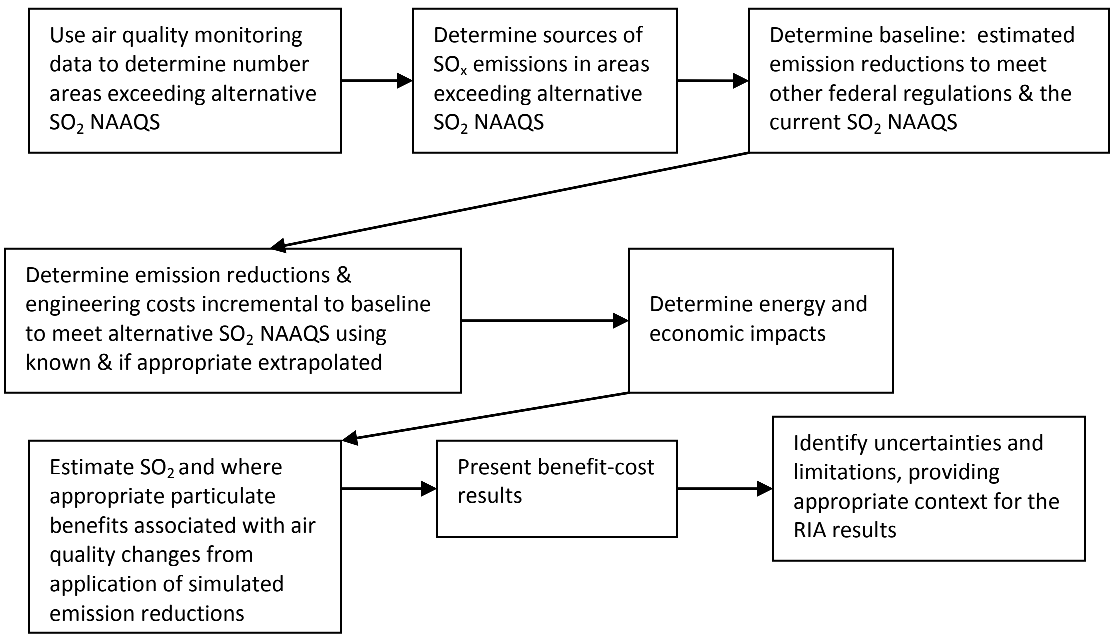
The illustrative goals of this RIA are somewhat different from other EPA analyses of national rules, or the implementation plans states develop, and the distinctions are worth brief mention. This RIA does not assess the regulatory impact of an EPA-prescribed national or regional rule, nor does it attempt to model the specific actions that any state would take to implement a revised SO_2 standard. This analysis attempts to estimate the costs and human and welfare benefits of cost-effective implementation strategies which might be undertaken to achieve national attainment of new standards. These hypothetical strategies represent a scenario where states use one set of cost-effective controls to attain a revised SO2 NAAQS. Because states—not EPA—will implement any revised NAAQS, they will ultimately determine appropriate emissions control scenarios. 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.

The illustrative attainment scenarios presented in this RIA were constructed with the understanding that there are inherent uncertainties in projecting emissions and controls. Furthermore, certain emissions inventory, control, modeling and monitoring limitations and uncertainties inhibit EPA's ability to model full attainment in all areas. Despite these limitations, EPA has used the best available data and methods to produce this RIA.

1.3 Overview and Design of the RIA

This Regulatory Impact Analysis evaluates the costs and benefits of hypothetical national strategies to attain several potential revised primary SO_2 standards. The document is intended to be straightforward and written for the lay person with a minimal background in chemistry, economics, and/or epidemiology. Figure 1-1 provides an illustration of the process used to create this RIA.

Figure 1-1: The Process Used to Create this RIA



1.3.1 Baseline and Years of Analysis

The analysis year for this regulatory impact analysis is 2020, which approximates the required attainment year under the Clean Air Act. Many areas will reach attainment of any alternative SO_2 standard before 2020. For purposes of this analysis, we assess attainment by 2020 for all areas. Some areas for which we assume 2020 attainment may in fact need more time to meet one or more of the analyzed standards, while others will need less time. This analysis does not prejudge the attainment dates that will ultimately be assigned to individual areas under the Clean Air Act.

The methodology first estimates what baseline SO_2 levels might look like in 2020 with existing Clean Air Act programs, including application of controls to meet the current SO_2 NAAQS, various maximum achievable control technology (MACT) standards, and then predicts the change in SO_2 levels following the application of additional controls to reach tighter alternative standards. This allows for an analysis of the incremental change between the current standard and alternative standards.

1.3.2 Control Scenarios Considered in this RIA

In this RIA we analyzed the final NAAQS of 75 ppb, as well as hypothetical target NAAQS levels of 50 and 100 ppb. Hypothetical control strategies were developed for each NAAQS level. First, we used outputs from CMAQ model runs to estimate air quality changes that would result from the application of emissions control options that are known to be available to different types of sources in areas with monitoring levels currently exceeding the alternative standards. However, given and the amount of improvement in air quality needed to reach the some standards in some areas, as well as circumstances specific to those areas, it was also expected that applying these known controls would not reduce SO_2 concentrations sufficiently to allow these two areas to reach some standards. In order to bring these monitor areas into attainment, we calculated the cost of unspecified emission reductions by extrapolating from a range of fixed costs per ton of emission control that are generally identified nationally.

1.3.3 Evaluating Costs and Benefits

We applied a two step methodology for estimating emission reductions needed to reach full attainment. First, we quantified the costs associated with applying known controls. Second, we estimated costs of the additional tons of extrapolated emission reductions estimated which were needed to reach full attainment. This methodology enabled us to evaluate nationwide costs and benefits of attaining a tighter SO_2 standard using hypothetical strategies, albeit with substantial additional uncertainty regarding the second step estimates. [3]

To streamline this RIA, this document refers to several previously published documents, including two technical documents EPA produced to prepare for promulgation of the SO_2 NAAQS. The first was the Integrated Science Assessment (ISA) created by EPA's Office of Research and Development (U.S. EPA, 2008), which presented the latest available pertinent information on atmospheric science, air quality, exposure, health effects, and environmental effects of SO_2. The second was the Risk and Exposure Assessment (REA) (U.S. EPA, 2009) for various standard levels. The REA also includes staff conclusions and recommendations to the Administrator regarding potential revisions to the standards.

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[3] Because the secondary SO_2 NAAQS is under development in a separate regulatory process, no additional costs and benefits were calculated in this RIA.

1.4 SO_2 Standard Alternatives Considered

EPA has performed an illustrative analysis of the potential costs and human health and visibility benefits of nationally attaining SO_2 NAAQS of 50, 75, and 100 ppb, assuming a baseline of no additional control beyond the controls expected from rules that are already in place (including the current $PM_{2.5}$ NAAQS), and solely within the bounds of the existing monitoring network. The benefit and cost estimates below are calculated incremental to a 2020 baseline that incorporates air quality improvements achieved through the projected implementation of existing regulations and attainment of the existing PM National Ambient Air Quality Standards (NAAQS). The baseline also includes the MACT program, the clean air interstate rule (CAIR), and implementation of current consent decrees, all of which would help many areas move toward attainment of the SO_2 standard.

1.5 References

U.S. Environmental Protection Agency (U.S. EPA). 1970. Clean Air Act. 40 CFR 50.

U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Sulfur Oxides - Health Criteria (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. September. Available on the Internet at < http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843>.

U.S. Environmental Protection Agency (U.S. EPA). 2009. Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards: Final Report. Office of Air Quality Planning and Standards, Research Triangle Park, NC. August. Available on the Internet at <http://www.epa.gov/ttn/naaqs/standards/so2/data/Risk%20and%20Exposure%20Assessment%20to%20Support%20the%20Review%20of%20the%20SO2%20Primary%20National%20Ambient%20Air%20Quality%20Standards-%20Final%20Report.pdf>.

Chapter 2: SO_2 Emissions and Monitoring Data

Synopsis

This chapter describes the available SO_2 emissions and air quality data used to inform and develop the control strategies outlined in this RIA. We first describe data on SO_2 emission sources contained in available EPA emission inventories. We then provide an overview of data sources for air quality measurement. For a more in-depth discussion of SO_2 emissions and air quality data, see the Integrated Science Assessment for the SO_2 NAAQS.[1]

2.1 Sources of SO_2

In order to estimate risks associated with SO_2 exposure, principal sources of the pollutant must first be characterized because the majority of human exposures are likely to result from the release of emissions from these sources. Anthropogenic SO_2 emissions originate chiefly from point sources, with fossil fuel combustion at electric utilities (~66%) and other industrial facilities (~29%) accounting for the majority of total emissions (ISA, section 2.1). Other anthropogenic sources of SO_2 include both the extraction of metal from ore as well as the burning of high sulfur containing fuels by locomotives, large ships, and non-road diesel equipment. Notably, almost the entire sulfur content of fuel is released as SO_2 or SO_3 during combustion. Thus, based on the sulfur content in fuel stocks, oxides of sulfur emissions can be calculated to a higher degree of accuracy than can emissions for other pollutants such as PM and NO_2 (ISA, section 2.1).

The largest natural sources of SO_2 are volcanoes and wildfires. Although SO_2 constitutes a relatively minor fraction (0.005% by volume) of total volcanic emissions, concentrations in volcanic plumes can be in the range of several to tens of ppm (thousands of ppb). Volcanic sources of SO_2 in the U.S. are limited to the Pacific Northwest, Alaska, and Hawaii. Emissions of SO_2 can also result from burning vegetation. The amount of SO_2 released from burning vegetation is generally in the range of 1 to 2% of the biomass burned and is the result of sulfur from amino acids being released as SO_2 during combustion.

[1] U.S. Environmental Protection Agency (2007c), Review of the National Ambient Air Quality Standards for SO_2: Policy Assessment of Scientific and Technical Information, Integrated Science Assessment, Chapter 2, EPA-452/R-08-xxx, Office of Air Quality Planning and Standards, RTP, NC.

Emissions inventory inputs representing the year 2005 for the sources above were developed to provide a base year for the air quality analysis presented in Chapter 3. The 2005 National Emissions Inventory (NEI), version 2 from October 6, 2008 was the starting point for the U.S. inventories used for the air quality analysis. This inventory includes 2005-specific data for most point and mobile sources, while most nonpoint and other data were carried forward from version of the 2002 NEI. For more information on the 2005 NEI, upon which significant portions of the 2005 modeling platform are based, see http://www.epa.gov/ttn/chief/net/2005inventory.html.

2.2 Air Quality Monitoring Data

2.2.1 Background on SO_2 monitoring network

The following section provides general background on the SO_2 monitoring network. A more detailed description of this network can be found in Watkins (2009). The SO_2 monitoring network was originally deployed to support implementation of the SO_2 NAAQS established in 1971. Despite the establishment of an SO_2 standard, uniform minimum monitoring requirements for SO_2 monitoring did not appear until May 1979. From the time of the implementation of the 1979 monitoring rule through 2008, the SO_2 network has steadily decreased in size from approximately 1496 sites in 1980 to the approximately 488 sites operating in 2008.

The 1979 monitoring rule established two categories of SO_2 monitoring sites: State and Local Ambient Monitoring Stations (SLAMS) and the smaller set of National Ambient Monitoring Stations (NAMS). No minimum requirements were established for SLAMS. Minimum requirements (described below) were established for NAMS. The 1979 rule also required that SO_2 only be monitored using Federal Reference Methods (FRMs) or Federal Equivalent Methods (FEMs). The 1979 monitoring rule called for a range of number of sites in a metropolitan statistical area (MSA) based both on population size and known concentrations relative to the NAAQS (at that point in time; see Watkins, 2009).

In October 2006, EPA revised the monitoring requirements for SO_2 in light of the fact that there was not an SO_2 non-attainment problem (Watkins, 2009). The 2006 rule eliminated the minimum requirements for the number of SO_2 monitoring sites. The current SO_2 monitoring rule, 40 CFR Part 58, Appendix D, section 4.4 states:

Sulfur Dioxide (SO_2) Design Criteria:

(a) There are no minimum requirements for the number of SO_2 monitoring sites. Continued operation of existing SLAMS SO_2 sites using FRM or FEM is required until discontinuation is approved by the EPA Regional Administrator. Where SLAMS SO_2 monitoring is ongoing, at least one of the SLAMS SO_2 sites must be a maximum concentration site for that specific area.

(b) The appropriate spatial scales for SO_2 SLAMS monitoring are the microscale, middle, and possibly neighborhood scales. The multi-pollutant NCore sites can provide for metropolitan area trends analyses and general control strategy progress tracking. Other SLAMS sties are expected to provide data that are useful in specific compliance actions, for maintenance plan agreements, or for measuring near specific stationary sources of SO_2.

(1) Micro and middle scale – Some data uses associated with microscale and middle scale measurements for SO_2 include assessing the effects of control strategies to reduce concentrations (especially for the 3-hour and 24-hour averaging times) and monitoring air pollution episodes.

(2) Neighborhood scale – This scale applies where there is a need to collect air quality data as part of an ongoing SO_2 stationary source impact investigation. Typical locations might include suburban areas adjacent to SO_2 stationary sources for example, or for determining background concentrations as part of these studies of population responses to exposure to SO_2.

(c) Technical guidance in reference 1 of this appendix should be used to evaluate the adequacy of each existing SO_2 site, to relocate an existing site, or to locate new sites.

To ascertain what the current SO_2 network is addressing or characterizing, and in light of the relatively recent removal of a specific SO_2 monitoring requirement, EPA reviewed some of the SO_2 network meta-data (Watkins, 2009). The data reviewed are those available from AQS for calendar year 2008, for any monitors reporting data at any point during the year. In 2008, there were 488 SO_2 monitors reporting data to AQS at some point during the year.

2.2.2 Ambient concentrations of SO_2

Since the integrated exposure to a pollutant is the sum of the exposures over all time intervals for all environments in which the individual spends time, understanding the temporal and spatial patterns of SO_2 levels across the U.S is an important component of conducting air quality, exposure, and risk analyses. SO_2 emissions and ambient concentrations follow a strong east to west gradient due to the large numbers of coal-fired electric generating units in the Ohio River Valley and upper Southeast regions. In the 12 CMSAs that had at least 4 SO_2 regulatory monitors from 2003-2005, 24-hour average concentrations in the continental U.S. ranged from a reported low of ~1 ppb in Riverside, CA and San Francisco, CA to a high of ~12 ppb in Pittsburgh, PA and Steubenville, OH (ISA, section 2.4.4). In addition, inside CMSAs from 2003-2005, the annual average SO_2 concentration was 4 ppb (ISA, Table 2-8). However, spikes in hourly concentrations occurred; the mean 1-hour maximum concentration was 130 ppb, with a maximum value of greater than 700 ppb (ISA, Table 2-8).

In addition to considering 1-hour, 24-hour, and annual SO_2 levels, examining the temporal and spatial patterns of 5-minute peaks of SO_2 is also important given that human clinical studies have demonstrated exposure to these peaks can result in adverse respiratory effects in exercising asthmatics (see REA, Chapter 4). Although the total number of SO_2 monitors across the continuous U.S. can vary from year to year, in 2006 there were approximately 500 SO_2 monitors in the NAAQS monitoring network (ISA, section 2.5.2). State and local agencies responsible for these monitors are required to report 1-hour average SO_2 concentrations to the EPA Air Quality System (AQS). However, a small number of sites, only 98 total from 1997 to 2007, and not the same sites in all years, voluntarily reported 5-minute block average data to AQS (ISA, section 2.5.2). Of these, 16 reported all twelve 5-minute averages in each hour for at least part of the time between 1997 and 2007. The remainder reported only the maximum 5-minute average in each hour. When maximum 5-minute concentrations were reported, the absolute highest concentration over the ten-year period exceeded 4000 ppb, but for all individual monitors, the 99^{th} percentile was below 200 ppb (ISA, section 2.5.2). Medians from these monitors reporting data ranged from 1 ppb to 8 ppb, and the average for each maximum 5-minute level ranged from 3 ppb to 17 ppb. Delaware, Pennsylvania, Louisiana, and West Virginia had mean values for maximum 5-minute data exceeding 10 ppb (ISA, section 2.5.2). Among aggregated within-state data for the 16 monitors from which all 5-minute average intervals were reported, the median values ranged from 1 ppb to 5 ppb, and the means ranged from 3 ppb to 11 ppb (ISA, section 2.5.2). The highest reported concentration was 921 ppb, but the 99th percentile values for aggregated within-state data were all below 90 ppb (ISA, section 2.5.2).

Chapter 3: Air Quality Analysis

Synopsis

This chapter describes the approach used to calculate 2020 baseline SO_2 design values and the amount of emissions reductions needed to attain the alternative 1-hour SO_2 NAAQS. The NAAQS being analyzed are 50, 75, and 100 ppb based on design values calculated using the 3-year average of the 99th percentile 1-hour daily maximum concentrations based on the monitoring network described in Chapter 2. The projected 2020 baseline SO_2 design values are used to identify 2020 nonattainment counties and to calculate, for each such county, the amount of reduction in SO_2 concentration necessary to attain the alternative NAAQS. This chapter also describes the approach for calculating "ppb SO_2 concentration per ton SO_2 emissions" ratios that are used to estimate the amount of SO_2 emissions reductions that may be needed to provide for attainment of the alternative SO_2 standards. As described below, the air quality analysis relies on SO_2 emissions from simulations of the Community Multiscale Air Quality (CMAQ) model coupled with ambient 2005-2007 design values and emissions data to project 2020 SO_2 design value concentrations and the "ppb per ton" ratios. A description of CMAQ is provided in the Ozone NAAQS RIA Air Quality Modeling Platform Document (EPA, 2008).

3.1 2005-2007 Design Values

The proposed standard is based on the 3-year average of the 99th percentile concentration of the daily 1-hour maximum concentration for a year. The design value for each percentile is calculated as:

- Identify daily 1-hour maximum concentration for each day for each year
- Calculate 99th percentile values of the daily 1-hour maximum concentrations for each year
- Average the 99th percentile values for the three years.

Monitors that had valid measurements for at least 75% of the day, 75% of the days in a quarter and all 4 quarters for all three years were included in the analysis[1]. The resulting 3-year averaged 99th percentile daily 1-hour maximum concentrations are shown in Figure 3.1 for 229 monitored counties. Counties in blue, green, and dark red would exceed the lowest alternative standard considered in the RIA, 50 ppb. Monitors with design values of 50.0 to 50.4 ppb would not exceed the standard 50 ppb as those concentrations would round to 50 ppb.

[1] Email from Rhonda Thompson to James Thurman, January 22, 2009.

Concentrations 50.5 ppb and higher are considered exceeding the lowest alternative standard. Similar rounding is done for the 75, and 100 ppb alternative standards (75.4 and 100.4 are the cut-offs for nonattainment). A summary of the number of counties exceeding the alternative standards for 2005-2007 is shown in Table 3.1. Appendix 3 contains the complete list of 2005-2007 design values used in calculation of the 2020 design values. Table 3.2 lists the top ten counties for the 99th percentile design values for 2005-2007.

Figure 3.1. 2005-2007 3-year averaged design values (ppb) for 99th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

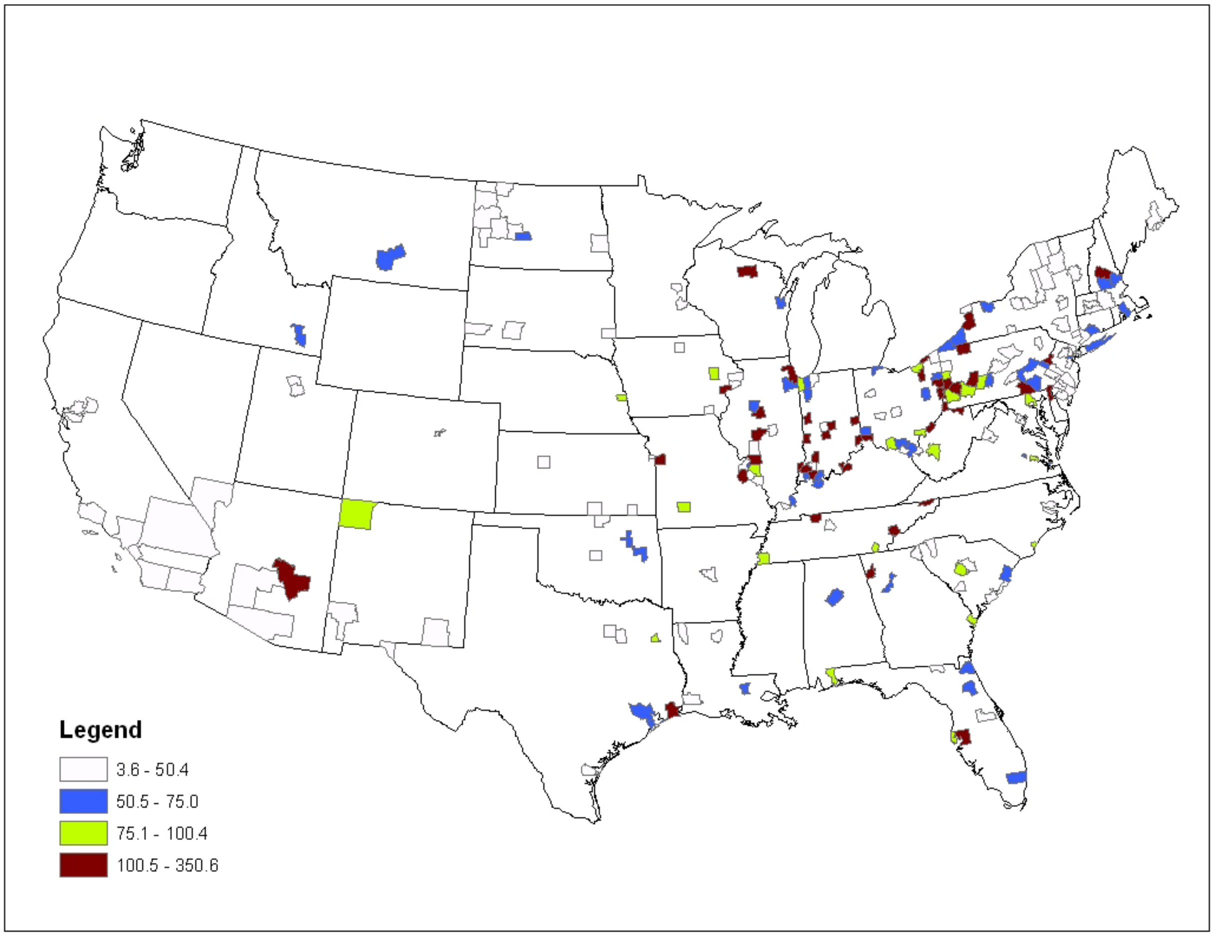


Table 3.1. Number of monitors and counties exceeding 50, 75, and 100 ppb alternative standards for the 99th percentile design values for 2005-07.

Alternative standard (ppb)	Number of monitors	Number of counties
50	169	119
75	95	70
100	59	46

Table 3.2. Top 10 2005-07 counties 99th percentile design values.

State	County	Design value (ppb)
MO	Jefferson	350.6
AZ	Gila	286.0
IL	Tazewell	222.3
PA	Warren	214.0
TN	Blount	196.3
PA	Northampton	187.0
IN	Fountain	183.0
OH	Lake	180.3
WI	Oneida	179.0
IN	Floyd	176.3

3.2 Calculation of 2020 Projected Design Values

The 2020 baseline design values were determined using CMAQ gridded emissions for 2005 and 2020. Gridded emissions were utilized instead of county emissions because of the influence of stationary sources on SO_2 concentrations. For monitors near county boundaries, stationary sources in a neighboring county may have more influence over the monitor than a stationary source in the monitor's home county. The SO_2 emissions in the CMAQ runs reflect reductions from the following controls and programs shown in Table 3.3.

Table 3.3. Controls in the 2020 SO_2 inventory.

Control Strategies	Approach or Reference:
Non-EGU Point Controls	
Consent decrees apportioned to several plants	
DOJ Settlements: plant SCC controls Alcoa, TX Premcor (formerly MOTIVA), DE	1
Refinery Consent Decrees: plant/SCC controls	2
Closures, pre-2007: plant control of 100% Auto plants Pulp and Paper Large Municipal Waste Combustors Small Municipal Waste Combustors Plants closed in preparation for 2005 inventory	3
Small Municipal Waste Combustors (SMWC)	4
Solid Waste Rules (Section 129d/111d) Hospital/Medical/Infectious Waste Incinerator Regulations	EPA, 2005
MACT rules, plant-level, PM & SO_2: Lime Manufacturing	5
Stationary Area Assumptions	
Residential Wood Combustion Growth and Changeouts to year 2020	6
EGU Point Controls	
Clean Air Interstate Rule	7; EPA, 2005
Onroad Mobile and Nonroad Mobile Controls (list includes all key mobile control strategies but is not exhaustive)	
Tier 2 Rule	EPA, 1999
2007 Onroad Heavy-Duty Rule	EPA, 2000
Final Mobile Source Air Toxics Rule (MSAT2)	EPA, 2007
Renewable Fuel Standard	EPA, 2010
Clean Air Nonroad Diesel Final Rule – Tier 4	8, EPA, 2004
Control of Emissions from Nonroad Large-Spark Ignition Engines and Recreational Engines (Marine and Land Based): "Pentathalon Rule" Clean Bus USA Program Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder	8,9,10
Aircraft, Locomotives, and Commercial Marine Assumptions	
Aircraft: Itinerant (ITN) operations at airports to year 2020	11
Locomotives: Energy Information Administration (EIA) fuel consumption projections for freight rail Clean Air Nonroad Diesel Final Rule – Tier 4 Locomotive Emissions Final Rulemaking, December 17, 1997 Control of Emissions of Air Pollution from Locomotives and Marine	EPA, 2009; 12; 9

Control Strategies	Approach or Reference:
Commercial Marine: EIA fuel consumption projections for diesel-fueled vessels OTAQ ECA C3 Base 2020 inventory for residual-fueled vessels Clean Air Nonroad Diesel Final Rule – Tier 4 Emissions Standards for Commercial Marine Diesel Engines, December 29, 1999 Tier 1 Marine Diesel Engines, February 28, 2003	12; EPA, 2009

1. For ALCOA consent decree, used http:// cfpub.epa.gov/compliance/cases/index.cfm; for MOTIVA: used information sent by State of Delaware
2. Used data provided by Brenda Shine, EPA, OAQPS
3. Closures obtained from EPA sector leads; most verified using the world wide web.
4. Used data provided by Walt Stevenson, EPA, OAQPS
5. Percent reductions recommended are determined from the existing plant estimated baselines and estimated reductions as shown in the Federal Register Notice for the rule. SO_2 % reduction will therefore be 6147/30,783 = 20% and PM10 and PM2.5 reductions will both be 3786/13588 = 28%
6. Expected benefits of woodstoves change-out program: http://www.epa.gov/woodstoves/index.html
7. http://www.epa.gov/airmarkets/progsregs/epa-ipm/docs/summary2006.pdf
8. http://www.epa.gov/nonroad-diesel/2004fr.htm
9. http://www.epa.gov/cleanschoolbus/
10. http://www.epa.gov/otaq/marinesi.htm
11. Federal Aviation Administration (FAA) Terminal Area Forecast (TAF) System, December 2007: http://www.apo.data.faa.gov/main/taf.asp
12. http://www.epa.gov/nonroad-diesel/2004fr.htm

In brief, these CMAQ emissions were at 12 km horizontal resolution for two modeling domains which, collectively, cover the lower 48 States and adjacent portions of Canada and Mexico. The boundaries of these two domains are shown in Figure 3.2. The spatial distribution of the emissions for 2005 and 2020 can be seen in Figures 3.3 and 3.4 respectively. In both figures, the lines radiating from the coast are the commercial marine vessel emissions. Figure 3.5 shows the reduction in emissions between 2005 (16.3 million tons) and 2020 (9.6 million tons) by source sector (EGU, non-EGU point, commercial marine vessel, and other sources) with the decrease from 2005 to 2020 due mostly to decreases in EGU emissions.

3.2.1 2020 Design Value Calculation Methodology

Ambient monitored data were assigned to CMAQ grid cells using ArcGIS. Since there were areas of the country where the eastern and western domains overlapped, monitors in these overlapping areas were assigned to the eastern or western grid cells by using a "combined grid." This combined grid was a mesh of the eastern and western domains, with overlapping areas assigned eastern grid cells or western grid cells based on the location relative to the dividing line shown in Figure 3.2. Figure 3.2 shows the assignment of monitors to the two domains. An example of monitors in both domains was the El Paso County monitors. These monitors were assigned to the western domain. The gridded 2006 and 2020 emissions were also assigned to the combined grid based on the same grid assignments as the monitors.

Figure 3.2. Monitor domain assignments. Western domain is outlined in blue and eastern domain outlined in red. Black vertical line denotes dividing line between eastern and western domains for monitor assignments. Monitors in blue were assigned to the western domain and monitors in red were assigned to the eastern domain.

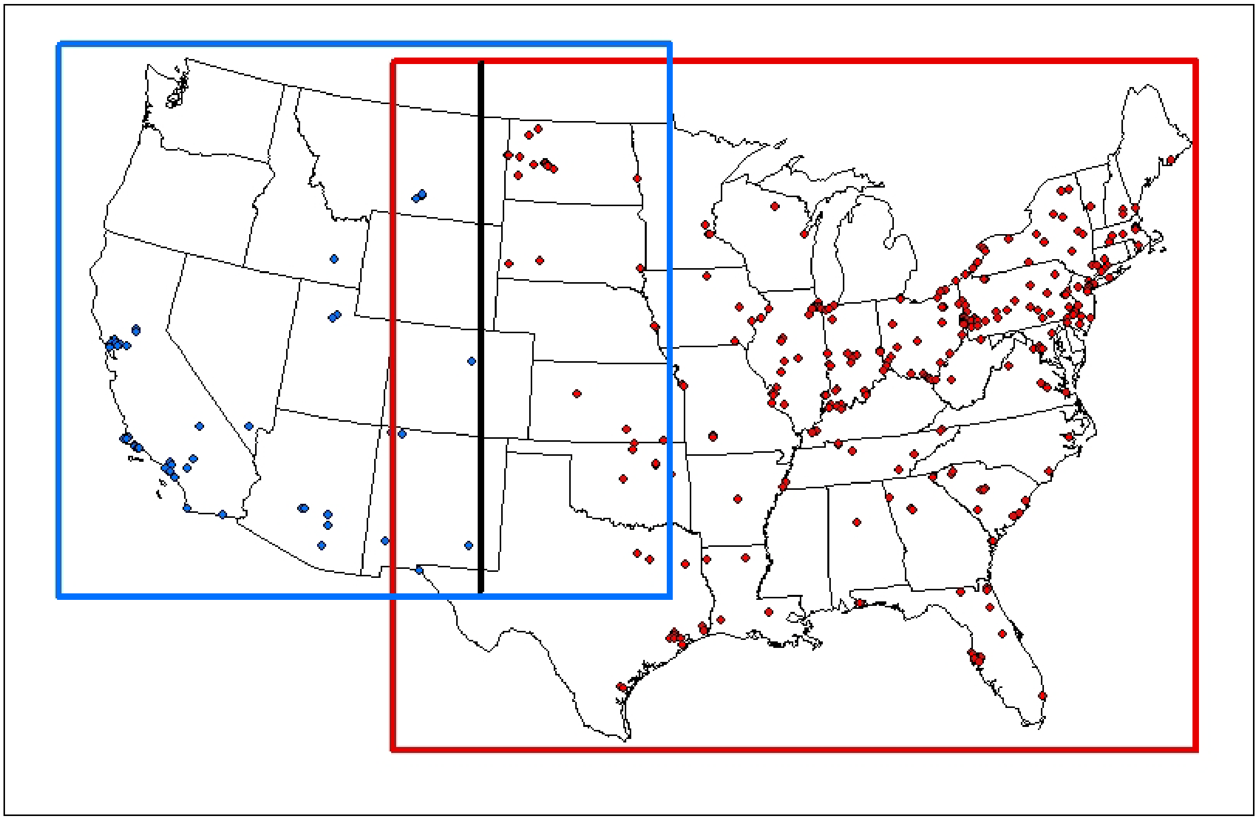


Figure 3.3. 2005 annual 12 km gridded SO_2 emissions (tons).

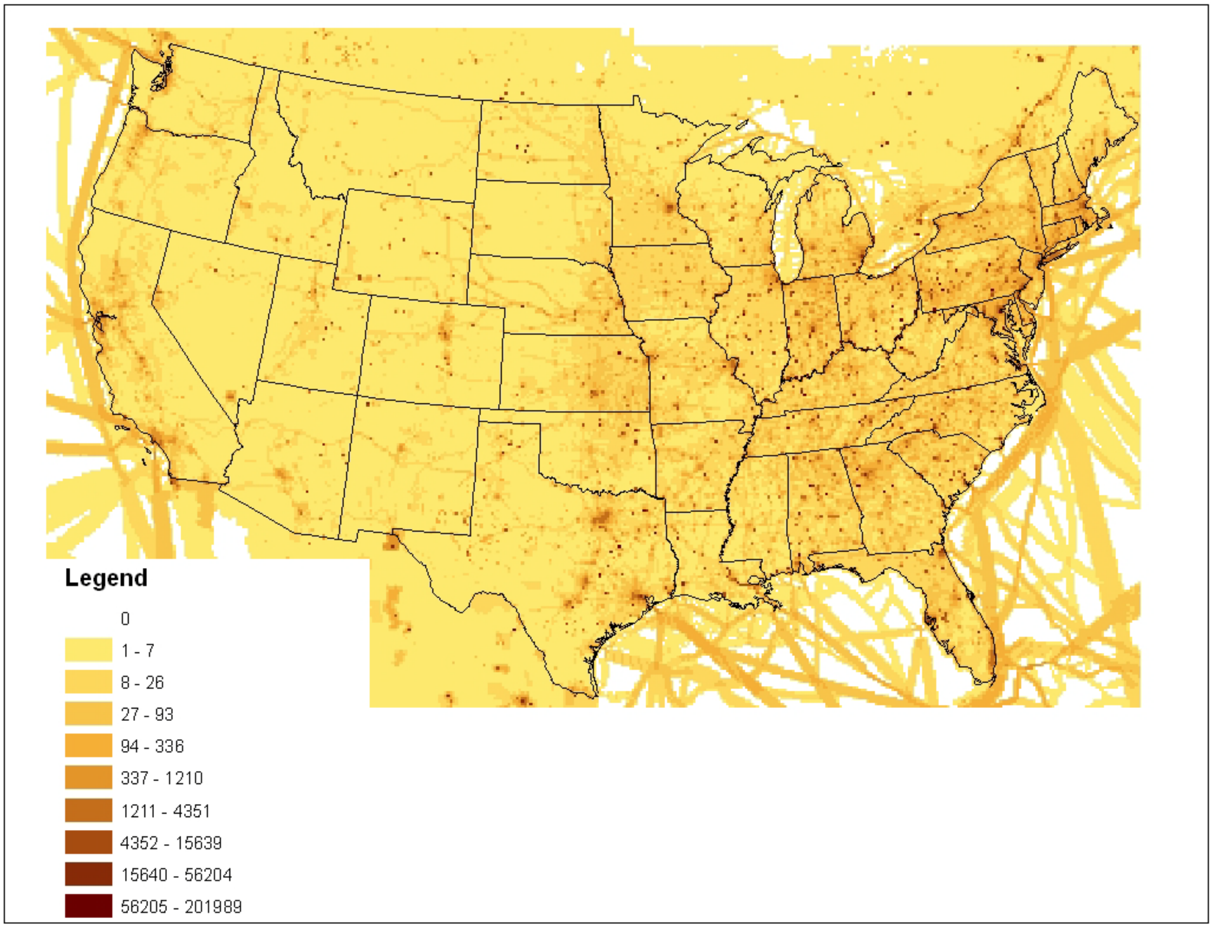


Figure 3.4. 2020 annual 12 km gridded SO_2 emissions (tons).

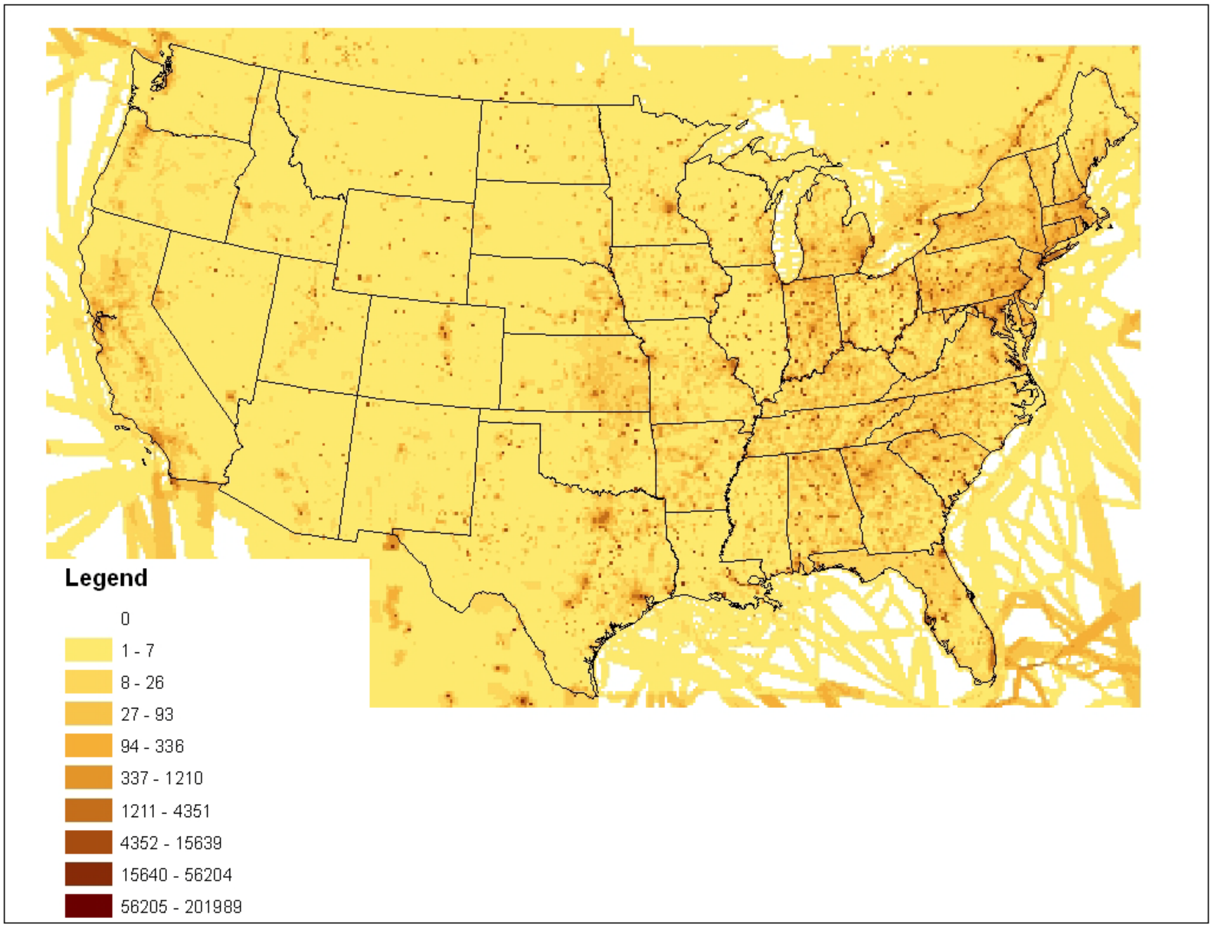
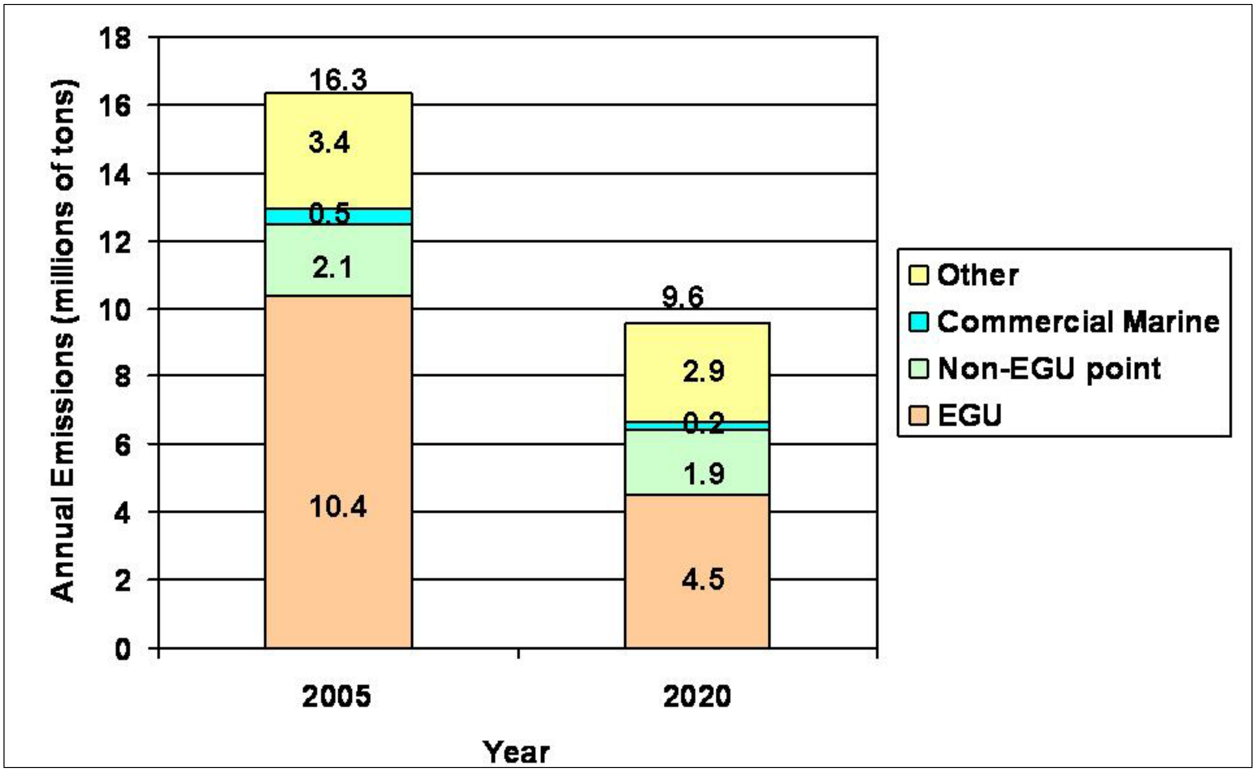
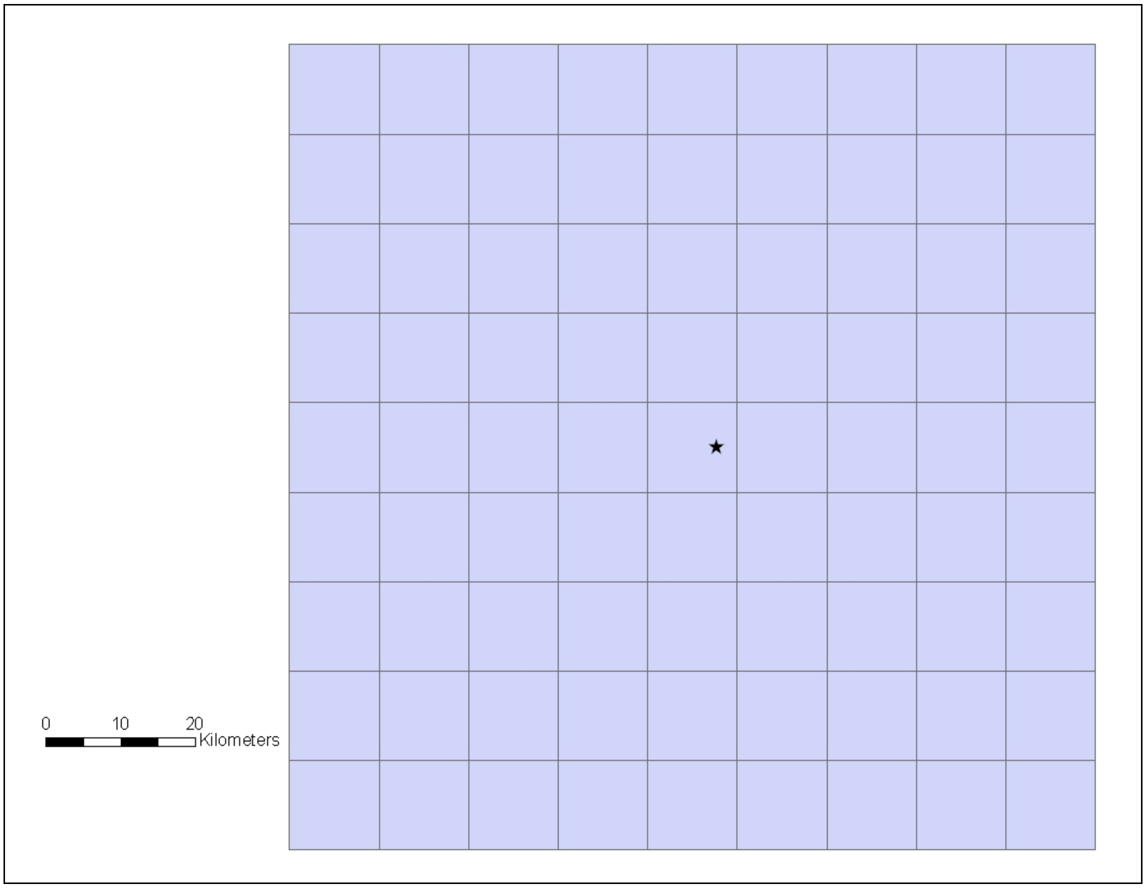


Figure 3.5. 2005 and 2020 SO_2 emissions (tons) by source sector.



Once the monitors and emissions were assigned to the combined grid, for each monitor, a 9x9 matrix of grid cells was selected, centered on the monitor's grid cell. An example is shown in Figure 3.6. The 9x9 matrix represented an approximate domain of emissions extending out 50 km from the monitor, the upper range of near-field dispersion. Since the design values were based on hourly concentrations, extending the radius of influential emissions on the monitor grid cell to 50 km was considered appropriate.

Figure 3.6. 9 x 9 matrix of 12km grid cells centered on CMAQ cell containing an SO_2 monitor (star).



Once the matrices of grid cells were created for each monitor, the 2005 and 2020 gridded emissions were summed for each year across the 81 grid cells to result in total 2005 and 2020 emissions for each monitor. The summed 2020 emissions were then divided by the 2005 emissions to get an emissions change ratio:

$$E_{ratio} = \frac{E_{2020}}{E_{2005}} \tag{3.1}$$

Where E_{2020} are the summed 81 grid cell emissions for 2020, E_{2005} are the summed 81 grid cell emissions for 2005 and E_{ratio} is the ratio of 2020 emissions to 2005 emissions.

The 2005-2007 99th percentile design value concentrations were then multiplied by the emissions ratio to calculate the 2020 design values.

$$DV_{2020"99} = DV_{2005-2007:99} \times E_{ratio} \tag{3.2}$$

Where E_{ratio} is as defined above, $DV_{2005\text{-}2007:99}$ is the 2005-2007 3-year averaged design value for the 99th percentile, and $DV_{2020:99}$ is the projected 2020 design value for the 99th percentile.

After calculating the 2020 design values, a ppb/ton estimate was calculated by:

$$ppb/ton_{99} = \left(DV_{20205:99} - DV_{2005-2007:99}\right) \Big/ \left(E_{2020} - E_{2005}\right) \quad (3.3)$$

Where E_{2020} and E_{2005} are the summed emissions as defined for Equation 3.1, $DV_{2005\text{-}2007:99}$ and $DV_{2020:99}$ are as defined above and ppb/ton_{99} is the ppb/ton estimate for the 99th percentile.

Residual nonattainment estimates for the three alternative standards of 50, 75, and 100 ppb were calculated by subtracting the alternative standard from the 2020 design value. The absolute values of the alternative standards (50, 75, or 100 ppb) were not subtracted but rather the highest value that would meet the standards (50.4, 75.4, and 100.4 ppb) if design values were rounded to the nearest whole ppb. Once residual nonattainment was calculated for each alternative standard, for monitors exceeding the standards, tons needed for control were calculated by dividing residual nonattainment by the ppb/ton estimate:

$$Tons_{99:AS} = \frac{NA_{99:AS}}{ppb/ton_{99}} \quad (3.4)$$

Where ppb/ton_{99} is as defined above, $NA_{99:AS}$ is the residual nonattainment for alternative standard AS (50, 75, or 100 ppb) for the 99th percentile, and $Tons_{99:AS}$ are the tons needed to reach attainment for alternative standard AS for the 99th percentile.

3.2.2 Methodology Limitations

While the approach described in Section 3.2.1 is reasonable for a national analysis, there are limitations to the approach that may be better addressed by other methods such as near-field dispersion modeling on a case by case basis or fine scale CMAQ modeling. Given the number of monitors in the analysis, dispersion modeling for all monitors would not be feasible. Also, given that the CMAQ concentrations associated with the emissions used in this analysis are at 12 km horizontal resolution and that SO_2 is affected by nearby stationary sources, the CMAQ results may not be reasonable for this analysis, due to allocation of individual emission points within the grid cell. Limitations of this analysis include:

- Distance from source to monitor is not factored in the emissions sums used in Equation 3.1. All emission sources, regardless of distance and tonnage, are weighted equally.

Using Figure 3.6 as an example, a source may be located in the most northwestern grid cell and a source may be located in the same grid cell that contains the monitor. No distance weighting is applied to either source, based on its proximity to the monitor. They are both added to the emissions sum as is. Some monitors' emission sums may include large emission sources that are farther away from the monitor than smaller emission sources but the large emissions sources dominate the emissions used to calculate the ratio in Equation 3.1. These large sources, may have large changes in emissions from 2005 to 2020 and these changes could drastically affect the emissions ratio. Given the nature of the projection approach described in Section 3.2.1, these large emission changes may overestimate or underestimate the concentration change at the monitor given the distance from the source to the monitor and the factors mentioned in the points below, meteorology and terrain.

- Meteorology and terrain influences are not factored into the analysis. A source may not have a significant impact on a monitor because the prevailing wind direction is not from the source to the monitor, or the terrain between the source and monitor is configured such that the source does not have a significant impact on the monitor. This would also depend on building downwash effects and stack parameters such as stack height, exit temperature, stack diameter, and exit velocity.

3.3 Results

3.3.1. Nonattainment results

Table 3.4 lists the number of monitors and counties exceeding the three alternative standards for the 99th percentile 2020 design values. The number of counties exceeding each of the alternative standards decreased from 2005-2007 to 2020. Figure 3.7 shows the maximum 2020 design value for monitored counties for the 99th percentile design values. Counties in blue, green, and scarlet exceed the 50 ppb alternative standard. Table 3.5 lists the top 10 counties in 2020 for the 99th percentile design value along with residual nonattainment and tons needed for control to meet attainment. A complete list of 2020 design values for all monitors can be found in Appendix 3.

Table 3.4. Number of monitors and counties exceeding 50, 75, and 100 ppb alternative standards for the 99th percentile design values for 2020.

Alternative standard (ppb)	Number of monitors	Number of counties
50	71	56
75	27	24
100	11	9

Figure 3.7. 2020 design values (ppb) for 99th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

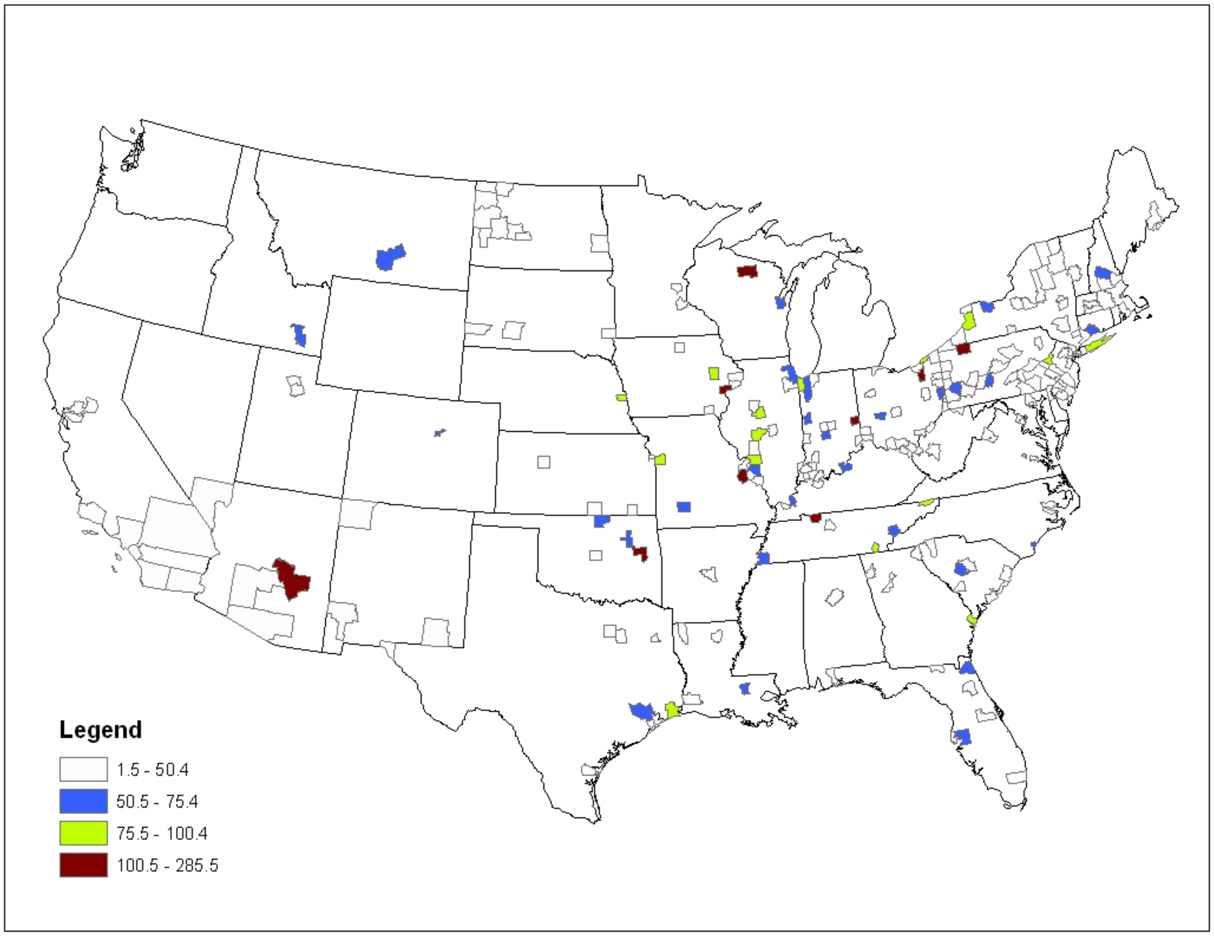


Table 3.5. Top 10 2020 counties 99th percentile design values (ppb).

State	County	2020 DV	Alternative standards (ppb)					
			50		75		100	
			Residual nonattainment	Tons for control	Residual nonattainment	Tons for control	Residual nonattainment	Tons for control
MO	Jefferson	285.5	235.1	139,033	210.1	124,249	185.1	109,464
AZ	Gila	284.8	234.4	21,930	209.4	19,591	184.4	17,252
PA	Warren	217.2	166.8	10,379	141.8	8,824	116.8	7,268
WI	Oneida	175.3	124.9	6,866	99.9	5,491	74.9	4,117
TN	Montgomery	144.3	93.9	19,764	68.9	14,502	43.9	9,240
IN	Wayne	134.3	83.9	24,088	58.9	16,911	33.9	9,733
IA	Muscatine	126.2	75.8	27,365	50.8	18,340	25.8	9,314
OK	Muskogee	104.9	54.5	45,542	29.5	24,651	4.5	3,760
OH	Summit	103.9	53.5	26,690	28.5	14,218	3.5	1,746
PA	Northampton	100.4	50.0	20,652	25.0	10.326	-	-

3.3.2 Example monitors

This section describes the emissions changes for two monitors' 99th percentile design values shown in Figures 3.8 and 3.9. One monitor's design value, Tazewell County, IL decreased from 2005-2007 to 2020 (Figure 3.8) and the other monitor's (Montgomery County, TN) design value increased from 2005-2007 to 2020 (Figure 3.9). Emissions summaries in the 81 cell matrices for both monitors are shown in Figure 3.10.

Figure 3.8. Location of monitor in Tazewell County, IL.

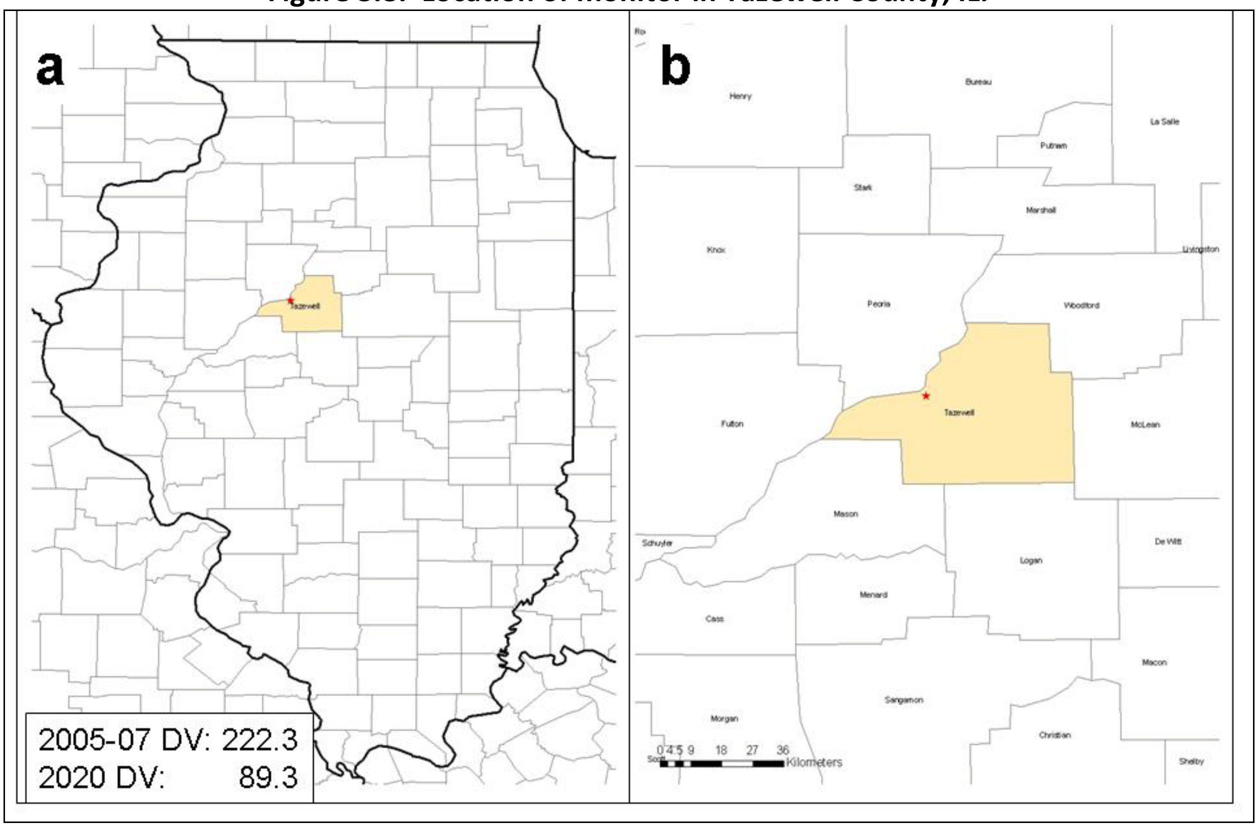


Figure 3.9. Location of monitor in Montgomery County, TN.

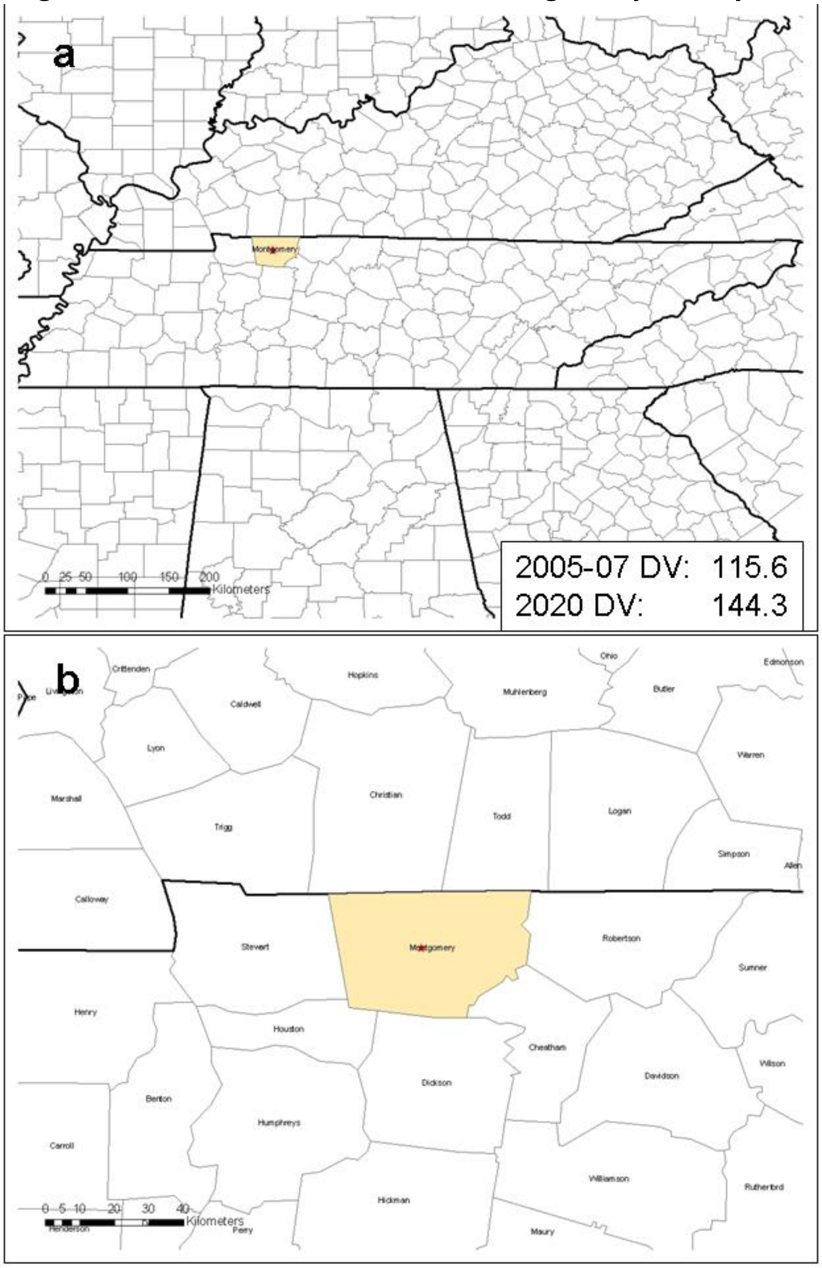
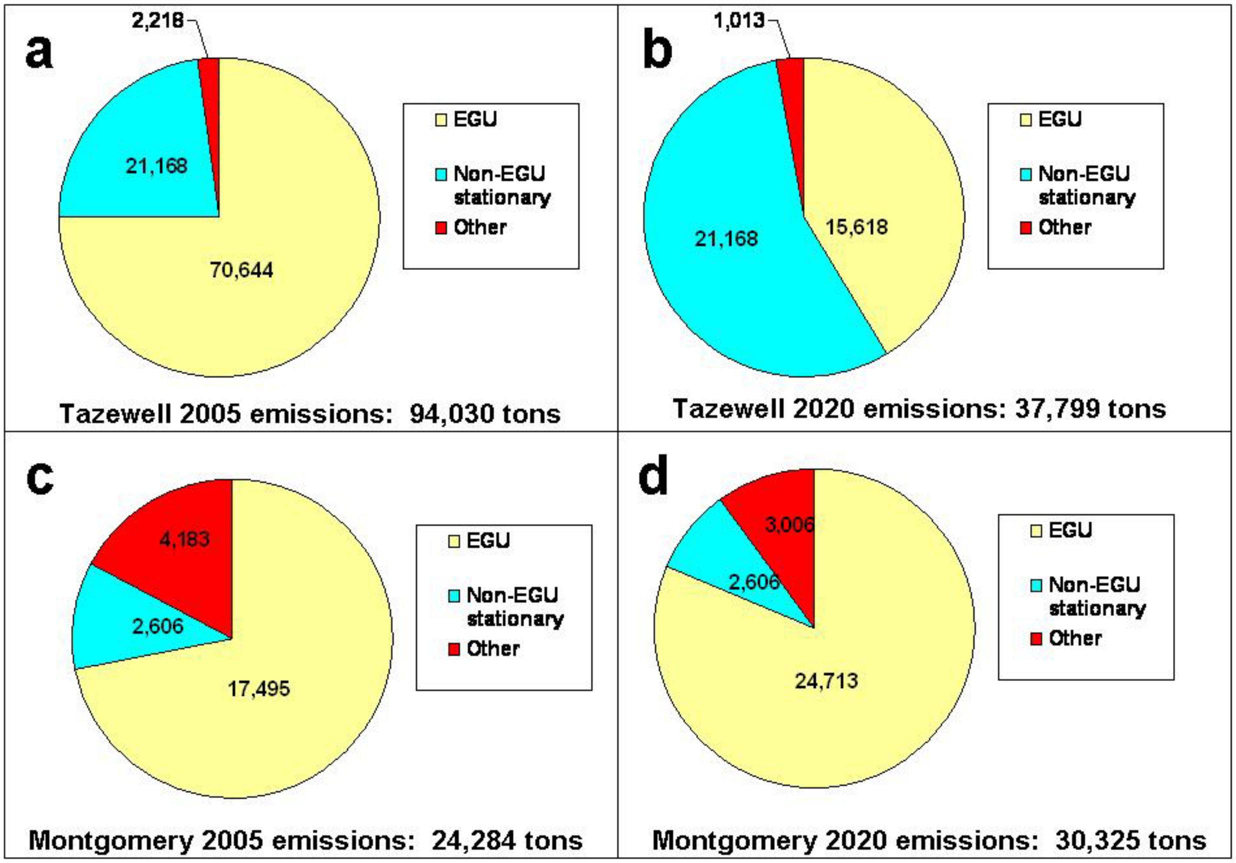


Figure 3.10. Tazewell County, IL and Montgomery County, TN monitors emissions (tons) for 2005 and 2020.



3.3.2.1 Tazewell County

Emissions affecting the Tazewell County monitor decreased from approximately 94,000 tons in 2005 to approximately 38,000 tons in 2020 (Figure 3.10 a and b). The decrease was mostly due to decreases in EGU emissions. The decrease caused the EGU sector drop from about 75% of the emissions to around 40% of the emissions. Figure 3.11 shows the spatial distribution of 2005 total emissions (all sources) within 50 km of the monitor and Figure 3.12 shows the spatial distribution of 2020 total emissions within 50 km of the monitor. The decrease in emissions can be seen as the emissions become more uniform outside of the “hotspot” grid cells.

Figure 3.11. 2005 12 km grid cell SO_2 total emissions (tons) for Tazewell County monitor. The red star represents the monitor location.

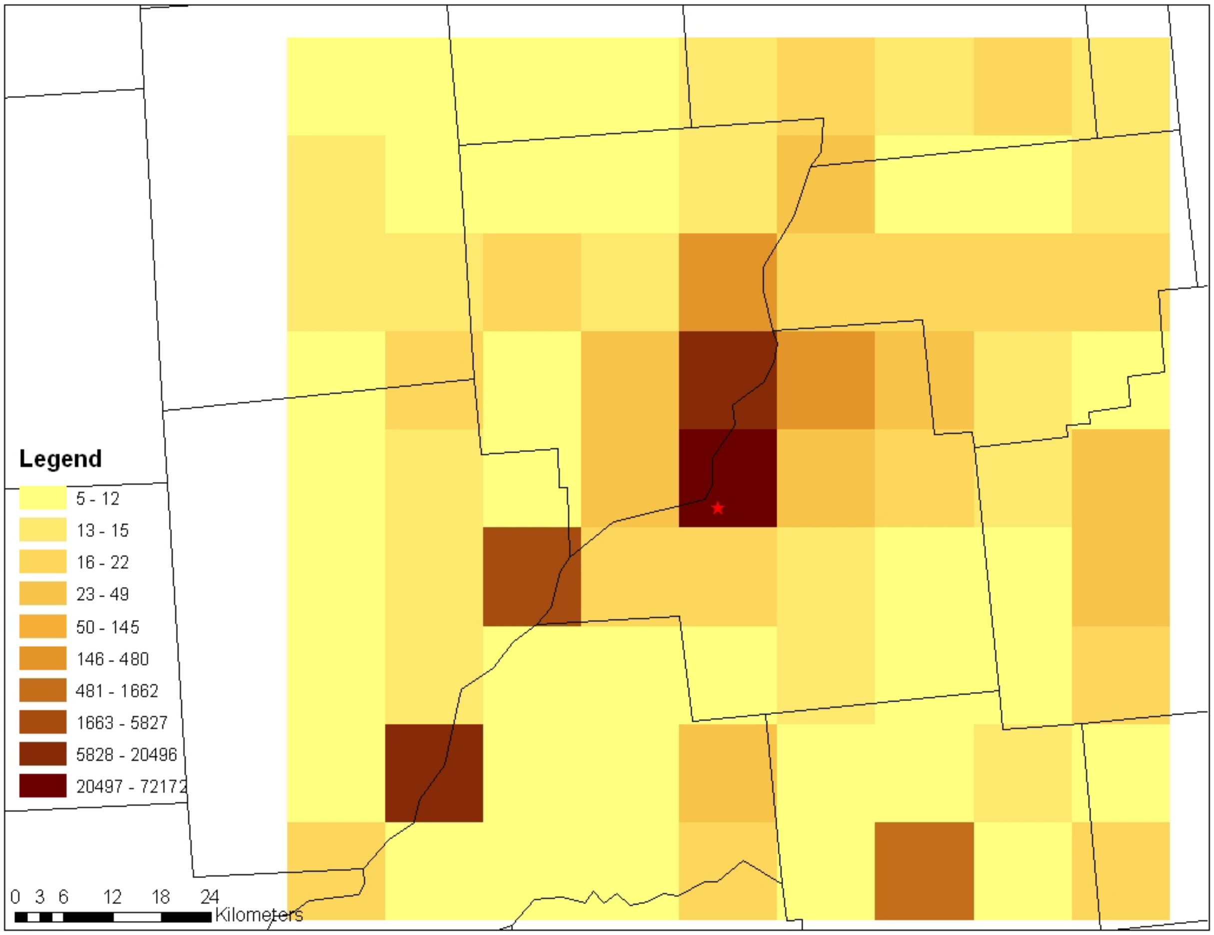
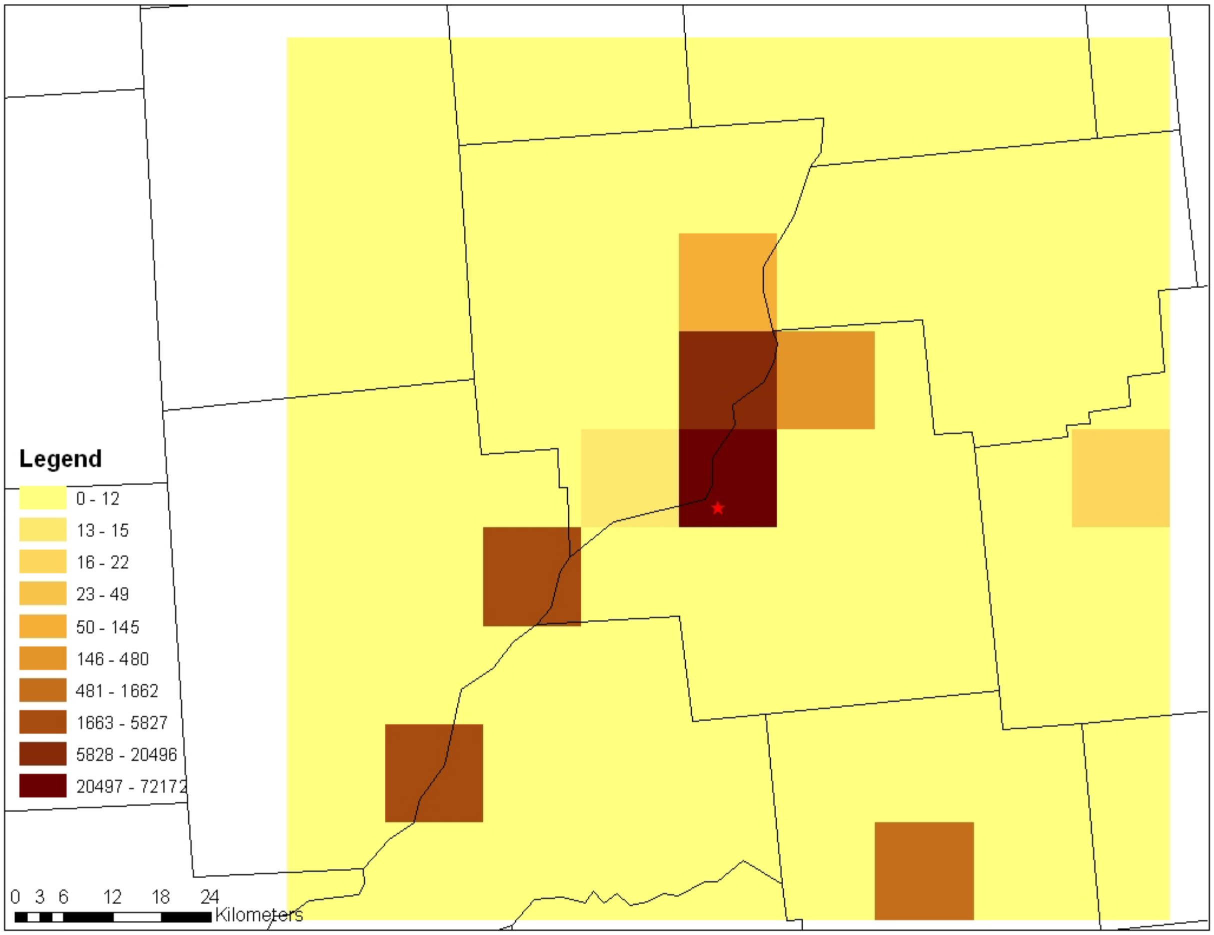


Figure 3.12. 2020 12 km grid cell SO_2 total emissions (tons) for Tazewell County monitor. The red star represents the monitor location.



3.3.2.2 Montgomery County

The design value for Montgomery County increased from 2005-07 to 2020 due to an increase in EGU emissions (Figure 3.10 c and d). Figures analogous to Figure 3.11 and Figure 3.12 are shown in Figure 3.13 and Figure 3.14. While emissions decrease outside the “hotspot” grid cells, the emissions within those hotspots increase from 2005 to 2020, as these are the locations of EGU facilities and the emissions increase from 2005 to 2020.

Figure 3.13. 2005 12 km grid cell SO_2 total emissions (tons) for Montgomery County monitor. The red star represents the monitor location.

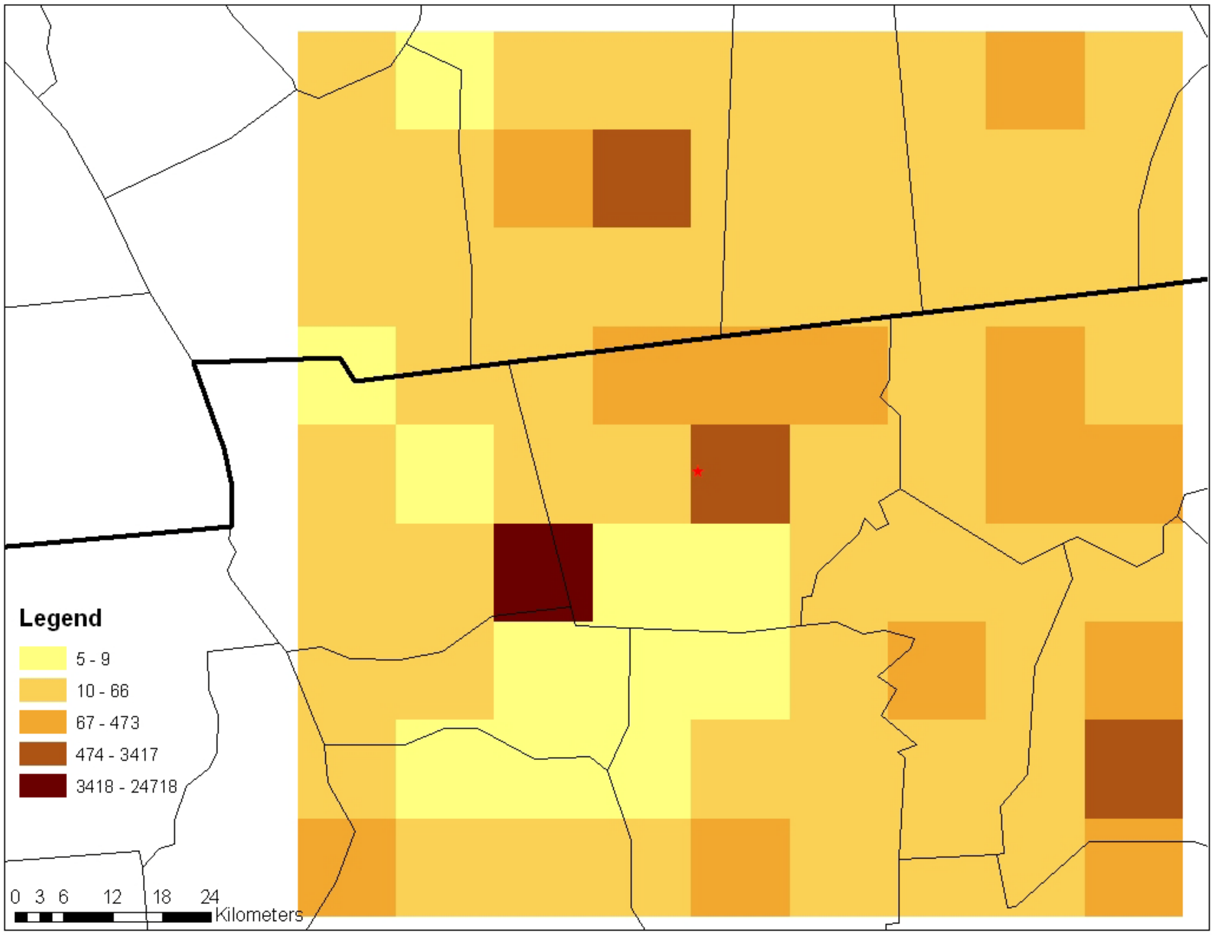
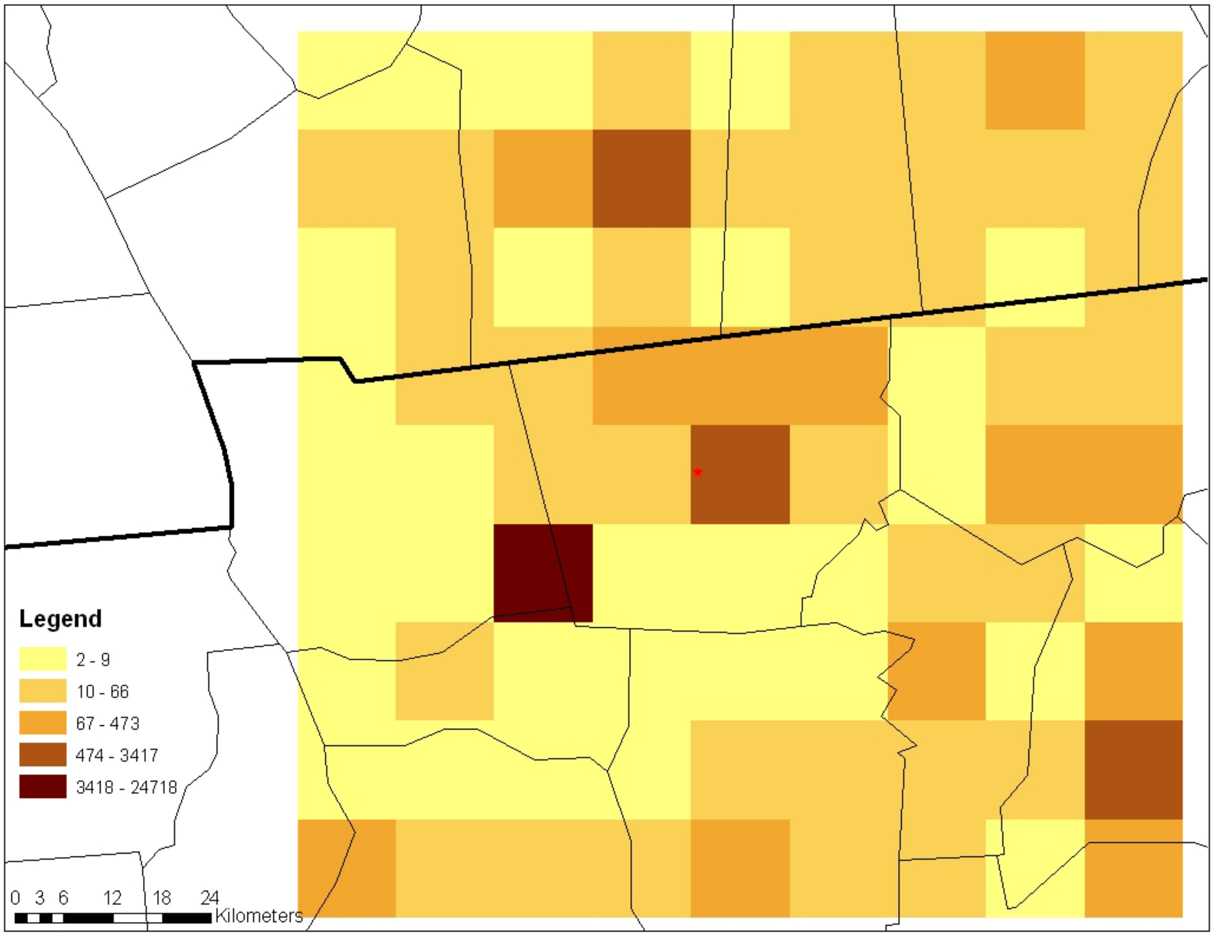


Figure 3.14. 2020 12 km grid cell SO_2 total emissions (tons) for Montgomery County monitor. The red star represents the monitor location.



3.4 Summary

In summary, 2020 baseline NO_2 design value concentrations were projected from 2005-2007 observed design values using CMAQ emissions output from 2005 and 2020. Results of the projections showed that, in 2020, nonattainment occurred for all three alternative standards (50, 75, and 100 ppb). However, the number of counties exceeding the standards dropped from the 2005-2007 period.

3.5 References

U.S. Environmental Protection Agency (EPA). 1999*.* *Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-99-023, December 1999. Available at http://www.epa.gov/tier2/frm/ria/r99023.pdf.

U.S. Environmental Protection Agency (EPA). 2000. *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-00-026, December 2000. Available at http://www.epa.gov/otaq/highway-diesel/regs/exec-sum.pdf

U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-04-007, May 2004. Available at http://www.epa.gov/nonroaddiesel/2004fr/420r04007.pdf.

U.S. Environmental Protection Agency (EPA). 2005. *Clean Air Interstate Rule Emissions Inventory Technical Support Document*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, March 2005. Available at http://www.epa.gov/cair/pdfs/finaltech01.pdf.

U.S Environmental Protection Agency (EPA), 2007. *Control of Hazardous Air Pollutants from Mobile Sources; Final Rule.* 40 CFR Parts 59, 80,85, 86, et al. Available at http://www.epa.gov/fedrgstr/EPA-AIR/2007/February/Day-26/a2667a.pdf

U.S. Environmental Protection Agency (EPA). 2008. *Air Quality Modeling Platform for the Ozone National Ambient Air Quality Standard Final Rule Regulatory Impact Analysis*. North Carolina. EPA-454/R-08-003.

U.S. Environmental Protection Agency (EPA), 2009. *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder.* U.S. Environmental Protection Agency Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-08-001a, May 2009. Available at: http://www.epa.gov/otaq/regs/nonroad/420r08001a.pdf

U.S. Environmental Protection Agency (EPA), 2010. *RFS2 Emissions Inventory for Air Quality Modeling Technical Support Document*, February, 2010. Available at: http://www.epa.gov/otaq/renewablefuels/420r10005.pdf.

Appendix 3a: 2005-2007 and 2020 Design Values

Table 3a-1 lists the 2005-2007 design values used in projecting 2020 design values for all monitors meeting the completeness criteria described in Section 3.1 of Chapter 3. Design values in black are below the 50 ppb alternative standard. Design values in blue exceed the 50 ppb alternative standard but are below 75 ppb. Design values in green exceed the 75 ppb alternative standard but are below 100 ppb. Values in red exceed 100 ppb. Exceedances of the alternative standards are based on the criteria discussed in Section 3.1 of Chapter 3.

Table 3a-1. SO_2 2005-2007 and 2020 projected 99th percentile design values (ppb).

State	County	Monitor	2005-07	2020
AL	Jefferson	1003	63.3	19.3
AZ	Gila	9	131.6	131.2
AZ	Gila	1001	286.0	284.8
AZ	Maricopa	3002	14.0	4.1
AZ	Maricopa	3003	9.3	2.8
AZ	Pima	1011	14.0	16.5
AR	Pulaski	7	10.0	12.5
CA	Contra Costa	2	18.6	12.5
CA	Contra Costa	6	18.0	11.6
CA	Contra Costa	1002	12.3	8.1
CA	Contra Costa	1004	14.6	9.4
CA	Contra Costa	2001	22.6	14.8
CA	Contra Costa	3001	25.6	17.2
CA	Imperial	5	20.9	20.4
CA	Los Angeles	1002	6.6	4.0
CA	Los Angeles	1103	10.6	6.3
CA	Los Angeles	4002	27.6	15.6
CA	Los Angeles	5005	19.6	11.6
CA	Orange	1003	9.3	5.4
CA	Sacramento	2	5.0	4.5
CA	Sacramento	6	5.6	5.1
CA	San Bernardino	306	10.0	8.2
CA	San Bernardino	1234	11.3	19.6
CA	San Bernardino	2002	8.0	7.2
CA	San Diego	1	9.6	8.6
CA	San Francisco	5	15.3	9.9
CA	Santa Barbara	8	4.0	0.6
CA	Santa Barbara	1013	4.6	2.0
CA	Santa Barbara	1020	44.3	6.7
CA	Santa Barbara	1025	8.0	1.3
CA	Santa Barbara	2004	5.6	1.6
CA	Santa Barbara	2011	3.3	0.5

State	County	Monitor	2005-07	2020
CA	Santa Barbara	4003	2.6	1.3
CA	Solano	4	10.0	6.5
CO	Denver	2	32.6	66.8
CT	Fairfield	12	35.6	46.4
CT	Fairfield	1123	25.3	24.2
CT	Fairfield	9003	27.6	29.4
CT	New Haven	27	60.6	60.9
CT	New Haven	2123	27.8	22.8
DE	New Castle	1008	125.0	48.7
DE	New Castle	2004	49.6	23.0
FL	Broward	10	64.6	35.4
FL	Duval	80	21.3	17.6
FL	Duval	81	69.0	57.0
FL	Duval	97	42.0	34.5
FL	Escambia	4	76.3	26.7
FL	Hamilton	15	31.6	24.5
FL	Hillsborough	81	47.3	20.6
FL	Hillsborough	95	42.6	19.1
FL	Hillsborough	109	119.0	53.5
FL	Hillsborough	1035	71.3	32.1
FL	Orange	2002	11.3	4.7
FL	Pinellas	23	96.3	36.4
FL	Pinellas	3002	42.0	15.8
FL	Pinellas	5002	77.6	27.8
FL	Pinellas	5003	83.3	43.2
FL	Putnam	1008	51.6	11.7
GA	Chatham	21	62.3	57.5
GA	Chatham	1002	94.6	87.4
GA	Floyd	3	110.0	10.2
GA	Fulton	48	73.0	10.2
GA	Fulton	55	60.0	22.7
ID	Bannock	4	69.6	61.7
IL	Cook	50	37.0	27.7
IL	Cook	63	40.6	29.2
IL	Cook	76	45.6	33.3
IL	Cook	1601	104.0	63.7
IL	Cook	4002	68.3	48.9
IL	Macon	13	47.0	48.6
IL	Macoupin	2	27.0	13.8
IL	Madison	1010	83.6	52.6
IL	Madison	3007	59.0	37.1
IL	Madison	3009	142.0	89.4
IL	Peoria	24	73.6	31.1
IL	Randolph	1	29.6	20.9
IL	St. Clair	10	91.3	59.4
IL	Sangamon	6	110.6	99.3
IL	Tazewell	4	222.3	89.3
IL	Wabash	1	152.3	40.5
IL	Wabash	1001	125.3	33.3

State	County	Monitor	2005-07	2020
IL	Will	13	64.6	32.0
IN	Daviess	2	112.6	36.5
IN	Dearborn	4	109.6	36.4
IN	Floyd	4	140.3	52.7
IN	Floyd	7	159.6	59.9
IN	Floyd	1004	176.3	66.2
IN	Fountain	1	183.0	56.0
IN	Gibson	1	108.6	28.8
IN	Hendricks	2	41.0	19.5
IN	Jasper	2	57.0	56.9
IN	Lake	22	92.0	81.8
IN	Lake	2008	42.6	32.8
IN	La Porte	5	27.3	27.0
IN	Marion	42	92.3	36.2
IN	Marion	57	117.3	45.5
IN	Marion	73	62.0	24.4
IN	Morgan	1001	129.6	52.5
IN	Pike	5	19.3	6.2
IN	Porter	11	63.6	59.6
IN	Spencer	10	60.0	15.9
IN	Vanderburgh	12	67.3	18.9
IN	Vanderburgh	1002	35.0	9.1
IN	Vigo	18	93.6	28.4
IN	Vigo	1014	125.0	31.8
IN	Warrick	2	148.3	38.3
IN	Wayne	6	106.7	134.3
IN	Wayne	7	84.1	105.9
IA	Cerro Gordo	18	13.2	12.3
IA	Clinton	19	48.3	41.3
IA	Linn	29	46.0	48.8
IA	Linn	31	88.6	94.0
IA	Muscatine	16	122.1	91.7
IA	Muscatine	17	65.5	50.0
IA	Muscatine	20	165.1	126.2
IA	Scott	15	27.6	21.0
IA	Van Buren	6	6.9	6.8
KS	Montgomery	6	16.6	15.0
KS	Sumner	2	8.6	4.7
KS	Trego	1	4.3	2.1
KS	Wyandotte	21	50.0	33.2
KY	Boyd	17	60.3	19.1
KY	Daviess	5	71.0	20.0
KY	Greenup	7	46.0	13.3
KY	Jefferson	1041	150.6	73.4
KY	Livingston	4	53.3	53.5
KY	McCracken	1024	26.3	26.2
LA	Bossier	8	20.6	16.7
LA	Calcasieu	8	42.3	36.1
LA	East Baton Rouge	9	65.3	54.6

State	County	Monitor	2005-07	2020
LA	Ouachita	4	22.3	20.4
ME	Hancock	103	6.3	5.4
MD	Baltimore	3001	99.3	43.3
MA	Bristol	1004	64.3	21.5
MA	Hampden	16	39.0	29.7
MA	Hampshire	4002	17.0	13.0
MA	Suffolk	2	26.6	17.1
MA	Suffolk	20	23.0	14.7
MA	Suffolk	21	32.3	20.6
MA	Suffolk	40	40.3	25.9
MA	Suffolk	42	27.3	17.5
MA	Worcester	23	20.6	17.7
MN	Anoka	1002	21.3	10.4
MN	Dakota	20	18.0	7.2
MN	Dakota	423	14.0	5.6
MN	Dakota	441	7.0	2.8
MN	Dakota	442	8.0	3.2
MO	Greene	26	67.6	48.0
MO	Greene	32	25.0	17.7
MO	Greene	37	90.6	65.0
MO	Greene	40	81.3	58.3
MO	Greene	41	25.6	18.3
MO	Jackson	34	156.3	97.4
MO	Jefferson	4	350.6	285.5
MO	St. Louis	3001	49.6	34.6
MO	St. Louis city	7	56.6	40.3
MO	St. Louis city	86	67.6	47.2
MT	Yellowstone	16	40.0	46.3
MT	Yellowstone	1065	68.0	73.3
MT	Yellowstone	2005	54.6	58.8
NE	Douglas	53	89.3	87.6
NE	Douglas	55	18.6	18.2
NV	Clark	539	8.0	6.3
NH	Hillsborough	20	58.3	20.6
NH	Merrimack	1006	157.0	51.8
NH	Rockingham	14	59.6	28.3
NJ	Atlantic	5	19.0	11.7
NJ	Bergen	5001	29.3	21.6
NJ	Burlington	1001	27.6	12.8
NJ	Camden	3	38.0	16.7
NJ	Camden	1001	26.6	13.3
NJ	Cumberland	7	23.0	8.6
NJ	Gloucester	2	32.6	13.9
NJ	Hudson	6	42.0	33.7
NJ	Hudson	1002	47.6	38.2
NJ	Middlesex	2003	29.3	12.1
NJ	Morris	3001	36.0	14.4
NJ	Union	4	51.0	23.2
NM	Eddy	1004	4.6	4.6

State	County	Monitor	2005-07	2020
NM	Grant	1003	4.0	2.1
NM	San Juan	9	12.6	5.3
NM	San Juan	1005	77.0	33.0
NY	Albany	12	22.0	21.0
NY	Chautauqua	6	61.4	41.5
NY	Chautauqua	11	32.1	28.7
NY	Chemung	3	24.6	24.8
NY	Erie	5	30.6	16.4
NY	Erie	4002	118.6	75.9
NY	Essex	3	9.9	9.2
NY	Franklin	4	9.1	8.3
NY	Hamilton	5	10.3	9.2
NY	Herkimer	5	9.8	8.8
NY	Madison	6	20.0	27.2
NY	Monroe	1007	52.0	58.6
NY	New York	56	62.6	44.3
NY	Niagara	2008	21.7	13.8
NY	Onondaga	1015	17.0	39.8
NY	Putnam	5	21.9	20.0
NY	Queens	124	44.0	33.4
NY	Schenectady	3	23.0	21.9
NY	Suffolk	9	56.0	75.6
NY	Ulster	1005	15.5	15.2
NC	Beaufort	6	47.3	45.9
NC	New Hanover	6	87.6	58.4
ND	Billings	2	6.3	3.1
ND	Burke	4	29.4	29.2
ND	Cass	1004	5.5	4.1
ND	Dunn	3	11.6	8.8
ND	McKenzie	2	11.0	5.6
ND	McKenzie	104	17.6	12.3
ND	McKenzie	111	25.6	16.9
ND	Mercer	4	35.0	18.8
ND	Mercer	102	35.3	19.0
ND	Mercer	118	34.3	18.5
ND	Mercer	123	39.0	21.0
ND	Mercer	124	37.3	21.7
ND	Oliver	2	56.3	30.4
ND	Williams	103	44.3	37.3
OH	Adams	1	88.3	21.8
OH	Allen	2	22.3	19.6
OH	Ashtabula	1001	36.6	30.3
OH	Butler	4	72.0	29.0
OH	Butler	1004	57.3	23.6
OH	Clark	3	40.0	62.8
OH	Columbiana	22	121.3	42.7
OH	Cuyahoga	45	65.0	35.2
OH	Cuyahoga	60	84.3	45.7
OH	Cuyahoga	65	87.0	47.2

State	County	Monitor	2005-07	2020
OH	Franklin	34	41.6	14.9
OH	Hamilton	10	123.6	49.9
OH	Jefferson	17	175.6	52.6
OH	Lake	3	53.3	27.1
OH	Lake	3002	180.3	94.7
OH	Lawrence	6	53.3	15.4
OH	Lucas	8	68.3	32.4
OH	Lucas	24	53.3	25.3
OH	Mahoning	13	63.0	48.4
OH	Meigs	1001	98.6	25.3
OH	Scioto	13	36.6	20.6
OH	Scioto	20	51.8	17.4
OH	Summit	17	108.0	103.9
OH	Summit	22	62.0	59.6
OH	Tuscarawas	6	71.0	15.8
OK	Kay	602	40.3	67.8
OK	Kay	9010	14.6	24.3
OK	Muskogee	167	65.6	104.9
OK	Oklahoma	1037	6.6	4.8
OK	Tulsa	175	65.3	51.3
OK	Tulsa	235	61.3	48.2
OK	Tulsa	501	48.6	38.2
PA	Allegheny	10	71.3	18.4
PA	Allegheny	21	73.0	31.5
PA	Allegheny	64	142.0	60.0
PA	Allegheny	67	67.0	22.5
PA	Beaver	2	140.0	48.1
PA	Beaver	14	69.0	34.2
PA	Blair	801	58.6	57.2
PA	Bucks	12	37.3	17.3
PA	Cambria	11	86.3	34.4
PA	Centre	100	31.0	25.8
PA	Dauphin	401	64.6	15.7
PA	Erie	3	54.0	30.4
PA	Indiana	4	111.3	47.0
PA	Lackawanna	2006	40.6	20.5
PA	Lancaster	7	66.0	19.5
PA	Lawrence	15	95.0	44.0
PA	Lehigh	4	52.6	30.1
PA	Lycoming	100	50.3	7.0
PA	Mercer	100	45.3	30.6
PA	Montgomery	13	32.3	16.4
PA	Northampton	25	46.6	26.3
PA	Northampton	8000	187.0	100.4
PA	Perry	301	33.6	6.4
PA	Philadelphia	55	40.0	17.4
PA	Schuylkill	3	55.3	10.1
PA	Warren	3	63.0	63.9
PA	Warren	4	214.0	217.2

State	County	Monitor	2005-07	2020
PA	Washington	5	79.6	32.8
PA	Washington	200	79.6	20.0
PA	Washington	5001	90.0	29.6
PA	Westmoreland	8	76.6	30.3
PA	York	8	104.0	30.7
SC	Barnwell	1	17.0	19.1
SC	Charleston	3	37.3	24.4
SC	Charleston	46	23.6	9.6
SC	Georgetown	6	55.0	14.2
SC	Greenville	8	27.0	15.8
SC	Greenville	9	25.0	14.6
SC	Lexington	8	96.3	68.9
SC	Oconee	1	20.0	17.7
SC	Richland	7	28.6	20.1
SC	Richland	1003	36.3	25.5
SD	Custer	132	4.3	3.2
SD	Jackson	1	3.6	1.5
SD	Minnehaha	7	18.0	15.2
TN	Blount	2	196.3	60.0
TN	Blount	6	84.9	25.6
TN	Bradley	102	85.3	80.2
TN	Davidson	11	23.6	26.1
TN	Montgomery	6	53.0	66.1
TN	Montgomery	106	115.6	144.3
TN	Shelby	46	65.3	49.0
TN	Shelby	1034	81.3	56.5
TN	Sullivan	7	170.6	88.2
TN	Sullivan	9	141.8	73.3
TX	Dallas	69	11.6	10.3
TX	El Paso	37	9.3	9.1
TX	El Paso	53	12.6	12.4
TX	Galveston	5	59.0	42.9
TX	Gregg	1	78.3	38.9
TX	Harris	46	34.0	27.4
TX	Harris	51	31.0	24.9
TX	Harris	62	55.3	43.7
TX	Harris	70	68.6	54.3
TX	Harris	1035	74.6	58.9
TX	Harris	1050	17.3	12.7
TX	Jefferson	9	123.0	98.9
TX	Jefferson	11	94.6	74.9
TX	Kaufman	5	15.3	13.4
TX	Nueces	25	24.0	12.4
TX	Nueces	26	8.0	4.1
TX	Nueces	32	36.0	18.7
UT	Davis	4	22.6	24.1
UT	Salt Lake	1001	32.0	34.5
VT	Rutland	2	48.2	45.5
VA	Charles City	2	88.6	24.9

State	County	Monitor	2005-07	2020
VA	Fairfax	5	25.6	6.8
VA	Fairfax	1005	37.0	8.2
VA	Fairfax	5001	37.3	14.6
VA	Rockingham	3	14.6	13.0
VA	Alexandria city	9	55.3	12.2
VA	Hampton city	4	64.0	46.3
VA	Richmond city	24	62.0	15.2
WV	Brooke	5	150.3	45.0
WV	Brooke	7	164.6	49.3
WV	Brooke	11	155.3	46.5
WV	Cabell	6	41.6	7.4
WV	Hancock	5	164.0	56.3
WV	Hancock	7	132.0	42.4
WV	Hancock	8	115.3	40.6
WV	Hancock	9	136.6	43.9
WV	Hancock	15	121.3	42.7
WV	Hancock	1004	135.6	43.6
WV	Kanawha	10	88.0	22.4
WV	Marshall	1002	155.0	41.8
WV	Monongalia	3	171.3	41.5
WV	Wood	1002	130.6	37.8
WI	Brown	5	74.3	64.7
WI	Oneida	996	179.0	175.3

Chapter 4: Emissions Controls Analysis – Design and Analytical Results

Synopsis

This chapter documents the illustrative emission control strategy we applied to simulate attainment with the alternative standards being analyzed for the final SO_2 NAAQS. Section 4.1 describes the approach we followed to select emissions controls to simulate attainment in each geographic area of analysis. Section 4.2 summarizes the emission reductions we simulated in each area based on current knowledge of identified emission controls, while Section 4.3 presents the air quality impacts of these emissions reductions. Section 4.4 discusses the application of additional controls, beyond the level of control already assumed to be in place for the analysis year[1], that we estimate will be necessary to reach attainment in certain monitor areas. Section 4.5 discusses key limitations in the approach we used to estimate the optimal control strategies for each alternative standard.

The final rule will set a new short-term SO_2 primary standard based on the average of the 99th percentile of 1-hour daily maximum concentrations from three consecutive years of data. This new standard will be set at 75 parts per billion (ppb). OMB Circular A-4 requires the RIA to contain, in addition to analysis of the impacts of the final NAAQS, analysis of a level more stringent and a level less stringent than the final NAAQS. For a more stringent standard level, we chose an alternative primary standard of 50 parts per billion (ppb). We also include analyses for a less stringent standard, 100 ppb.

For the range of alternative standards, we analyzed the impact that additional emissions controls applied to numerous sectors would have on predicted ambient SO_2 concentrations, incremental to the baseline set of controls. Thus the analysis for a revised standard focuses specifically on incremental improvements beyond the current standards, and uses control options that might be available to states for application by 2020. The hypothetical control strategy presented in this RIA is one illustrative option for achieving emissions reductions to move towards a national attainment of a tighter standard. It is not a recommendation for how a tighter SO_2 standard should be implemented, and states will make all final decisions regarding implementation strategies once a final NAAQS has been set.

Generally, we expect that the nation will be able to make significant progress towards attainment of a tighter SO_2 NAAQS without the addition of new controls beyond those already being planned for the attainment of existing $PM_{2.5}$ standards by the year 2020. As States

[1] Note that the baseline or starting point for this analysis includes rules that are already “on the books” and will take affect prior to the analysis year, as well as control strategies applied in the recent PM and Ozone NAAQS RIAs.

develop their plans for attaining these existing standards, they are likely to consider adding controls to reduce sulfur dioxide, as SO_2 is a precursor to both $PM_{2.5}$. In addition, proposed standards such as the Portland cement NESHAP, the ICI boilers NESHAPs, and the eventual rule to replace the existing CAIR may also yield in total considerable additional reductions of SO_2 emissions if they are implemented as proposed. These controls will also directly help areas meet a tighter SO_2 standard.

As part of our economic analysis of the tighter SO_2 standard, our 2020 analysis baseline assumes that States will put in place the necessary control strategies to attain the current $PM_{2.5}$ standards. The cost of these control strategies was included in the RIAs for those rulemakings. We do not include the cost of those controls in this analysis, in order to prevent counting the cost of installing and operating the controls twice. Of course, the health and environmental benefits resulting from installation of those controls were attributed to attaining those standards, and are not counted again for the analysis of this SO_2 standard.

In addition, we include the SO_2 control requirements for Category 3 (C3) marine vessels that will be affected by a new mobile source rule promulgated by EPA in December 2009.[2] These requirements call for changes in the diesel fuel program to allow for use of lower sulfur fuel (1,000 ppm sulfur content) in U.S.-flagged C3 marine vessels beginning in 2011. Reductions of SO_2 associated with this final rule are included in our 2020 analysis baseline. Thus, we estimate no costs or benefits associated with these reductions.

It is important to note also that this analysis does not attempt to estimate attainment or nonattainment for any areas of the country other than those counties currently served by one of the 349 monitors in the current network. Chapter 3 explains that the current network is focused on longer terms indicators that that included in this final rule.

Finally, we note that because it was not possible, in this analysis, to bring all areas into attainment with the alternative standards in all areas using only identified (or known) controls, EPA conducted a second step in the analysis, and estimated the cost of further tons of emission reductions needed to attain the alternative primary NAAQS. It is uncertain what controls States would put in place to attain a tighter standard, since additional abatement strategies are not currently recognized as being commercially available. We should also note that because of data and resource limitations, we are not able to adequately represent in this analysis the impacts of some local emission control programs such as discussed in Chapter 3.

[2] Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder. Signed on December 18, 2009. For more information on this final rule and its RIA, please refer to http://www.epa.gov/otaq/oceanvessels.htm.

4.1 Developing the Identified Control Strategy Analysis

The 2020 baseline air quality estimates revealed that 27 monitors in 24 counties had projected design values exceeding 75 ppb. We then developed a hypothetical control strategy that could be adopted to bring the current highest emitting monitor in each of those counties into attainment with a primary standard of 75 ppb, as well as additional target levels of 50 ppb and 100 ppb, by 2020. (For more information on the development of the air quality estimates for this analysis see Chapter 3.) Controls for three emissions sectors were included in the control analysis: Non-Electricity Generating Unit Point Sources (nonEGU), Non-Point Area Sources (Area), and Electricity Generating Unit Point Sources (EGU). Each of these sectors is defined below for clarity.

- NonEGU point sources as defined in the National Emissions Inventory (NEI) are stationary sources that emit 100 tons per year or more of at least one criteria pollutant. NonEGU point sources are found across a wide variety of industries, such as chemical manufacturing, cement manufacturing, petroleum refineries, and iron and steel mills.
- Area Sources[3] are stationary sources that are too numerous or whose emissions are too small to be individually included in a stationary source emissions inventory. Area sources are the activities where aggregated source emissions information is maintained for the entire source category instead of each point source, and are reported at the county level.
- Electricity Generating Unit Point Sources are stationary sources of 25 megawatts (MW) capacity or greater producing and selling electricity to the grid, such as fossil-fuel-fired boilers and combustion turbines.

It should be noted that no additional SO_2 controls beyond our baseline are applied to onroad and nonroad mobile sources because mobile source measures to reduce sulfur content from diesel engine rules will be well-applied in onroad and nonroad mobile source fleets by 2020, and thus there is little capability to achieve further reductions for this analysis beyond those described in this report.

We began the control strategy analysis by applying controls to EGUs first before applying controls to other sources. We applied controls in this sequence for the following reasons: 1) there are many more SO_2 emissions from EGUs than from non-EGU sources in the areas included in this analysis, and 2) SO_2 reductions from EGUs are less costly than from other

[3] Area Sources include the nonpoint emissions sector only.

source categories included in this analysis. Chapter 6 provides a table showing that the EGU control costs for SO_2 as estimated for this analysis have a lower annual cost/ton compared to those from the non-EGU point and area source categories.

The air quality impact of the needed emissions reductions was calculated using impact ratios as discussed further in Chapter 3. The results of analyzing the control strategy indicate that there were four areas projected not to attain 75 ppb in 2020 using all identified control measures. To complete the analysis, EPA then extrapolated the additional emission reductions required to reach attainment. The methodology used to develop those estimates and those calculations are presented in Section 4.4.

4.1.1 Controls Applied for EGU Sector

The baseline in this RIA for EGUs accounts for extensive reductions in SO_2 emissions from EGUs as implemented in the Clean Air Interstate Rule (CAIR).[4] While the US District Court for District of Columbia has remanded the CAIR, it still is in full effect. The Agency is working at this time on a proposal to replace the CAIR, but that proposal is not yet complete. No additional controls for SO_2 from EGUs are implemented in the baseline.

The Integrated Planning Model (IPM) was used to develop the baseline emissions for the control strategy applied for the alternative standards. Historically, EPA has used the IPM model to assess the cost and effectiveness of additional EGU controls for a large number of rulemakings (e.g., CAIR, NOx SIP call, Ozone NAAQS, etc.). For this RIA, we applied controls on a unit by unit basis to obtain reductions from units that contribute to nonattainment at violating monitors in 2020. The end result of this approach mimics an approach which could be used by individual states as they try to apply targeted controls on EGUs which affect attainment in a specific area.

In this analysis, EGU controls were applied to uncontrolled coal-fired units of size 25 MW and larger within the 50 km radius of violating monitors. Each unit was retrofitted with a Wet Flue Gas Desulfurization (FGD) scrubber with 95 percent SO_2 reduction efficiency. This control measure is applicable to coal-fired EGUs with unit capacities above 25 MW.[5] More

[4] For more information on the CAIR rule, please refer to http://www.epa.gov/airmarkt/progsregs/cair/.

[5] Costs of FGD scrubber applications increase progressively as EGU capacity approaches 25 MW. At an capital cost of more than $1000/kW, it is typically more economical to retire a unit than to operate it with a scrubber. It is possible to duct emissions from more than one EGU to a single scrubber, but that approach is not included in this analysis.

information on EGU SO_2 measures, particularly for EGUs with 100 MW or larger capacity, can be found in the documentation for the IPM version used for this RIA.[6]

4.1.2 Controls Applied for the NonEGU Point and Area Sectors

NonEGU point and Area control measures were identified using AirControlNET 4.2 as well as the Control Strategy Tool[7] (CoST). To reduce nonEGU point SO_2 emissions, least cost control measures were identified for emission sources within 50 km of the violating monitor (see Chapter 3 for rationale). Area source emissions data are generated at the county level, and therefore controls for this emission sector were applied to the county containing the violating monitor.

The SO_2 emission control measures used in this analysis are similar to those used in the $PM_{2.5}$ RIA prepared about three years ago. FGD scrubbers can achieve 95% control of SO_2 for non-EGU point sources and for utility boilers. Spray dryer absorbers (SDA) are another commonly employed technology, and SDA 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 4.2 control measures documentation report.[8]

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[6] Documentation on the version of IPM used for this RIA can be found at http://www.epa.gov/airmarkt/progsregs/epa-ipm/index.html.

[7] See http://www.epa.gov/ttn/ecas/cost.htm for a description of CoST.

[8] For a complete description of AirControlNET control technologies see AirControlNET 4.2 control measures documentation report, prepared by E.H. Pechan and Associates. May 2008. More information on AirControlNET (in this case, version 4.1) and the control technologies included in the tool are available at http://www.epa.gov/ttn/ecas/AirControlNET.htm.

Table 4-1: Example SO_2 Control Measures for Non-EGU Point Sources Applied in Identified Control Measures Control Strategy Analyses[a]

Control Measure	Sectors to which These Control Measures Can Be Applied	Control Efficiency (percent)	Average Annualized Cost/ton (2006$)
Wet and Dry FGD scrubbers and SDA	ICI boilers—all fuel types, kraft pulp mills, Mineral Products (e.g., Portland cement plants (all fuel types), primary metal plants, petroleum refineries	95—FGD scrubbers, 90 - for 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	95-98	\$1,000 – 4,000
Cesium promoted catalyst	Sulfuric Acid Plants with Double-Absorption process	50%	\$1,000

Sources: AirControlNET 4.2 control measures documentation report, May 2008, NESCAUM Report on Applicability of NOx, SO_2, and PM Control Measures to Industrial Boilers, November 2008 available at http://www.nescaum.org/documents/ici-boilers-20081118-final.pdf , and Comprehensive Industry Document on Sulphuric Acid Plant, Govt. of India Central Pollution Control Board, May 2007. The estimates for these control measures reflect applications of control where there is no SO_2 control measure currently operating except for the Cesium promoted catalyst.

In applying these SO_2 controls, we employ a decision rule in which we do not apply controls to any non-EGU source with 50 tons/year of emissions or less. This decision rule is the same one we employed for such sources in the $PM_{2.5}$ RIA completed four years ago.[9] The reason for applying this decision rule is based on a finding that most point sources with emissions of this level or less had SO_2 controls already on them. This decision rule aids in gap filling for a lack of information regarding existing controls on nonEGU sources. In addition, we also apply the decision rule that we do not apply SO_2 nonEGU point source controls that yield emission reductions of 50 tons/year or less. We apply this decision rule in order to reduce the number the sources affected our non-EGU control strategies to those sources whose reductions are relatively more cost-effective.

The analysis for non-EGUs mostly applied controls to the following source categories: industrial boilers, commercial and institutional boilers, sulfuric acid plants (both standalone and at other facilities such as copper and lead smelters), primary metal plants (iron and steel mills,

[9] $PM_{2.5}$ RIA, Chapter 3, p. 3-10. This RIA was completed in October, 2006 and is available at http://www.epa.gov/ttn/ecas/ria.html.

lead smelters), mineral products (primarily cement kilns) and petroleum refineries. These source categories are the most prevalent SO_2 emitters in the areas included in this analysis.

4.1.3 Data Quality for this Analysis

The estimates of emission reductions associated with our control strategies above are subject to important limitations and uncertainties. EPA's analysis is based on its best judgment for various input assumptions that are uncertain. As a general matter, the Agency selects the best available information from available engineering studies of air pollution controls and has set up what it believes is the most reasonable framework for analyzing the cost, emission changes, and other impacts of regulatory control.

4.2 SO_2 Emission Reductions Achieved with Identified Controls Analysis

We identified illustrative control strategies that might be employed to reduce emissions to bring air quality into compliance with the alternative standard being analyzed. As part of this exercise, we considered the cost-effectiveness of various control options and selected the lowest cost controls, based on available cost information. Applying identified control measures, we were able to illustrate attainment for most, but not all of the areas. [10]

Table 4.2 presents the emission reductions achieved through applying identical control measures, both by sector and in total. As this table reveals, a majority of the emission reductions were achieved through EGU emission controls. As indicated in this table, the estimate emission reductions from the identified controls applied in this analysis under the 75 ppb alternative standard in 2020 are 372,000 tons. About 260,000 tons of the reductions are from EGUs, and 112,000 are from non-EGU point sources. For the other alternative standards, the total emission reductions in 2020 are estimated to range from 186,000 tons for the 100 ppb standard to 803,000 tons for the 50 ppb standard. For all of these standards, this analysis shows that roughly 60 to 70 percent of these reductions are from EGUs. Most of the remaining reductions obtained come from non-EGU point sources. Reductions from area sources are generally a very small portion of those estimated except for the 50 ppb alternative standard, where 1.8 percent of reductions come from this sector.

Table 4.2: Emission Reductions from Identified Controls in 2020 in Total and by Sector (Tons) [a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb
Total Emission Reductions from Identified Controls:[b]	800,000	370,000	190,000
EGUs	540,000	260,000	110,000
Non-EGUs	250,000	110,000	79,000
Area Sources	15,000	200	100

[a]All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b]These values represent emission reductions for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

Table 4.3 presents the emission reductions by individual non-EGU point source category in 2020. As this table shows, the majority of reductions are from industrial boilers for all alternative standards except for 100 ppb. The percentage of non-EGU point source reductions from industrial boilers ranges from 50 (50 ppb) to 33 (100 ppb). Reductions from primary metal

[10] As will be discussed below, the application of identified controls was insufficient to bring all monitor areas into compliance with the alternative standards.

units provide most of the reductions at 100 ppb (59 percent) and this source category has the next highest percent of reductions for the other alternative standards (21 percent at 50 ppb, 43 percent at 75 ppb).

Table 4.3: Emission Reductions from Identified Controls By Non-EGU Point Source Category in 2020 in Total (Tons)[a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb
Total Non-EGU Emission Reductions from Identified Controls:[b]	246,000	112,000	79,000
Industrial Boilers	124,000	49,000	26,000
Sulfuric Acid Plants	3,000	2,000	1,000
Commercial/Institutional Boilers	20,000	4,000	4,000
Primary Metal Products	52,000	48,000	47,000
Petroleum Refineries	23,000	6,000	1,000
Mineral Products	22,000	5,000	600

[a]All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b]These values represent emission reductions for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

Table 4.4 presents the SO_2 emissions reductions realized in each geographic area under the control strategies applied for the final standard of 75 ppb and also for the other two alternative standards.

Table 4.4: Emission Reductions by County in 2020 for Each Alternative Standard Analyzed [a]

State	County	50 ppb	75 ppb	100 ppb
Arizona	Gila Co	9,000	9,000	9,000
Colorado	Denver Co	10,000	-	-
Connecticut	New Haven Co	8,000	-	-
Florida	Duval Co	5,100	-	-
Florida	Hillsborough Co	1,300	-	-
Georgia	Chatham Co	19,000	5,400	-
Idaho	Bannock Co	590	-	-
Illinois	Cook Co	39,000	-	-
Illinois	Madison Co	29,000	14,000	-
Illinois	St Clair Co	82,000	-	-
Illinois	Sangamon Co	22,000	11,000	-
Illinois	Tazewell Co	17,000	6,700	-
Indiana	Floyd Co	15,000	-	-
Indiana	Fountain Co	9,000	-	-
Indiana	Jasper Co	21,000	-	-
Indiana	Lake Co	65,000	20,000	-
Indiana	Morgan Co	3,300	-	-
Indiana	Porter Co	50,000	-	-

Indiana	Wayne Co	10,000	10,000	9,800
Iowa	Linn Co	9,200	4,700	-
Iowa	Muscatine Co	27,000	21,000	11,000
Kentucky	Jefferson Co	16,000	-	-
Kentucky	Livingston Co	4,900	-	-
Louisiana	East Baton Rouge Par	12,000	-	-
Missouri	Greene Co	3,000	-	-
Missouri	Jackson Co	25,000	13,000	-
Missouri	Jefferson Co	130,000	130,000	120,000
Montana	Yellowstone Co	6,100	-	-
Nebraska	Douglas Co	24,000	24,000	-
New Hampshire	Merrimack Co	2,700	-	-
New York	Erie Co	8,200	3,200	-
New York	Monroe Co	12,000	-	-
New York	Suffolk Co	11,000	4,400	-
North Carolina	New Hanover Co	6,200	-	-
Ohio	Clark Co	6,000	-	-
Ohio	Jefferson Co	12,000	-	-
Ohio	Lake Co	34,000	15,000	-
Ohio	Summit Co	22,000	15,000	3,100
Oklahoma	Kay Co	18,000	-	-
Oklahoma	Muskogee Co	52,000	35,000	17,000
Oklahoma	Tulsa Co	15,000	-	-
Pennsylvania	Allegheny Co	8,800	-	-
Pennsylvania	Blair Co	4,300	-	-
Pennsylvania	Northampton Co	21,000	12,000	-
Pennsylvania	Warren Co	6,100	6,100	6,100
South Carolina	Lexington Co	7,800	-	-
Tennessee	Blount Co	4,000	-	-
Tennessee	Bradley Co	11,000	1,200	-
Tennessee	Montgomery Co	1,000	1,000	1,000
Tennessee	Shelby Co	4,900	-	-
Tennessee	Sullivan Co	24,000	8,400	-
Texas	Harris Co	28,000	-	-
Texas	Jefferson Co	12,000	7,000	-
West Virginia	Hancock Co	25,000	-	-
Wisconsin	Brown Co	11,000	-	-
Wisconsin	Oneida Co	7,000	7,000	7,000

[a] All estimates rounded to two significant figures.

4.3 Impacts Using Identified Controls

As discussed in Chapter 3, we estimated the overall change in ambient air quality achieved as a result of each of the control strategies identified above using an impact ratio of emission reductions to air quality improvement. Table 4.5 presents a detailed breakdown of the estimated ambient SO_2 concentrations in 2020 at each of the counties that do not reach attainment under one or more of the alternative standards.

According to the data presented in Table 4.5, 20 of the 24 monitor areas are expected to reach attainment with a standard of 75 ppb following implementation of the identified control strategy. For four areas, identified controls are not sufficient to reach attainment with the standard of 75 ppb. For the areas projected to violate the NAAQS with the application of identified controls, we assume that emission reductions beyond identified controls will be applied, as discussed further below.

Table 4.5: 2020 SO_2 Design Values after Application of Identified Controls for Alternative Standards

State	County	50 ppb	75 ppb	100 ppb
Arizona	Gila Co	188.9	188.9	188.9
Colorado	Denver Co	50.3		
Connecticut	New Haven Co	46.9		
Florida	Duval Co	50.4		
Florida	Hillsborough Co	52.5		
Georgia	Chatham Co	34.4	72.1	
Idaho	Bannock Co	41.2		
Illinois	Cook Co	39.6		
Illinois	Madison Co	57.0	74.0	
Illinois	St Clair Co	20.1		
Illinois	Sangamon Co	35.9	67.5	
Illinois	Tazewell Co	47.9	73.5	
Indiana	Floyd Co	53.2		
Indiana	Fountain Co	46.3		
Indiana	Jasper Co	33.6		
Indiana	Lake Co	49.1	71.5	
Indiana	Morgan Co	47.8		
Indiana	Porter Co	37.4		
Indiana	Wayne Co	98.1	98.1	100.2
Iowa	Linn Co	50.8	71.7	
Iowa	Muscatine Co	50.0	68.3	96.9
Kentucky	Jefferson Co	54.6		
Kentucky	Livingston Co	50.2		
Louisiana	East Baton Rouge Par	48.6		
Missouri	Greene Co	44.5		
Missouri	Jackson Co	47.3	71.9	

Missouri	Jefferson Co	66.4	73.8	78.7
Montana	Yellowstone Co	45.8		
Nebraska	Douglas Co	47.2	47.2	
New Hampshire	Merrimack Co	42.6		
New York	Erie Co	51.5	66.4	
New York	Monroe Co	46.5		
New York	Suffolk Co	66.4	72.0	
North Carolina	New Hanover Co	44.7		
Ohio	Clark Co	50.7		
Ohio	Jefferson Co	46.0		
Ohio	Lake Co	37.3	70.4	
Ohio	Summit Co	59.2	74.6	97.6
Oklahoma	Kay Co	41.2		
Oklahoma	Muskogee Co	42.2	63.2	84.2
Oklahoma	Tulsa Co	28.3		
Pennsylvania	Allegheny Co	57.0		
Pennsylvania	Blair Co	50.1		
Pennsylvania	Northampton Co	49.8	70.4	
Pennsylvania	Warren Co	118.8	118.8	118.8
South Carolina	Lexington Co	39.2		
Tennessee	Blount Co	52.9		
Tennessee	Bradley Co	33.2	75.2	
Tennessee	Montgomery Co	139.5	139.5	139.5
Tennessee	Shelby Co	46.0		
Tennessee	Sullivan Co	45.2	73.3	
Texas	Harris Co	42.4		
Texas	Jefferson Co	49.6	69.3	
West Virginia	Hancock Co	42.7		
Wisconsin	Brown Co	47.2		
Wisconsin	Oneida Co	47.1	47.1	47.1

Table 4.6 Number of Areas Projected to be in Nonattainment for Each Alternative Standard After Application of Identified Controls in 2020[a]

	50 ppb	75 ppb	100 ppb
Number of Areas Needing Emission Reductions Beyond Identified Controls	16	4	3

[a] There are 56 areas included in this analysis.

4.4 Emission Reductions Needed Beyond Identified Controls

As shown through the identified control strategy analysis, there were not enough identified controls for every area in the analysis to achieve attainment with neither the 75 ppb final standard nor the other alternative standards in 2020. Therefore additional emission reductions will be needed for these areas to attain these alternative standards. Table 4.7 shows the emission reductions needed beyond identified controls for counties to attain the alternative standards being analyzed. The total emission reductions for full attainment of each alternative standard are also included in this table. Table 4.8 presents the emission reductions needed for each area beyond identified controls for each alternative standard. Chapter 6 presents the discussion of extrapolated costs associated with the emission reductions needed beyond identified controls.

Table 4.7: Total Emission Reductions and those from Extrapolated Controls in 2020 in Total and by Sector (Tons)[a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb
Total Emission Reductions from Identified and Unidentified Controls	920,000	350,000	170,000
Total Emission Reductions from Unidentified Controls	110,000	33,000	18,000
Unidentified Reductions from EGUs	33,000	5,000	-
Unidentified Reductions from non-EGUs	54,000	22,000	15,000
Unidentified Reductions from Area Sources	19,000	6,400	3,000

[a] All estimates rounded to two significant figures.

Table 4.8: Emission Reductions Needed Beyond Identified Controls in 2020

State	County	50 ppb	75 ppb	100 ppb
Arizona	Gila Co	13,000	11,000	8,300
Colorado	Denver Co	-	-	-
Connecticut	New Haven Co	-	-	-
Florida	Duval Co	-	-	-
Florida	Hillsborough Co	2,800	-	-
Georgia	Chatham Co	-	-	-
Idaho	Bannock Co	-	-	-
Illinois	Cook Co	-	-	-
Illinois	Madison Co	5,800	-	-
Illinois	St Clair Co	-	-	-
Illinois	Sangamon Co	-	-	-
Illinois	Tazewell Co	-	-	-
Indiana	Floyd Co	3,200	-	-
Indiana	Fountain Co	-	-	-
Indiana	Jasper Co	-	-	-
Indiana	Lake Co	-	-	-
Indiana	Morgan Co	-	-	-
Indiana	Porter Co	-	-	-
Indiana	Wayne Co	14,000	6,500	-
Iowa	Linn Co	84	-	-
Iowa	Muscatine Co	-	-	-
Kentucky	Jefferson Co	3,500	-	-
Kentucky	Livingston Co	-	-	-
Louisiana	East Baton Rouge Par	-	-	-

Missouri	Greene Co	-	-	-
Missouri	Jackson Co	-	-	-
Missouri	Jefferson Co	9,500	-	-
Montana	Yellowstone Co	-	-	-
Nebraska	Douglas Co	-	-	-
New Hampshire	Merrimack Co	-	-	-
New York	Erie Co	360	-	-
New York	Monroe Co	-	-	-
New York	Suffolk Co	19,000	-	-
North Carolina	New Hanover Co	-	-	-
Ohio	Clark Co	130	-	-
Ohio	Jefferson Co	-	-	-
Ohio	Lake Co	-	-	-
Ohio	Summit Co	4,400	-	-
Oklahoma	Kay Co	-	-	-
Oklahoma	Muskogee Co	-	-	-
Oklahoma	Tulsa Co	-	-	-
Pennsylvania	Allegheny Co	20,000	-	-
Pennsylvania	Blair Co	-	-	-
Pennsylvania	Northampton Co	-	-	-
Pennsylvania	Warren Co	4,300	2,700	1,100
South Carolina	Lexington Co	-	-	-
Tennessee	Blount Co	1,400	-	-
Tennessee	Bradley Co	-	-	-
Tennessee	Montgomery Co	19,000	13,000	8,200
Tennessee	Shelby Co	-	-	-
Tennessee	Sullivan Co	-	-	-
Texas	Harris Co	-	-	-
Texas	Jefferson Co	-	-	-
West Virginia	Hancock Co	-	-	-
Wisconsin	Brown Co	-	-	-
Wisconsin	Oneida Co	-	-	-

[a] All estimates rounded to two significant figures.

4.5 Key Limitations

The estimates of emission reductions associated with the control strategies described above are subject to important limitations and uncertainties. We summarize these limitations as follows:

- *Actual State Implementation Plans May Differ from our Simulation*: In order to reach attainment with the final NAAQS, each state will develop its own implementation plan implementing a combination of emissions controls that may differ from those simulated in this analysis. This analysis therefore represents an approximation of the emissions reductions that would be required to reach attainment and should not be treated as a precise estimate.

- *Use of Existing CMAQ Model Runs:* This analysis represents a screening level analysis. We did not conduct new regional scale modeling specifically targeting SO_2. More explanation on the screening level analysis done for this RIA can be found in Chapter 3.

- *Analysis Year of 2020:* Data limitations necessitated the choice of an analysis year of 2020, as opposed to the presumptive implementation year of 2017. Emission inventory projections are available for 5-year increments; i.e. we have inventories for 2015 and 2020, but not 2017. In addition, the CMAQ model runs upon which we relied were also based on an analysis year of 2020.

- *Unidentified controls*: We have limited information on available controls for some of the monitor areas included in this analysis. For a number of small non-EGU and area sources, there is little or no information available on SO_2 controls.

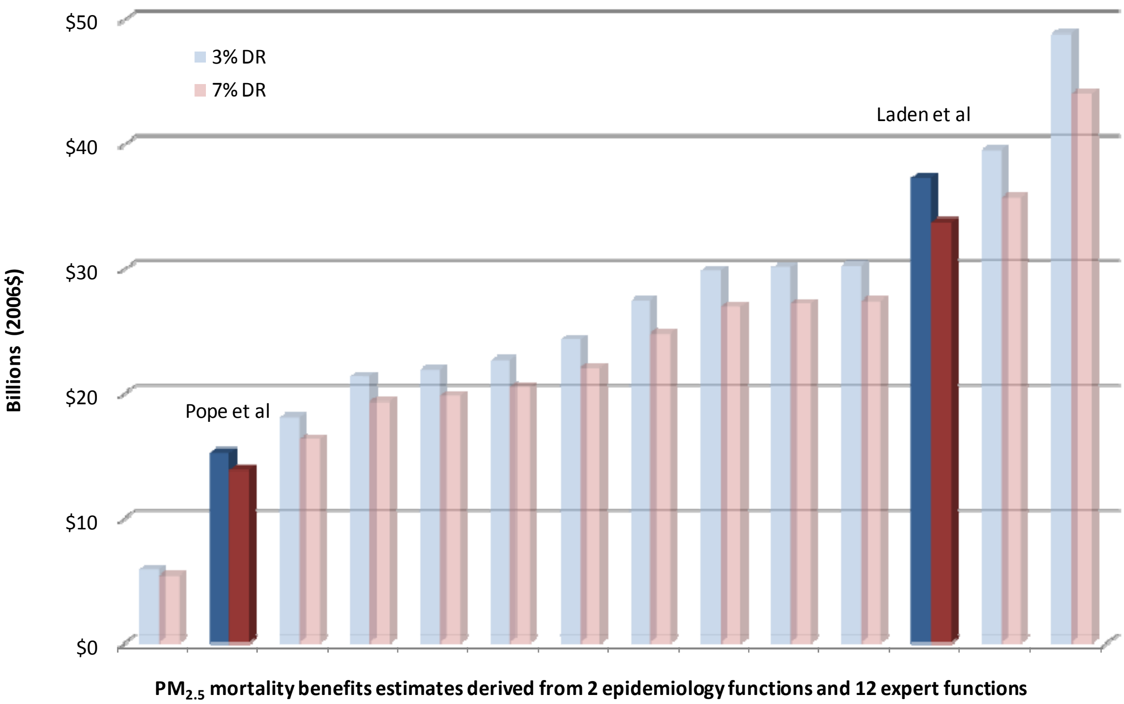
Chapter 5: Benefits Analysis Approach and Results

Synopsis

EPA estimated the monetized human health benefits of reducing cases of morbidity among populations exposed to SO_2 and cases of morbidity and premature mortality among populations exposed to $PM_{2.5}$ in 2020 for the selected standard and alternative standard levels in 2006$. Because SO_2 is also a precursor to $PM_{2.5,}$ reducing SO_2 emissions in the projected non-attainment areas will also reduce $PM_{2.5}$ formation, human exposure and the incidence of $PM_{2.5}$-related health effects. For the selected SO_2 standard at 75 ppb (99th percentile, daily 1-hour maximum), the total monetized benefits would be $15 to $37 billion at a 3% discount rate and $14 to $33 billion at a 7% discount rate. For an SO_2 standard at 50 ppb, the total monetized benefits would be $34 to $83 billion at a 3% discount rate and $31 to $75 billion at a 7% discount rate. For an SO_2 standard at 100 ppb, the total monetized benefits would be $7.4 to $18 billion at a 3% discount rate and $6.7 to $16 billion at a 7% discount rate.

These estimates reflect EPA's most current interpretation of the scientific literature and are consistent with the methodology used for the proposal RIA. These benefits are incremental to an air quality baseline that reflects attainment with the 2008 ozone and 2006 $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). More than 99% of the total dollar benefits are attributable to reductions in $PM_{2.5}$ exposure resulting from SO_2 emission controls. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided in Figure 5.1 for the selected standard of 75 ppb. Methodological limitations prevented EPA from quantifying the impacts to, or monetizing the benefits from several important benefit categories, including ecosystem effects from sulfur deposition, improvements in visibility, and materials damage. Other direct benefits from reduced SO_2 exposure have not been quantified, including reductions in premature mortality.

Figure 5.1: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Attaining 75 ppb in 2020*



*This graph shows the estimated total monetized benefits in 2020 for the selected standard of 75 ppb using the no-threshold model at discount rates of 3% and 7% using effect coefficients derived from the Pope et al. study and the Laden et al. study, as well as 12 effect coefficients derived from EPA's expert elicitation on PM mortality. The results shown are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response function provided in those studies. Graphs for alternative standards would show a similar pattern.

5.1 Introduction

This chapter documents our analysis of health benefits expected to result from achieving alternative levels of the SO_2 NAAQS in 2020, relative to baseline ambient concentrations that represent attainment with previously promulgated regulations, including the 2008 ozone and 2006 $PM_{2.5}$ NAAQS. We first describe our approach for estimating and monetizing the health benefits associated with reductions of SO_2. Next, we provide a summary of our results, including an analysis of the sensitivity of several assumptions in our model. We then estimate the $PM_{2.5}$ co-benefits from controlling SO_2 emissions. Finally, we discuss the key results of the benefits analysis and indicate limitations and areas of uncertainty in our approach.

5.2 Primary Benefits Approach

This section presents our approach for estimating avoided adverse health effects due to SO_2 exposure in humans resulting from achieving alternative levels of the SO_2 NAAQS, relative to a baseline concentration of ambient SO_2. First, we summarize the scientific evidence concerning potential health effects of SO_2 exposure, and then we present the health endpoints we selected for our primary benefits estimate. Next, we describe our benefits model, including the key input data and assumptions. Finally, we describe our approach for assigning an economic value to the SO_2 health benefits. The approach for estimating the benefits associated with exposure to PM is described in section 5.7.

We estimated the economic benefits from annual avoided health effects expected to result from achieving alternative levels of the SO_2 NAAQS (the "control scenarios") in the year 2020. We estimated benefits in the control scenarios relative to the incidence of health effects consistent with the ambient SO_2 concentration expected in 2020 (the "baseline"). Note that this "baseline" reflects emissions reductions and ambient air quality improvements that we anticipate will result from implementation of other air quality rules, including compliance with previously promulgated regulations, including the 2008 ozone and 2006 $PM_{2.5}$ NAAQS.[1]

We compare benefits across three alternative SO_2 NAAQS levels: 50 ppb, 75 ppb, and 100 ppb (99th percentile). Consistent with EPA's approach for RIA benefits assessments, we estimate the health effects associated with an incremental difference in ambient concentrations between a baseline scenario and a pollution control strategy. As indicated in Chapter 4, several areas of the country may not be able to attain the alternative standard levels using known pollution control methods. For this reason, we provide an estimate of the benefits associated with partially attaining the standard using known controls as well as the full attainment results in Table 5.13 of this chapter. Because some areas require emission reductions from unknown sources to attain the various standards, the results are sensitive to assuming full attainment. All of the other results tables in this chapter assume full attainment with the various standard levels. The full attainment results include extrapolated tons from unknown controls, which were spread across the sectors in proportion to the emissions in the county.[2]

5.3 Overview of analytical framework for benefits analysis

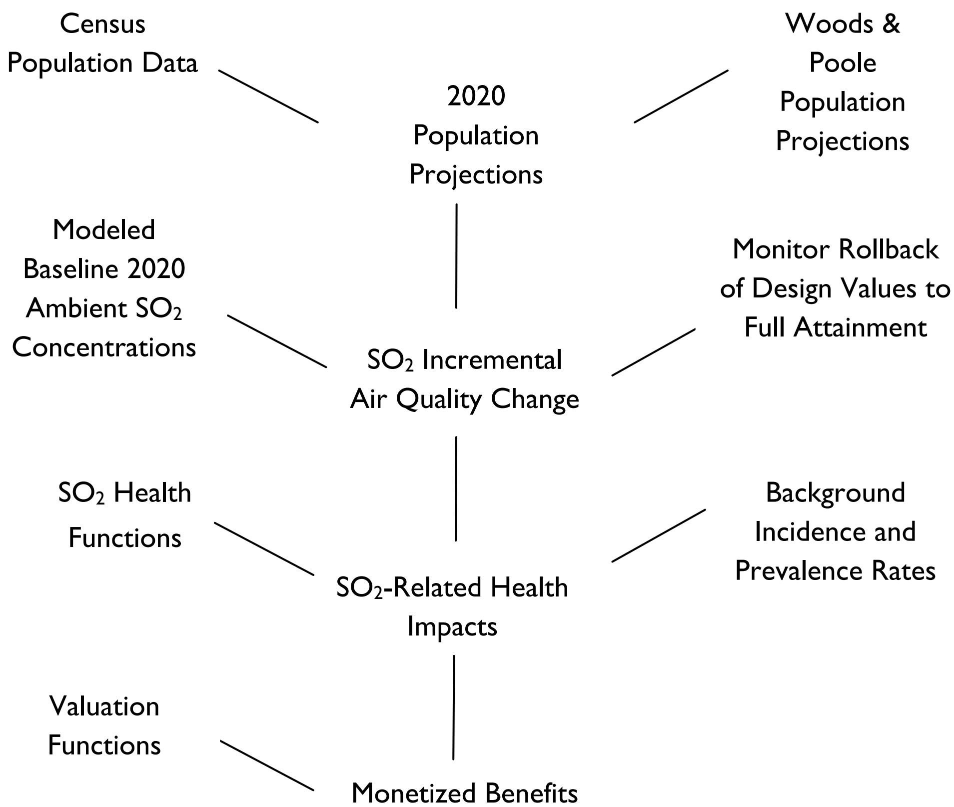
5.3.1 Benefits Model

For the SO_2 benefits analysis, we use the Environmental Benefits Mapping and Analysis Program (BenMAP, version 3) (Abt Associates, 2008) to estimate the health benefits occurring as a result of implementing alternative SO_2 NAAQS levels. Although EPA has used BenMAP

[1] See Chapter 2 of this RIA for more information on the rules incorporated into the baseline.
[2] See Chapter 4 of this RIA for more information on the extrapolated tons estimated to reach full attainment.

extensively to estimate the health benefits of reducing exposure to $PM_{2.5}$ and ozone in previous RIAs, the proposal RIA was the first RIA in which EPA used BenMAP to estimate the health benefits directly attributable to reducing exposure to SO_2 to support a change in the NAAQS. Figure 5.2 below shows the major components of, and data inputs to, the BenMAP model.

Figure 5.2: Diagram of Inputs to BenMAP model for SO_2 Analysis



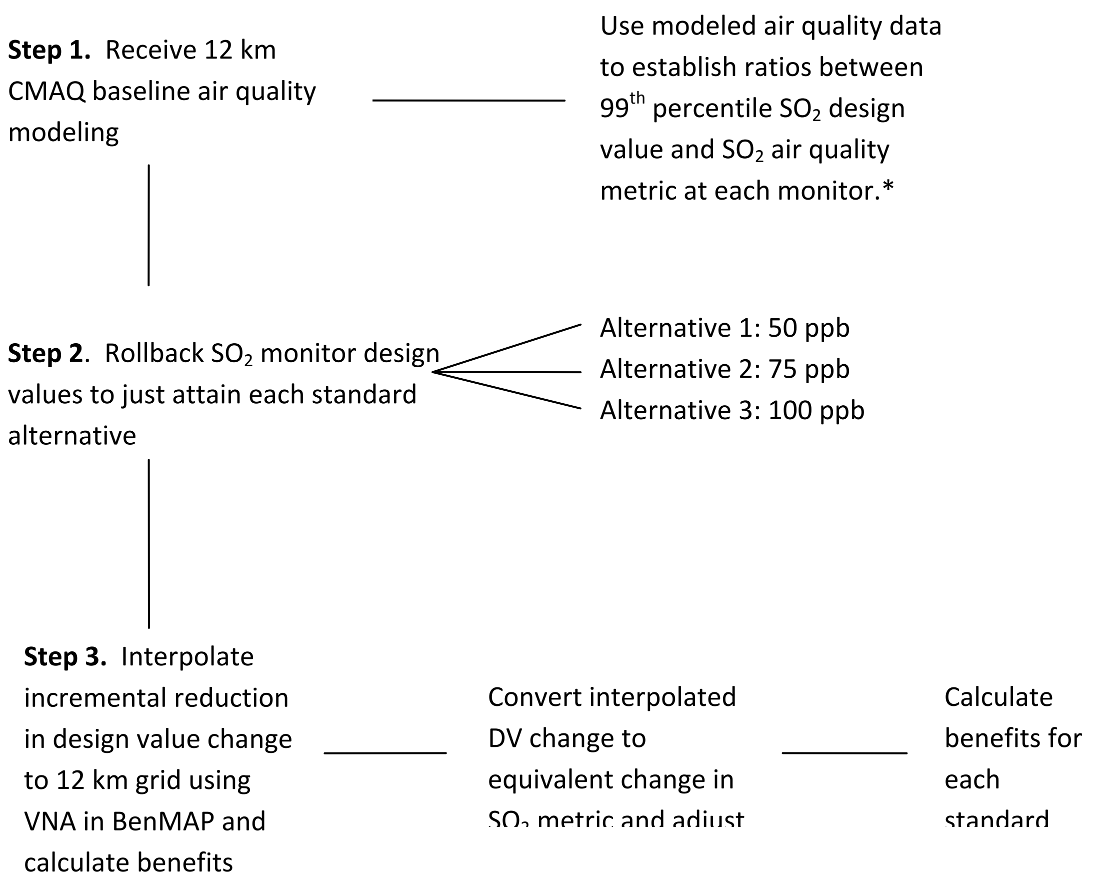
5.3.2 Air Quality Estimates

As Figure 5.2 shows, the primary input to any benefits assessment is the estimated changes in ambient air quality expected to result from a simulated control strategy or attainment of a particular standard. EPA typically relies upon air quality modeling to generate these data, but time and technical limitations described in Chapter 3 prevented us from generating new air quality modeling to simulate the changes in ambient SO_2 resulting from each control strategy. Instead, we utilize the ambient SO_2 concentrations modeled by CMAQ as part of the upcoming PM NAAQS RIA as our baseline.[3]

[3] See Chapter 3 for more detail regarding the air quality data used in this analysis.

The CMAQ air quality model provides projects both design values at SO_2 monitors and air quality concentrations at 12 km by 12 km grid cells nationwide. To estimate the benefits of fully attaining the standards in all areas, EPA employed the "monitor rollback" approach to approximate the air quality change resulting from just attaining alternative SO_2 NAAQS at each design value monitor. Figure 5.3 depicts the rollback process, which differs from the technique described in Chapter 3. The emission control strategy estimated the level of emission reductions necessary to attain each alternate NAAQS standard, whereas the approach described here aims to estimate the change in population exposure associated with attaining an alternate NAAQS. This approach relies on data from the existing SO_2 monitoring network and the inverse distance squared variant of the Veronoi Neighborhood Averaging (VNA) interpolation method to adjust the CMAQ-modeled SO_2 concentrations such that each area just attains the standard alternatives. We believe that the interpolation method using inverse distance squared most appropriately reflects the exposure gradient for SO_2 around each monitor (EPA, 2008c). A sensitivity analysis in Table 5.6 shows that the results are not particularly sensitive to the interpolation method.

Figure 5.3: Diagram of Rollback Method



*Metrics used in the epidemiology studies include the 24-hr mean, 3-hr mean, 8-hr max, and 1-hr max.

Because the VNA rollback approach interpolates monitor values, it is most reliable in areas with a denser monitoring network. In areas with a sparser monitoring network, there is less observed monitoring data to support the VNA interpolation and we have less confidence in the predicted air quality values further away from the monitors. For this reason, we interpolated air quality values—and estimated health impacts—within the CMAQ grid cells that are located within 50 km of the monitor, assuming that emission changes within this radius would affect the SO_2 concentration at each monitor. Limiting the interpolation to this radius attempts to account for the limitations of the VNA approach, the air quality data limitations identified in Chapter 3 and ensures that the benefits and costs analyses consider a consistent geographic area.[4] Therefore, the primary benefits analysis assesses health impacts occurring to populations living in the CMAQ grid cells located within the 50 km buffer for the specific geographic areas assumed to not attain the alternate standard levels. We test the sensitivity of this assumption relative to other exposure buffers in Table 5.6.

5.4 Estimating Avoided Health Effects from SO_2 Exposure

Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the U.S. EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2 (U.S. EPA, 2008c). The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. This response is mediated by chemosensitive receptors in the tracheobronchial tree, which trigger reflexes at the central nervous system level resulting in bronchoconstriction, mucus secretion, mucosal vasodilation, cough, and apnea followed by rapid shallow breathing. In some cases, local nervous system reflexes also may be involved. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. This inflammation may lead to enhanced release of mediators, alterations in the autonomic nervous system and/or sensitization of the chemosensitive receptors. These biological processes are likely to underlie the bronchoconstriction and decreased lung function observed in response to SO_2 exposure. A clear concentration-response relationship has been demonstrated in laboratory studies following exposures to SO_2 at concentrations between 20 and 100 ppb, both in terms of increasing severity of effect and percentage of asthmatics adversely affected.

5.4.1 Selection of Health Endpoints for SO_2

Epidemiological researchers have associated SO_2 exposure with adverse health effects in numerous toxicological, clinical and epidemiological studies, as described in the Integrated

[4] Please see Chapter 3 for more information regarding the technical basis for the 50 km assumption.

Science Assessment for Oxides of Sulfur - Health Criteria (Final Report) (U.S. EPA, 2008c); hereafter, "SO_2 ISA"). The SO_2 ISA provides a comprehensive review of the current evidence of health and environmental effects of SO_2.

Previous reviews of the SO_2 primary NAAQS, most recently in 1996, did not include a quantitative benefits assessment for SO_2 exposure. As the first health benefits assessment for SO_2 exposure, we build on the methodology and lessons learned from the SO_2 risk and exposure assessment (U.S. EPA, 2009c) and the benefits assessments for the recent $PM_{2.5}$, O_3, and NO_2 NAAQS (U.S. EPA, 2006a; U.S. EPA, 2008a; U.S. EPA, 2010a; U.S. EPA, 2010b).

We quantified SO_2-related health endpoints for which the SO_2 ISA provides the strongest evidence of an effect. 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)). The differing evidence and associated strength of the evidence for these different effects is described in detail in the SO_2 ISA.

Although a number of adverse health effects have been found to be associated with SO_2 exposure, this benefits analysis only includes a subset due to limitations in understanding and quantifying the dose-response relationship for some of these health endpoints. In this analysis, we only estimated the benefits for those endpoints with sufficient evidence to support a quantified concentration-response relationship using the information presented in the SO_2 ISA, which contains an extensive literature review for several health endpoints related to SO_2 exposure. Because the ISA only included studies published or accepted for publication through April 2008, we also performed supplemental literature searches in the online search engine PubMed® to identify relevant studies published between January 2008, and the present.[5] Based on our review of this information, we quantified four short-term respiratory morbidity endpoints that the SO_2 ISA identified as a "causal relationship": acute respiratory symptoms, asthma exacerbation, respiratory-related emergency department visits, and respiratory-related hospitalizations.

Table 5.1 presents the health effects related to SO_2 exposure quantified in this benefits analysis. In addition, the table includes other endpoints potentially linked to SO_2 exposure, but which we are not yet ready to quantify with dose-response functions. For a list of the health

[5] The O'Connor et al. study (2008) is the only study included in this analysis that was published after the cut-off date for inclusion in the SO2 ISA.

effects related to $PM_{2.5}$ exposure that we quantify in this analysis, please see Table 5.6 in section 5.7.

The SO_2 ISA concluded that the relationship between short-term SO_2 exposure and premature mortality was "suggestive of a causal relationship" because it is difficult to attribute the mortality risk effects to SO_2 alone. Therefore, we decided not to quantify premature mortality from SO_2 exposure in this analysis despite evidence suggesting a positive association (U.S. EPA, 2008c). Although the SO_2 ISA stated that studies are generally consistent in reporting a relationship between SO_2 exposure and mortality, there was a lack of robustness of the observed associations to adjustment for co-pollutants. As the literature continues to evolve, we may revisit this decision in future benefits assessment for SO_2.

As noted in Table 5.1, we are not able to quantify several welfare benefit categories in this analysis because we are limited by the available data or resources. Although we cannot quantify the ecosystem benefits of reducing sulfur deposition or visibility improvements in this analysis, we provide a qualitative analysis in section 5.9.

Table 5.1: Human Health and Welfare Effects of SO_2

Pollutant / Effect	Quantified and Monetized in Primary Estimates [a]	Unquantified Effects [b, c] Changes in:
SO_2 /Health	Respiratory Hospital Admissions	Premature mortality
	Asthma ER visits	Pulmonary function
	Asthma exacerbation	Other respiratory emergency department visits
	Acute Respiratory symptoms	Other respiratory hospital admissions
SO_2 /Welfare		Visibility improvements
		Commercial fishing and forestry from acidic deposition
		Recreation in terrestrial and aquatic ecosystems from acid deposition
		Increased mercury methylation

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the alternative standards.
[b] The categorization of unquantified toxic health and welfare effects is not exhaustive.
[c] Health endpoints in the unquantified benefits column include both a) those for which there is not consensus on causality and those for which causality has been determined but empirical data are not available to allow calculation of benefits.

5.4.2 Selection of Concentration-Response Functions

After identifying the health endpoints to quantify in this analysis, we then selected concentration-response functions drawn from the epidemiological literature identified in the SO_2 ISA. We considered several factors, in the order below, in selecting the appropriate epidemiological studies and concentration-response functions for this benefits assessment.

1. We considered ambient SO_2 studies that were identified as key studies in the SO_2 ISA (or a more recent study), excluding those affected by the general additive model (GAM) S-Plus issue.[6]
2. We judged that studies conducted in the United States are preferable to those conducted outside the United States, given the potential for effect estimates to be affected by factors such as the ambient pollutant mix, the placement of monitors, activity patterns of the population, and characteristics of the healthcare system especially for hospital admissions and emergency department visits. We include Canadian studies in sensitivity analyses, when available.
3. We only incorporated concentration-response functions for which there was a corresponding valuation function. Currently, we only have a valuation function for asthma-related emergency department visits, but we do not have a valuation function for all-respiratory-related emergency department visits.
4. We preferred concentration-response functions that correspond to the age ranges most relevant to the specific health endpoint, with non-overlapping ICD-9 codes. We preferred completeness when selecting functions that correspond to particular age ranges and ICD codes. Age ranges and ICD codes associated with the selected functions are identified in Table 5.2.
5. We preferred multi-city studies or combined multiple single city studies, when available.
6. When available, we judged that effect estimates with distributed or cumulative lag structures were most appropriate for this analysis.
7. When available, we selected SO_2 concentration-response functions based on multi-pollutant models. Studies with multi-pollutant models are identified in Table 5.2.

These criteria reflect our preferences for study selection, and it was possible to satisfy many of these, but not all. There are trade-offs inherent in selecting among a range of studies, as not all studies met all criteria outlined above. At minimum, we ensured that none of the studies were GAM affected, we selected only U.S. based studies, and we quantified health endpoints for which there was a corresponding valuation function.

We believe that U.S.-based studies are most appropriate studies to use in this analysis to estimate the number of hospital admissions associated with SO_2 exposure because of the

[6] The S-Plus statistical software is widely used for nonlinear regression analysis in time-series research of health effects. However, in 2002, a problem was discovered with the software's default conversion criteria in the general additive model (GAM), which resulted in biased relative risk estimates in many studies. This analysis does not include any studies that encountered this problem. For more information on this issue, please see U.S. EPA (2002).

characteristics of the ambient air, population, and healthcare system. Using only U.S.-based studies, we are limited to one epidemiology study for hospital admissions (Schwartz, 1996). However, there are several Canada-based epidemiology studies that also estimate respiratory hospital admissions (Fung, 2006; Luginaah, 2005; Yang, 2003). Table 5.12 provides the sensitivity of the SO_2 benefits using the effect estimates from the Canadian studies. Compared to the U.S. based study, the Canadian studies produce a substantially larger estimate of hospital admissions associated with SO_2 exposure.

When selecting concentration-response functions to use in this analysis, we reviewed the scientific evidence regarding the presence of thresholds in the concentration-response functions for SO_2 -related health effects to determine whether the function is approximately linear across the relevant concentration range. The SO_2 ISA concluded that, "The overall limited evidence from epidemiologic studies examining the concentration-response function of SO_2 health effects is inconclusive regarding the presence of an effect threshold at current ambient levels." For this reason, we have not incorporated thresholds in the concentration-response functions for SO_2 -related health effects in this analysis.

Table 5.2 shows the studies and health endpoints that we selected for this analysis. Table 5.3 shows the baseline health data used in combination with these health functions. Following these tables is a description of each of the epidemiology studies used in this analysis.

Table 5.2: SO_2 -Related Health Endpoints Quantified, Studies Used to Develop Health Impact Functions and Sub-Populations to which They Apply

Endpoint	Study	Study Population
Hospital Admissions		
All respiratory	Schwartz et al., 1996 – ICD-9 460-519	65 - 99
Emergency Department Visits		
Asthma	Pooled Estimate: Ito et al. (2007)—ICD-9 493 Michaud (2004) – ICD-9 493 NYDOH (2006)[b]—ICD-9 493 Peel et al. (2005)—ICD-9 493 Wilson (2005) – ICD-9 493	All ages
Other Health Endpoints		
Asthma exacerbations	Pooled estimate: Mortimer et al. (2002) (one or more symptoms)[a] O'Connor et al. (2008) (slow play, missed school days[c], nighttime asthma)[a, b] Schildcrout et al. (2006) (one or more symptoms)[a]	4 - 12
Acute Respiratory Symptoms	Schwartz et al. (1994)[b]	7 - 14

[a] The original study populations were 4 to 9 for the Mortimer et al. (2002) study and 5 to 12 for the O'Connor et al. (2008) study and the Schildcrout et al. (2006) study. We extended the applied population to facilitate the pooling process, recognizing the common biological basis for the effect in children in the broader age group. See: National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press, pg 117.

[b] Study specifies a multipollutant model.

[c] The form of this one function was not clear from the study. For this analysis, we assumed that it was log-linear, but we have subsequently determined that it is logistic. This adds a small amount to uncertainty regarding the asthmas incidence estimates, but this uncertainty is obscured by the rounding of the monetized estimates.

Table 5.3: National Average Baseline Incidence Rates used to Calculate SO_2 -Related Health Impacts [a]

Endpoint	Source	Notes	Rate per 100 people per year by Age Group						
			<18	18–24	25–34	35–44	45–54	55–64	65+
Respiratory Hospital Admissions	1999 NHDS public use data files [b]	incidence	0.043	0.084	0.206	0.678	1.926	4.389	11.629
Asthma ER visits	2000 NHAMCS public use data files [c]; 1999 NHDS public use data files [b]	incidence	1.011	1.087	0.751	0.438	0.352	0.425	0.232
Minor Restricted Activity Days (MRADs)	Schwartz (1994, table 2)	incidence	0.416	—	—	—	—	—	—
Asthma Exacerbations	Mortimer et al. (2002)	Incidence (and prevalence) among asthmatic children	Any morning symptom				0.116 (0.0567) [d]		
	O'Connor et al. (2008)	Incidence (and prevalence) among asthmatic children	Missed school One or more symptoms Slow play Nighttime asthma				0.057 (0.0567) [d] 0.207 (0.0567) [d] 0.157 (0.0567) [d] 0.121 (0.0567) [d]		
	Schildcrout et al. (2006)	Incidence (and prevalence) among asthmatic children	One or more symptoms				0.52 (0.0567) [d]		

[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] We assume that this prevalence rate for ages 5 to 9 is also applicable down to age 4.

Schwartz et al. (1996)

Schwartz et al. (1996) is a review paper with an example drawn from hospital admissions of the elderly in Cleveland, Ohio from 1988-1990. The authors argued that the central issue is control for seasonality. They illustrated the use of categorical variables for weather and sinusoidal terms for filtering season in the Cleveland example. After controlling for season, weather, and day of the week effects, hospital admissions of persons aged 65 and older in Cleveland for respiratory illness was associated with ozone (RR = 1.09, 95% CI 1.02, 1.16) and PM_{10} (RR = 1.12, 95% CI 1.01, 1.24), and marginally associated with SO_2 (RR = 1.03, 95% CI = 0.99, 1.06). All of the relative risks are for a 100 micrograms/m^3 increase in the pollutant.

Fung et al. (2006) – Sensitivity Analysis

Fung et al. (2006) assessed the impact of ambient gaseous pollutants (SO_2, NO_2, CO, and O_3) and particulate matters (PM_{10}, $PM_{2.5}$, and $PM_{10-2.5}$) as well as the coefficient of haze (COH) on recurrent respiratory hospital admissions (ICD-9 codes 460-519) among the elderly in Vancouver, Canada, for the period of June 1, 1995, to March 31, 1999, using a new method proposed by Dewanji and Moolgavkar (2000; 2002). The authors found significant associations between respiratory hospital admissions and 3-day, 5-day, and 7-day moving averages of the ambient SO_2 concentrations, with the strongest association observed at the 7-day lag (RR = 1.044, 95% CI: 1.018-1.070). The authors also found $PM_{10-2.5}$ for 3-day and 5-day lag to be significant, with the strongest association at 5-day lag (RR = 1.020, 95% CI: 1.001-1.039). No significant associations with admission were found with current day exposure.

Luginaah et al. (2005) – Sensitivity analysis

Luginaah et al. (2005) assessed the association between air pollution and daily respiratory hospitalization (ICD-9 codes 460-519) for different age and sex groups from 1995 to 2000. The pollutants included were NO_2, SO_2, CO, O_3, PM_{10}, coefficient of haze (COH), and total reduced sulfur (TRS). The authors estimated relative risks (RR) using both time-series and case-crossover methods after controlling for appropriate confounders (temperature, humidity, and change in barometric pressure). The results of both analyses were consistent. They found associations between NO_2, SO_2, CO, COH, or PM_{10} and daily hospital admission of respiratory diseases especially among females. For females 0-14 years of age, there was 1-day delayed effect of NO_2 (RR = 1.19, case-crossover method), a current-day SO_2 (RR = 1.11, time series), and current-day and 1- and 2-day delayed effects for CO by case crossover (RR = 1.15, 1.19, 1.22, respectively). Time-series analysis showed that 1-day delayed effect of PM_{10} on respiratory admissions of adult males (15-64 years of age), with an RR of 1.18. COH had significant effects on female respiratory hospitalization, especially for 2-day delayed effects on adult females, with RRs of 1.15 and 1.29 using time-series and case-crossover analysis, respectively. There were no significant associations between O_3 and TRS with respiratory admissions.

Yang et al. (2003) – Sensitivity analysis

Yang et al. (2003) examined the impact of ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and coefficient of haze on daily respiratory admissions (ICD-9 codes 460-519) in both young children (<3 years of age) and the elderly (65-99 years of age) in greater

Vancouver, British Columbia during the 13-yr period 1986-1998. Bidirectional case-crossover analysis was used to investigate associations and odds ratios were reported for single-pollutant, two-pollutant and multiple-pollutant models. Sulfur dioxide was found marginally significant in all models for elderly.

Ito et al. (2007)

Ito et al. (2007) assessed associations between air pollution and asthma emergency department visits in New York City for all ages. Specifically they examined the temporal relationships among air pollution and weather variables in the context of air pollution health effects models. The authors compiled daily data for $PM_{2.5}$, O_3, NO_2, SO_2, CO, temperature, dew point, relative humidity, wind speed, and barometric pressure for New York City for the years 1999-2002.The authors evaluated the relationship between the various pollutants' risk estimates and their respective concurvities, and discuss the limitations that the results imply about the interpretability of multi-pollutant health effects models.

Michaud et al. (2004)

Michaud et al. (2004) examined the association of emergency department (ED) visits in Hilo, Hawai'i, from January 1997 to May 2001 with volcanic fog, or "vog", measured as sulfur dioxide (SO_2) and submicrometer particulate matter (PM_1). Log-linear regression models were used with robust standard errors. The authors studied four diagnostic groups: asthma/COPD; cardiac; flu, cold, and pneumonia; and gastroenteritis. Before adjustments, highly significant associations with vog-related air quality were seen for all diagnostic groups except gastroenteritis. After adjusting for month, year, and day of the week, only asthma/COPD had consistently positive associations with air quality. They found that the strongest associations were for SO_2 with a 3-day lag (6.8% per 10 ppb; P=0.001) and PM_1, with a 1-day lag (13.8% per 10 $\mu g/m^3$; P=0.011).

NYDOH (2006)

New York State Department of Health (NYDOH) investigated whether day-to-day variations in air pollution were associated with asthma emergency department (ED) visits in Manhattan and Bronx, NYC and compared the magnitude of the air pollution effect between the two communities. NYDOH (2006) used Poisson regression to test for effects of 14 key air contaminants on daily ED visits, with control for temporal cycles, temperature, and day-of-week effects. The core analysis utilized the average exposure for the 0- to 4-day lags. Mean daily SO_2 was found significantly associated with asthma ED visits in Bronx but not Manhattan. Their findings of more significant air pollution effects in the Bronx are likely to relate in part to greater statistical power for identifying effects in the Bronx where baseline ED visits were greater, but they may also reflect greater sensitivity to air pollution effects in the Bronx.

Peel et al. (2005)

Peel et al. (2005) examined the associations between air pollution and respiratory emergency department visits (i.e., asthma (ICD-9 code 493, 786.09), COPD (491,492,496), URI (460-466, 477), pneumonia (480-486), and an all respiratory-disease group) in Atlanta, GA from 1 January 1993 to 31 August 2000. They used 3-Day Moving Average (Lags of 0, 1, and 2 Days) and unconstrained distributed lag (Lags of 0 to 13 Days) in the Poisson regression analyses. In single-pollutant models, positive associations persisted beyond 3 days for several outcomes, and over a week for asthma. The effects of NO_2, CO or PM_{10} on asthma ED visits were found significant but SO_2 or O_3 were not significantly associated with asthma ED visits.

Wilson et al. (2005)

Daily emergency room (ER) visits for all respiratory (ICD-9 codes 460-519) and asthma (ICD-9 code 493) were compared with daily SO_2, O_3, and weather variables over the period 1998-2000 in Portland, Maine and 1996-2000 in Manchester, New Hampshire. Seasonal variability was removed from all variables using nonparametric smoothed function (LOESS). Wilson et al.(2005) used generalized additive models to estimate the effect of elevated levels of pollutants on ER visits. Relative risks of pollutants were reported over their inter-quartile range (IQR, the 75^{th} -25^{th} percentile pollutant values). In Portland, an IQR increase in SO_2 was associated with a 5% (95% CI 2-7%) increase in all respiratory ER visits and a 6% (95% CI 1-12%) increase in asthma visits. An IQR increase in O_3 was associated with a 5% (95% CI 1-10%) increase in Portland asthmatic ER visits. No significant associations were found in Manchester, New Hampshire, possibly due to statistical limitations of analyzing a smaller population. The absence of statistical evidence for a relationship should not be used as evidence of no relationship. This analysis reveals that, on a daily basis, elevated SO_2 and O_3 have a significant impact on public health in Portland, Maine.

Villeneuve et al. (2007) – Sensitivity Analysis

Villeneuve et al. (2007) examined the associations between air pollution and emergency department (ED) visits for asthma among individuals two years of age and older in the census metropolitan area of Edmonton, Canada between April 1, 1992 and March 31, 2002 using a time stratified case-crossover design. Daily air pollution levels for the entire region were estimated from three fixed-site monitoring stations. Odds ratios and their corresponding 95% confidence intervals were estimated using conditional logistic regression with adjustment for temperature, relative humidity and seasonal epidemic of viral related respiratory disease. Villeneuve et al.(2007) found positive associations for asthma ED visits with outdoor air pollution levels between April and September, but such associations were absent during the remainder of the year. Effects were strongest among young children (2-4 years of age) and elderly (>75 years of age). Air pollution risk estimates were largely unchanged after adjustment for aeroallergen levels. This study is not included in the SO_2 ISA only because it was published after the cut-off date, but it met all of the other criteria for inclusion in this analysis.

Mortimer et al. (2002)

Mortimer et al. (2002) examined the effect of daily ambient air pollution within a cohort of 846 asthmatic children residing in eight urban areas of the USA between June 1 to August 31, 1993, using data from the National Cooperative Inner-City Asthma Study. Daily air pollution concentrations were extracted from the Aerometric Information Retrieval System database from the Environment Protection Agency in the USA. Logistic models were used to evaluate the effects of several air pollutants (O_3, NO_2, SO_2 and PM_{10}) on peak expiratory flow rate (PEFR) and symptoms in 846 children (ages 4-9 yrs) with a history of asthma. In single pollutant models, each pollutant was associated with an increased incidence of morning symptoms: (odds ratio (OR) = 1.16 (95% CI 1.02-1.30) per IQR increase in 4-day average O_3, OR = 1.32 (95% CI 1.03-1.70) per IQR increase in 2-day average SO_2, OR = 1.48 (95% CI 1.02-2.16) per IQR increase in 6-day average NO_2 and OR = 1.26 (95% CI 1.0-1.59) per IQR increase in 2-day average PM_{10}. This longitudinal analysis supports previous time-series findings that at levels below current USA air-quality standards, summer-air pollution is significantly related to symptoms and decreased pulmonary function among children with asthma.

O'Connor et al. (2008)

O'Connor et al. (2008) investigated the association between fluctuations in outdoor air pollution and asthma exacerbation (wheeze-cough, nighttime asthma, slow play and school absence) among 861 inner-city children (5-12 years of age) with asthma in seven US urban communities. Asthma symptom data were collected every 2 months during the 2-year study period. Daily pollution measurements were obtained from the Aerometric Information Retrieval System between August 1998 and July 2001. The relationship of symptoms to fluctuations in pollutant concentrations was examined by using logistic models. In single-pollutant models, significant or nearly significant positive associations were observed between higher NO_2 concentrations and each of the health outcomes. The O_3, $PM_{2.5}$, and SO_2

concentrations did not appear significantly associated with symptoms or school absence except for a significant association between $PM_{2.5}$ and school absence. This study is not included in the SO_2 ISA only because it was published after the cut-off date, but it met all of the other criteria for inclusion in this analysis.

Schildcrout et al. (2006)

Schildcrout et al. (2006) investigated the relation between ambient concentrations of the five criteria pollutants (PM_{10}, O_3, NO_2, SO_2, and CO) and asthma exacerbations (daily symptoms and use of rescue inhalers) among 990 children in eight North American cities during the 22-month prerandomization phase (November 1993-September 1995) of the Childhood Asthma Management Program. Short-term effects of CO, NO_2, PM_{10}, SO_2, and warm-season O_3 were examined in both one-pollutant and two-pollutant models, using lags of up to 2 days in logistic and Poisson regressions. Lags in CO and NO_2 were positively associated with both measures of asthma exacerbation, and the 3-day moving sum of SO_2 levels was marginally related to asthma symptoms. PM_{10} and O_3 were unrelated to exacerbations. The strongest effects tended to be seen with 2-day lags, where a 1-parts-per-million change in CO and a 20-parts-per-billion change in NO_2 were associated with symptom odds ratios of 1.08 (95% confidence interval (CI): 1.02, 1.15) and 1.09 (95% CI: 1.03, 1.15), respectively.

Schwartz et al. (1994)

Schwartz et al. (1994) studied the association between ambient air pollution exposures and respiratory illness among 1,844 school children (7-14 years of age) in six U.S. cities during five warm season months between April and August. Daily measurements of ambient sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), inhalable particles (PM_{10}), respirable particles ($PM_{2.5}$), light scattering, and sulfate particles were made, along with integrated 24-h measures of aerosol strong acidity. Significant associations in single pollutant models were found between SO_2, NO_2, or $PM_{2.5}$ and incidence of cough, and between sulfur dioxide and incidence of lower respiratory symptoms. Significant associations were also found between incidence of coughing symptoms and incidence of lower respiratory symptoms and PM_{10}, and a marginally significant association between upper respiratory symptoms and PM_{10}.

Delfino et al. (2003) – Sensitivity Analysis

Delfino et al. (2003) conducted a panel study of 22 Hispanic children with asthma who were 10-16 years old and living in a Los Angeles community with high traffic density. Subjects filled out symptom diaries daily for up to 3 months (November 1999 through January 2000). Pollutants included ambient hourly values of ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) and 24-hr values of volatile organic compounds (VOCs), particulate matter with aerodynamic diameter < 10 micro (PM_{10}), and elemental carbon (EC) and organic carbon (OC) PM_{10} fractions. Asthma symptom severity was regressed on pollutants using logistic models. The authors found positive associations of symptoms with criteria air pollutants (O_3, NO_2, SO_2, and PM_{10}). Selected adjusted odds ratio for more severe asthma symptoms from interquartile range increases in pollutants was, for 2.5 ppb 8-hr max SO_2, 1.36 [95% confidence interval (CI), 1.08-1.71]. Their findings support the view that air toxins in the pollutant mix from traffic and industrial sources may have adverse effects on asthma in children.

5.4.3 Pooling Multiple Health Studies

After selecting which health endpoints to analyze and which epidemiology studies provide appropriate effect estimates, we then selected a method to combine the multiple health studies to provide a single benefits estimate for each health endpoint. The purpose of pooling multiple studies together is to generate a more robust estimate by combining the evidence across multiple studies and cities. Because we used a single study for acute respiratory symptoms and a single study for hospital admission for asthma, there was no pooling necessary for those endpoints.

See Table 5.2 for more information on how the asthma studies were adjusted. Because asthma represents the largest benefits category in this analysis, we tested the sensitivity of the SO_2 benefits to alternate pooling choices in Table 5.6.

5.5 Valuation of Avoided Health Effects from SO_2 Exposure

The selection of valuation functions very similar to the NO_2 NAAQS RIA (U.S. EPA, 2010b) and the $PM_{2.5}$ NAAQS RIA (U.S. EPA, 2006a) with a couple exceptions. First, in this analysis, we estimated changes in all respiratory hospital admissions. This is consistent with the $PM_{2.5}$ NAAQS RIA, but inconsistent with the NO_2 NAAQS RIA, which estimated changes for only a subset of respiratory hospital admissions (i.e., chronic lung disease and asthma) because concentration-response functions were only available for the subset. Second, in this analysis, we used the any-of-19 symptoms valuation function for acute respiratory symptoms. This is consistent with the NO_2 NAAQS RIA, but inconsistent with the $PM_{2.5}$ NAAQS RIA, which used the valuation function for "minor-restricted activity day" (MRADs). The valuation for any-of-19-symptoms is approximately 50% of the valuation for MRADs. Consistent with economic theory, these valuation functions include adjustments for inflation (2006$) and income growth over time (2020 income levels). Table 5.4 provides the unit values used to monetize the benefits of reduced exposure to SO_2.

Table 5.4: Central Unit Values SO_2 Health Endpoints (2006$)*

Health Endpoint	Central Unit Value Per Statistical Incidence (2020 income level)	Derivation of Distributions of Estimates
Hospital Admissions and ER Visits		
Respiratory Hospital Admissions	$24,000	No distributional information available. The COI point 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 Emergency Room Visits	$370	No distributional information available. Simple average of two unit COI values: (1) $400 (2006$), from Smith et al. (1997) and (2) $340 (2006$), from Stanford et al. (1999).
Respiratory Ailments Not Requiring Hospitalization		
Asthma Exacerbation	$53	Asthma exacerbations are valued at $49 (2006$) 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 $19 and $83 (2006$).
Acute Respiratory Symptoms	$30	The valuation estimate for "any of 19 acute respiratory symptoms" is derived from Krupnick et al. (1990) assuming that this health endpoint consists either of upper respiratory symptoms (URS) or lower respiratory symptoms (LRS), or both. We assumed the following probabilities for a day of "any of 19 acute respiratory symptoms": URS with 40 percent probability, LRS with 40 percent probability, and both with 20 percent probability. The point estimate of WTP to avoid a day of "the presence of any of 19 acute respiratory symptoms" is $28 (2006$). The value is assumed have a uniform distribution between $0 and $56 (2006$).

*All estimates rounded to two significant figures. All values have been inflated to reflect values in 2006 dollars and income levels in 2020.

5.6 Health Benefits of Reducing Exposure to SO_2 Results

EPA estimated the monetized human health benefits of reducing cases of morbidity among populations exposed to SO_2 in 2020 for the selected standard and the alternative standard levels in 2006$. For the selected SO_2 standard at 75 ppb, the monetized benefits from reduced SO_2 exposure would be $2.2 million in 2020. Figure 5.4 shows the breakdown of the monetized SO_2 benefits by health endpoint. Table 5.5 shows the incidences of health effects and monetized benefits of attaining the alternative standard levels by health endpoint. Because all health effects from SO_2 exposure are expected to occur within the analysis year, the monetized benefits for SO_2 do not need to be discounted. Please note that these benefits do not include any of the benefits listed as "unquantified" in Table 5.1, nor do they include the PM co-benefits, which are presented in the section 5.7.

Figure 5.4: Breakdown of Monetized SO_2 Health Benefits by Endpoint

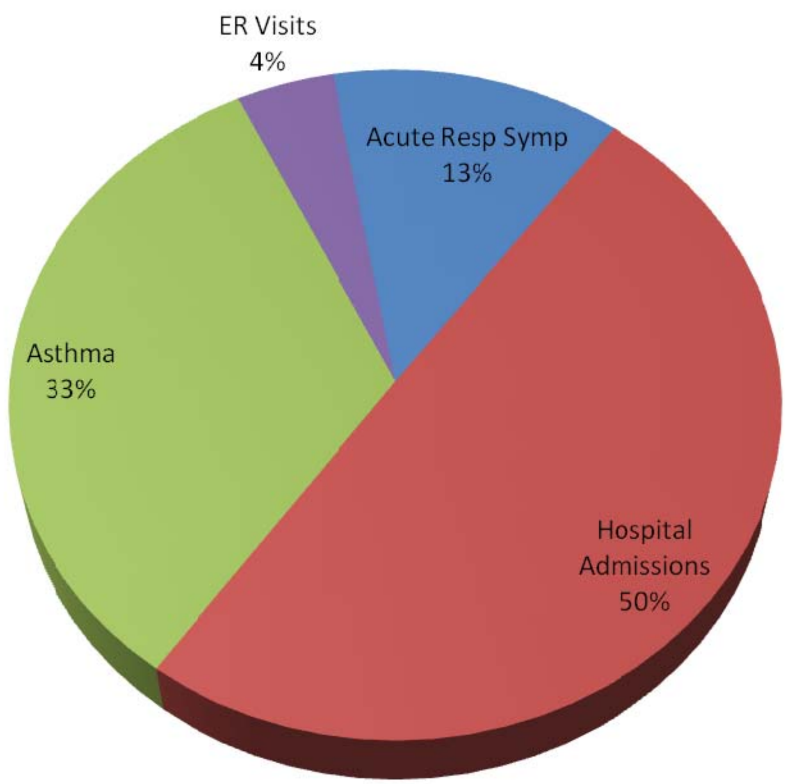


Table 5.5: SO_2 Health Benefits of Attaining Alternate Standard Levels in 2020 in 2006$ (95th percentile confidence interval)

		Incidence		Valuation	
50 ppb	Acute Respiratory Symptoms	38,000	(-21,000 -- 97,000)	$1,100,000	(-$730,000 -- $4,200,000)
	Hospital Admissions, Respiratory	170	(-10 -- 360)	$4,100,000	($120,000 -- $8,100,000)
	Asthma Exacerbation	55,000	(7,800 -- 130,000)	$2,900,000	($440,000 -- $8,800,000)
	Emergency Room Visits, Respiratory	930	(-230 -- 2,600)	$340,000	(-$53,000 -- $940,000)
			Total	**$8,500,000**	**(-$210,000 -- $22,000,000)**
75 ppb	Acute Respiratory Symptoms	9,400	(-5,200 -- 24,000)	$280,000	(-$180,000 -- $1,100,000)
	Hospital Admissions, Respiratory	46	(-3 -- 95)	$1,100,000	($33,000 -- $2,100,000)
	Asthma Exacerbation	14,000	(1,900 -- 33,000)	$720,000	($110,000 -- $2,200,000)
	Emergency Room Visits, Respiratory	260	(-65 -- 720)	$95,000	(-$15,000 -- $260,000)
			Total	**$2,200,000**	**(-$52,000 -- $5,600,000)**
100 ppb	Acute Respiratory Symptoms	2,600	(-1,500 -- 6,700)	$80,000	(-$50,000 -- $290,000)
	Hospital Admissions, Respiratory	13	(-1 -- 27)	$310,000	($9,500 -- $620,000)
	Asthma Exacerbation	3,800	(530 -- 9,200)	$200,000	($30,000 -- $610,000)
	Emergency Room Visits, Respiratory	74	(-19 -- 200)	$27,000	(-$4,400 -- $74,000)
			Total	**$620,000**	**(-$15,000 -- $1,600,000)**

*All estimates are rounded to two significant figures. The negative 5th percentile incidence estimates for acute respiratory symptoms are a result of the weak statistical power of the study and should not be inferred to indicate that decreased SO_2 exposure may cause an increase in this health endpoint.

In Table 5.6, we present the results of sensitivity analyses for the SO_2 benefits. We indicate each input parameter, the value used as the default, and the values for the sensitivity analyses, and then we provide the total monetary benefits for each input and the percent change from the default value.

Table 5.6: Sensitivity Analyses for SO_2 Health Benefits to Fully Attain 50 ppb Standard

		Total SO_2 Benefits (millions of 2006$)	% Change from Default
Exposure Estimation Method	50km radius	$2.2	N/A
	75km radius	$2.7	25%
	100km radius	$3.1	42%
	150km radius	$3.7	71%
Location of Hospital Admission Studies	w/US-based studies only	$2.2	N/A
	w/Canada-based studies only	$12	438%
Asthma Pooling Method	Pool all endpoints together	$2.2	N/A
	One or more symptoms only	$2.2	-0.2%
Interpolation Method	Inverse distance squared	$2.2	N/A
	Inverse distance	$2.5	12%

5.7 $PM_{2.5}$ Co-Benefits

Because SO_2 is also a precursor to $PM_{2.5}$, reducing SO_2 emissions in the projected non-attainment areas will also reduce $PM_{2.5}$ formation, human exposure and the incidence of $PM_{2.5}$-related health effects. In this analysis, we estimated the co-benefits of reducing $PM_{2.5}$ exposure for the alternative standards. Due to analytical limitations, it was not possible to provide a comprehensive estimate of $PM_{2.5}$-related benefits. Instead, we used the "benefit-per-ton" method to estimate these benefits (Fann et al, 2009). Please see Chapter 4 for more information on the tons of emission reductions calculated for the control strategy.[7]

The $PM_{2.5}$ benefit-per-ton methodology incorporates key assumptions described in detail below. These $PM_{2.5}$ benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of $PM_{2.5}$ from a specified source. EPA has used the benefit per-ton technique in previous RIAs, including the recent Ozone NAAQS RIA (U.S. EPA, 2010a) and NO_2 NAAQS RIA (U.S. EPA, 2010b). Table 5.7 shows the quantified and unquantified benefits captured in those benefit-per-ton estimates.

Table 5.7: Human Health and Welfare Effects of $PM_{2.5}$

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Unquantified Effects Changes in:
$PM_{2.5}$	Adult premature mortality	Subchronic bronchitis cases
	Bronchitis: chronic and acute	Low birth weight
	Hospital admissions: respiratory and cardiovascular	Pulmonary function
	Emergency room visits for asthma	Chronic respiratory diseases other than chronic bronchitis
	Nonfatal heart attacks (myocardial infarction)	Non-asthma respiratory emergency room visits
	Lower and upper respiratory illness	Visibility
	Minor restricted-activity days	Household soiling
	Work loss days	
	Asthma exacerbations (asthmatic population)	
	Infant mortality	

Consistent with the Portland Cement NESHAP, the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature, as well as the 12 functions obtained in EPA's expert elicitation study as a sensitivity analysis.

[7] Pollution controls installed to comply with this standard would also reduce ambient $PM_{2.5}$ concentrations. This illustrative analysis is incremental to the 2006 PM NAAQS, so these benefits are in addition to those estimates for that rule. Furthermore, the controls installed to comply with this standard might also help states attain a more stringent PM NAAQS if one is promulgated in 2011.

- One estimate is based on the concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as reported in Pope et al. (2002), a study that EPA has previously used to generate its primary benefits estimate. When calculating the estimate, EPA applied the effect coefficient as reported in the study without an adjustment for assumed concentration threshold of 10 μg/m^3 as was done in recent (2006-2009) Office of Air and Radiation RIAs.
- One estimate is based on the C-R function developed from the extended analysis of the Harvard Six Cities cohort, as reported by Laden et al. (2006). This study, published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS, has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ co-benefits estimates in RIAs completed since the $PM_{2.5}$ NAAQS. When calculating the estimate, EPA applied the effect coefficient as reported in the study without an adjustment for assumed concentration threshold of 10 μg/m^3 as was done in recent (2006-2009) RIAs.
- Twelve estimates are based on the C-R functions from EPA's expert elicitation study (IEc, 2006; Roman et al., 2008) on the $PM_{2.5}$-mortality relationship and interpreted for benefits analysis in EPA's final RIA for the $PM_{2.5}$ NAAQS. For that study, twelve experts (labeled A through L) provided independent estimates of the $PM_{2.5}$-mortality concentration-response function. EPA practice has been to develop independent estimates of $PM_{2.5}$-mortality estimates corresponding to the concentration-response function provided by each of the twelve experts, to better characterize the degree of variability in the expert responses.

The effect coefficients are drawn from epidemiology studies examining two large population cohorts: the American Cancer Society cohort (Pope et al., 2002) and the Harvard Six Cities cohort (Laden et al., 2006).[8] These are logical choices for anchor points in our presentation because, while both studies are well designed and peer reviewed, there are strengths and weaknesses inherent in each, which we believe argues for using both studies to generate benefits estimates. Previously, EPA had calculated benefits based on these two empirical studies, but derived the range of benefits, including the minimum and maximum results, from an expert elicitation of the relationship between exposure to $PM_{2.5}$ and premature mortality (Roman et al., 2008). Within this assessment, we include the benefits estimates derived from the concentration-response function provided by each of the twelve experts to better characterize the uncertainty in the concentration-response function for mortality and the degree of variability in the expert responses. Because the experts used these cohort studies to inform their concentration-response functions, benefits estimates using these functions generally fall between results using these epidemiology studies (see Figure 5.1). In

[8] These two studies specify multi-pollutant models that control for SO_2, among other co-pollutants.

general, the expert elicitation results support the conclusion that the benefits of $PM_{2.5}$ control are very likely to be substantial.

Readers interested in reviewing the general methodology for creating the benefit-per-ton estimates used in this analysis should consult Fann et al. (2009) or the Technical Support Document (TSD) accompanying the ozone NAAQS RIA (USEPA 2008a). As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates are developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (e.g., SO_2 emitted from electric generating units; SO_2 emitted from area sources). Our estimate of $PM_{2.5}$ co-control benefits is therefore based on the total $PM_{2.5}$ emissions controlled by sector and multiplied by this per-ton value.

The benefit-per-ton coefficients in this analysis were derived using modified versions of the health impact functions used in the PM NAAQS Regulatory Impact Analysis. Specifically, this analysis uses the benefit-per-ton estimates first applied in the Portland Cement NESHAP RIA (U.S. EPA, 2009a), which incorporated three updates: a new population dataset, an expanded geographic scope of the benefit-per-ton calculation, and the functions directly from the epidemiology studies without an adjustment for an assumed threshold.[9] Removing the threshold assumption is a key difference between the method used in this analysis of PM-co benefits and the methods used in RIAs prior to Portland Cement, and we now calculate incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. Based on our review of the body of scientific literature, EPA applied the no-threshold model in this analysis. EPA's final Integrated Science Assessment (2009d), which was recently reviewed by EPA’s Clean Air Scientific Advisory Committee (U.S. EPA-SAB, 2009a; U.S. EPA-SAB, 2009b), concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. In Table 5-12, we include an estimate of the sensitivity of the results to an assumed threshold at 10 $\mu g/m^3$.

As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve over time to reflect the Agency’s most current

[9] The benefit-per-ton estimates have also been updated since the Cement RIA to incorporate a revised VSL, as discussed on the next page.

interpretation of the scientific and economic literature. For a period of time (2004-2008), the Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature. The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$)[10] was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006) meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rule-makings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

During this time, the Agency continued work to update its guidance on valuing mortality risk reductions, including commissioning a report from meta-analytic experts to evaluate methodological questions raised by EPA and the SAB on combining estimates from the various data sources. In addition, the Agency consulted several times with the Science Advisory Board Environmental Economics Advisory Committee (SAB-EEAC) on the issue. With input from the meta-analytic experts, the SAB-EEAC advised the Agency to update its guidance using specific, appropriate meta-analytic techniques to combine estimates from unique data sources and different studies, including those using different methodologies (i.e., wage-risk and stated preference) (U.S. EPA-SAB, 2007).

Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore, the Agency has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[11] while the Agency continues its efforts to update its guidance on this issue. This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[12] The Agency is committed to using scientifically sound, appropriately reviewed evidence in valuing mortality risk reductions

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[10] After adjusting the VSL to account for a different currency year (2006$) and to account for income growth to 2020, the $5.5 million VSL is $7.7m.

[11] In the (draft) update of the Economic Guidelines (U.S. EPA, 2008d), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. Therefore, this report does not represent final agency policy.

[12] In this analysis, we adjust the VSL to account for a different currency year (2006$) and to account for income growth to 2020. After applying these adjustments to the $6.3 million value, the VSL is $8.9m.

and has made significant progress in responding to the SAB-EEAC's specific recommendations. The Agency anticipates presenting results from this effort to the SAB-EEAC in Spring 2010 and that draft guidance will be available shortly thereafter.

Table 5.8 provides the unit values used to monetize the benefits of reduced exposure to $PM_{2.5}$. Figure 5.5 illustrates the relative breakdown of the monetized $PM_{2.5}$ health benefits.

Table 5.8: Unit Values used for Economic Valuation of $PM_{2.5}$ Health Endpoints (2006$)*

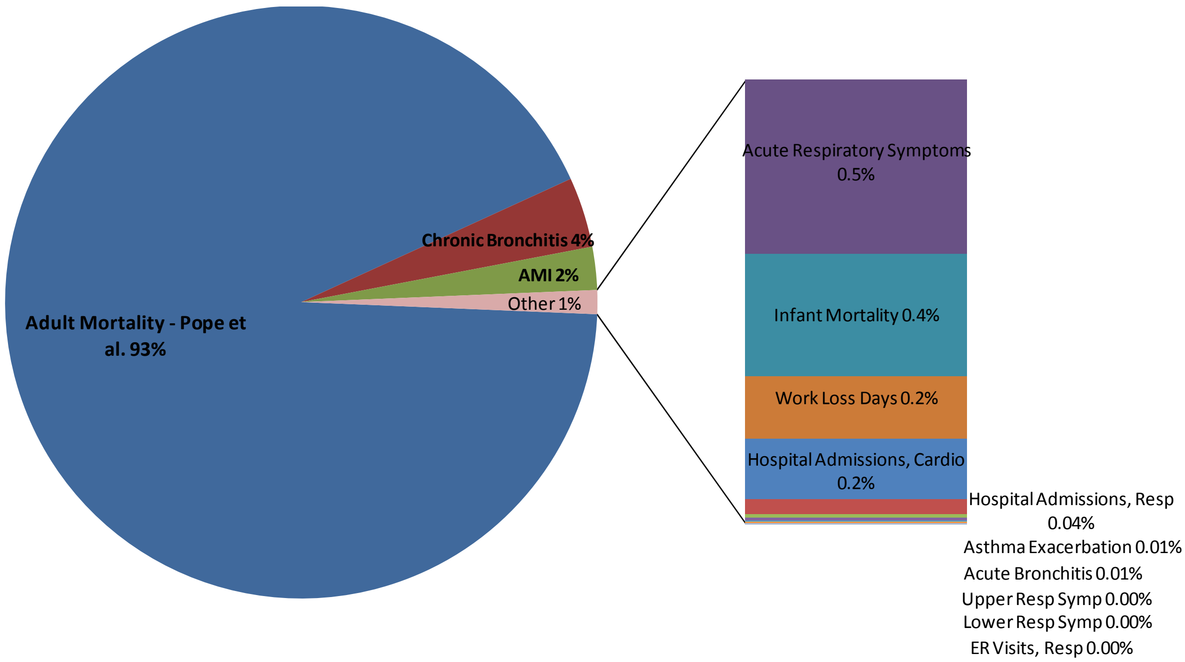
Health Endpoint	Central Estimate of Value Per Statistical Incidence (2020 income level)	Derivation of Distributions of Estimates
Premature Mortality (Value of a Statistical Life)	$8,900,000	EPA currently recommends a central VSL of $6.3m (2000$) based on a Weibull distribution fitted to 26 published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses (U.S. EPA, 2000).
Chronic Bronchitis (CB)	$490,000	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, 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, 1999b).
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 on period following a nonfatal MI. Lost earnings estimates are based Cropper and Krupnick (1990). Direct medical costs are based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990).
<u>3% discount rate</u>		Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings in (2006$):
Age 0–24	$80,000	age of onset: at 3%, at 7%
Age 25–44	$96,000	25–44: $11,000, $10,000
Age 45–54	$100,000	45–54: $17,000, $15,000
Age 55–65	$180,000	55–65: $96,000, $86,000
Age 66 and over	$80,000	

7% discount rate		Direct medical expenses: An average of: 1. Wittels et al. (1990) ($130,000—no discounting) 2. Russell et al. (1998), 5-year period ($29,000 at 3%, $27,000 at 7%)
Age 0–24	$80,000	
Age 25–44	$88,000	
Age 45–54	$92,000	
Age 55–65	$160,000	
Age 66 and over	$78,000	
Hospital Admissions and ER Visits		
Chronic Obstructive Pulmonary Disease (COPD)	$17,000	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	$8,900	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	$25,000	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).
All respiratory (ages 65+)	$25,000	No distributions available. The COI point 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).
All respiratory (ages 0–2)	$10,000	No distributions available. The COI point 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).
Emergency Room Visits for Asthma	$370	No distributional information available. Simple average of two unit COI values: (1) $400 (2006$), from Smith et al. (1997) and (2) $340 (2006$), from Stanford et al. (1999).
Respiratory Ailments Not Requiring Hospitalization		

Upper Respiratory Symptoms (URS)	$31	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 $11 and $50 (2006$).
Lower Respiratory Symptoms (LRS)	$19	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 $29 (2006$).
Asthma Exacerbations	$53	Asthma exacerbations are valued at $49 (2006$) 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 $19 and $83 (2006$).
Acute Bronchitis	$440	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 $12 (2006$) is the sum of the mid-range values recommended by IEc 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 $130 (2006$).
Work Loss Days (WLDs)	Variable	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.
Minor Restricted Activity Days (MRADs)	$63	Median WTP estimate to avoid one MRAD from Tolley et al. (1986). Distribution is assumed to be triangular with a minimum of $26 and a maximum of $97 (2006$). 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 $19 (2006$)) 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.

*All estimates rounded to two significant figures. All values have been inflated to reflect values in 2006 dollars.

Figure 5.5: Breakdown of Monetized $PM_{2.5}$ Health Benefits using Mortality Function from Pope et al.*



*This pie chart is an illustrative breakdown of the monetized PM co-benefits, using the results based on Pope et al. (2002) as an example. Using the Laden et al. (2006) function for premature mortality, the percentage of total monetized benefits due to adult mortality would be 97%. This chart shows the breakdown using a 3% discount rate, and the results would be similar if a 7% discount rate was used.

Because epidemiology studies have indicated that there is a lag between exposure to $PM_{2.5}$ and premature mortality, the discount rate has a substantial effect on the final monetized benefits.[13] We provide the PM co-benefit results using discount rates of 3% and 7% in Table 5.11 and the total monetized benefits (i.e., SO_2 and $PM_{2.5}$) results using both discount rates in Table 5.13. We test the sensitivity of the PM results to discount rates of 3% and 7% in Table 5.12.

[13] To comply with Circular A-4, EPA provides monetized benefits using discount rates of 3% and 7% (OMB, 2003). These benefits are estimated for a specific analysis year (i.e., 2020), and most of the PM benefits occur within that year with two exceptions: acute myocardial infarctions (AMIs) and premature mortality. For AMIs, we assume 5 years of follow-up medical costs and lost wages. For premature mortality, we assume that there is a "cessation" lag between PM exposures and the total realization of changes in health effects. Although the structure of the lag is uncertain, EPA follows the advice of the SAB-HES to assume a segmented lag structure characterized by 30% of mortality reductions in the first year, 50% over years 2 to 5, and 20% over the years 6 to 20 after the reduction in $PM_{2.5}$ (U.S. EPA-SAB, 2004). Changes in the lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths. Therefore, discounting only affects the AMI costs after the analysis year and the valuation of premature mortalities that occur after the analysis year. As such, the monetized benefits using a 7% discount rate are only approximately 10% less than the monetized benefits using a 3% discount rate.

The benefit-per-ton estimates are provided in Table 5.9 and the health incidences are provided in Table 5.10. Table 5.11 shows the monetized results using the two epidemiology-based estimates as well as the 12 expert-based estimates. Figure 5.6 provides a graphical breakdown of the $PM_{2.5}$ co-benefits by sector. Figure 5.7 provides a graphical representation of all 14 of the $PM_{2.5}$ co-benefits, at both a 3 percent and 7 percent discount rate.

Table 5.9: $PM_{2.5}$ Co-benefits associated with reducing SO_2 emissions (2006$)*

$PM_{2.5}$ Precursor	Benefit per Ton Estimate (Pope)	Benefit per Ton Estimate (Laden)
SO_2 EGU:	$42,000	$100,000
SO_2 non-EGU:	$30,000	$74,000
SO_2 area:	$19,000	$47,000

*Estimates have been rounded to two significant figures. Confidence intervals are not available for benefit per-ton estimates. Estimates shown use a 3% discount rate. Estimates at a 7% discount rate would be approximately 9% lower.

Table 5.10: Summary of Reductions in Health Incidences from $PM_{2.5}$ Co-Benefits to Attain Alternate Standard Levels in 2020*

	50 ppb	75 ppb	100 ppb
Avoided Premature Mortality			
Pope	5,100	2,300	1,100
Laden	13,000	5,900	2,900
Woodruff (Infant Mortality)	20	9	5
Avoided Morbidity			
Chronic Bronchitis	3,500	1,600	780
Acute Myocardial Infarction	8,600	3,900	1,900
Hospital Admissions, Respiratory	1,300	570	280
Hospital Admissions, Cardiovascular	2,800	1,300	620
Emergency Room Visits, Respiratory	4,900	2,200	1,100
Acute Bronchitis	8,200	3,700	1,800
Work Loss Days	650,000	290,000	150,000
Asthma Exacerbation	90,000	41,000	20,000
Acute Respiratory Symptoms	3,900,000	1,700,000	870,000
Lower Respiratory Symptoms	98,000	44,000	22,000
Upper Respiratory Symptoms	74,000	33,000	17,000

*All estimates are for the analysis year (2020) and are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but each $PM_{2.5}$ precursor pollutant has a different propensity to form $PM_{2.5}$. These results reflect full attainment with the various standard levels, including extrapolated tons, which were spread across the sectors in proportion to the emissions in the county.

Table 5.11: All $PM_{2.5}$ Co-Benefits Estimates to Attain Alternate Standard Levels in 2020 at discount rates of 3% and 7% (in millions of 2006$)*

	50 ppb		75 ppb		100 ppb	
	3%	7%	3%	7%	3%	7%
Benefit-per-ton Coefficients Derived from Epidemiology Literature						
Pope et al.	$34,000	$31,000	$15,000	$14,000	$7,400	$6,700
Laden et al.	$83,000	$75,000	$37,000	$34,000	$18,000	$16,000
Benefit-per-ton Coefficients Derived from Expert Elicitation						
Expert A	$88,000	$79,000	$40,000	$36,000	$19,000	$17,000
Expert B	$67,000	$61,000	$30,000	$27,000	$15,000	$13,000
Expert C	$67,000	$60,000	$30,000	$27,000	$15,000	$13,000
Expert D	$47,000	$43,000	$21,000	$19,000	$10,000	$9,400
Expert E	$110,000	$98,000	$49,000	$44,000	$24,000	$21,000
Expert F	$61,000	$55,000	$27,000	$25,000	$13,000	$12,000
Expert G	$40,000	$36,000	$18,000	$16,000	$8,700	$7,900
Expert H	$50,000	$46,000	$23,000	$21,000	$11,000	$9,900
Expert I	$66,000	$60,000	$30,000	$27,000	$14,000	$13,000
Expert J	$54,000	$49,000	$24,000	$22,000	$12,000	$11,000
Expert K	$13,000	$12,000	$5,900	$5,400	$2,900	$2,600
Expert L	$49,000	$44,000	$22,000	$20,000	$11,000	$9,600

*All estimates are rounded to two significant figures. Estimates do not include confidence intervals because they were derived through the benefit-per-ton technique described above. The benefits estimates from the Expert Elicitation are provided as a reasonable characterization of the uncertainty in the mortality estimates associated with the concentration-response function. These results reflect full attainment with the various standard levels, including extrapolated tons, which were spread across the sectors in proportion to the emissions in the county.

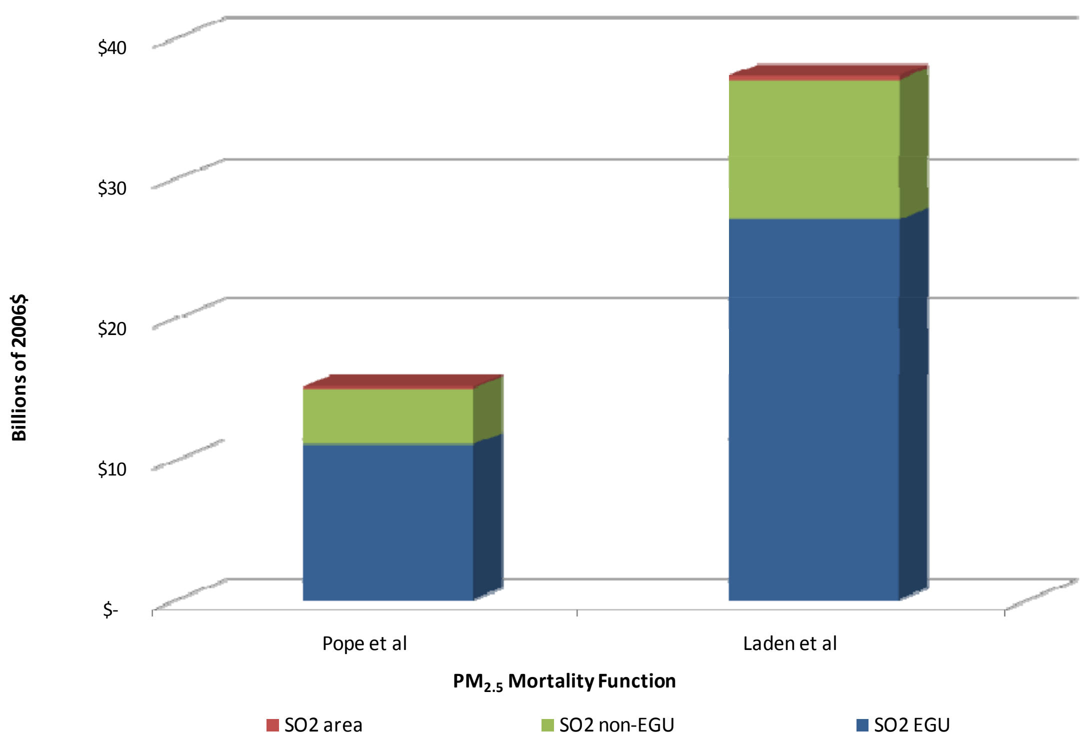
In Table 5.12, we present the results of sensitivity analyses for the PM co-benefits. We indicate each input parameter, the value used as the default, and the values for the sensitivity analyses, and then we provide the total monetary benefits for each input and the percent change from the default value.

Table 5.12: Sensitivity Analyses for $PM_{2.5}$ Health Co-Benefits to Fully Attain 75 ppb

		Total $PM_{2.5}$ Co-Benefits (billions of 2006$)	% Change from Default
Threshold Assumption (with Epidemiology Study)	No Threshold (Pope)	$15	N/A
	No Threshold (Laden)	$37	N/A
	Threshold (Pope)*	$10	-33%
	Threshold (Laden)*	$22	-41%
Discount Rate (with Epidemiology Study)	3% (Pope)	$15	N/A
	3% (Laden)	$37	N/A
	7% (Pope)	$14	-8%
	7% (Laden)	$34	-9%
Simulated Attainment (using Pope)	Full attainment	$15	N/A
	Partial Attainment	$14	-7%

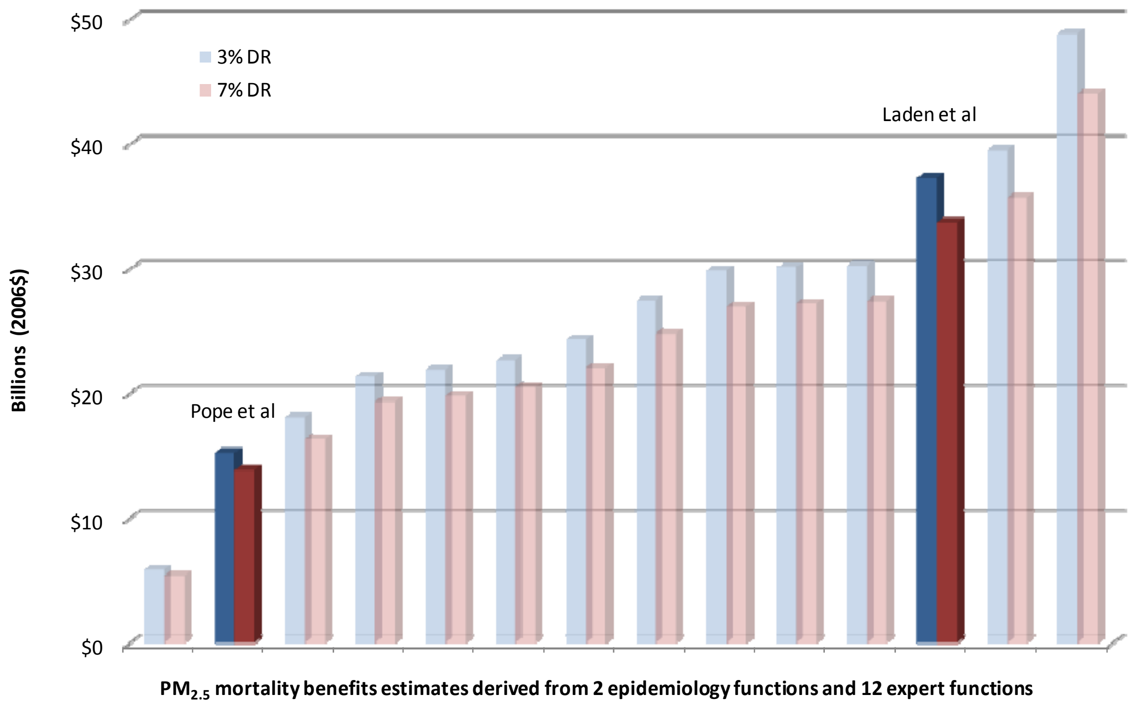
*The Threshold model is not directly comparable to the no-threshold model. The threshold model estimates do not include two technical updates, and they are based on data for 2015, instead of 2020. Directly comparable estimates are not available.

Figure 5.6: Monetized $PM_{2.5}$ Co-Benefits of Fully Attaining 75 ppb by $PM_{2.5}$ Precursor



* All estimates are for the analysis year (2020). All fine particles are assumed to have equivalent health effects, but each $PM_{2.5}$ precursor pollutant has a different propensity to form $PM_{2.5}$. Results using a 7% discount rate would show a similar breakdown. These results reflect full attainment with the various standard levels, including extrapolated tons, which were spread across the sectors in proportion to the emissions in the county.

Figure 5.7: Monetized $PM_{2.5}$ Co-Benefits of Fully Attaining 75 ppb*



* This graph shows the estimated co- benefits in 2020 for the selected standard of 75 ppb using the no-threshold model at discount rates of 3% and 7% using effect coefficients derived from the Pope et al. study and the Laden et al. study, as well as 12 effect coefficients derived from EPA's expert elicitation on PM mortality. The results shown are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response function provided in those studies. Graphs for alternative standards would show a similar pattern. These results reflect full attainment with the various standard levels, including extrapolated tons, which were spread across the sectors in proportion to the emissions in the county.

5.8 Summary of Total Monetized Benefits (SO_2 and $PM_{2.5}$)

EPA estimated the monetized human health benefits of reducing cases of morbidity and premature mortality among populations exposed to SO_2 and $PM_{2.5}$ in 2020 for each of the alternative standard levels in 2006$. For the selected SO_2 standard at 75 ppb, the total monetized benefits would be $15 to $37 billion at a 3% discount rate and $14 to $34 billion at a 7% discount rate.

All of the results in this chapter present benefits estimates that assume full attainment with the alternative standard levels. Partial attainment only incorporates the emission reductions from identified controls without the extrapolated emission reductions.[14] These results are shown in Table 5.13 along with the full attainment at discount rates of 3% and 7%. Table 5.14 shows the total incidences of avoided health effects. Figure 5.8 provides a graphical

[14] See Chapter 4 for more information regarding the control strategy, including the identified and extrapolated emission reductions.

representation of all 14 total monetized benefits estimates, at both a 3 percent and 7 percent discount rate, for the selected standard of 75 ppb, respectively.

Table 5.13: Total Monetized Benefits to attain Alternate Standard Levels at Discount Rates of 3% and 7% for Full and Partial Attainment (millions of 2006$)[a,c]

		SO_2	$PM_{2.5}$ (Pope)	$PM_{2.5}$ (Laden)	TOTAL (with Pope)	TOTAL (with Laden)
50 ppb	3% Full Attainment	$8.5	$34,000	$83,000	$34,000	$83,000
	7% Full Attainment	$8.5	$31,000	$75,000	$31,000	$75,000
	3% Partial Attainment	-[b]	$30,000	$74,000	$30,000	$74,000
	7% Partial Attainment	-[b]	$28,000	$67,000	$28,000	$67,000
75 ppb	3% Full Attainment	$2.2	$15,000	$37,000	$15,000	$37,000
	7% Full Attainment	$2.2	$14,000	$34,000	$14,000	$34,000
	3% Partial Attainment	-[b]	$14,000	$35,000	$14,000	$35,000
	7% Partial Attainment	-[b]	$13,000	$31,000	$13,000	$31,000
100 ppb	3% Full Attainment	$0.62	$7,400	$18,000	$7,400	$18,000
	7% Full Attainment	$0.62	$6,700	$16,000	$6,700	$16,000
	3% Partial Attainment	-[b]	$6,900	$17,000	$6,900	$17,000
	7% Partial Attainment	-[b]	$6,200	$15,000	$6,200	$15,000

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates.

[b] The approach used to simulate air quality changes for SO_2 did not provide the data needed to distinguish partial attainment benefits from full attainment benefits from reduced SO_2 exposure. Therefore, a portion of the SO_2 benefits is attributable to the known controls and a portion of the SO_2 benefits are attributable to the extrapolated controls.

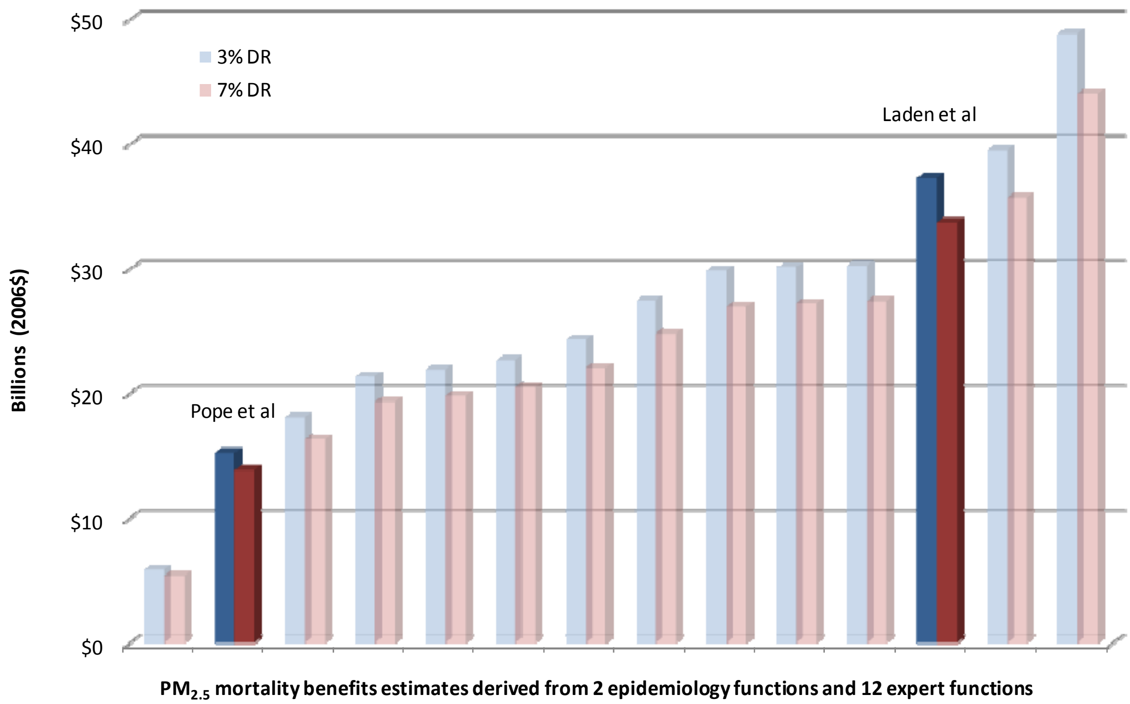
[c] These models assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality because there is no clear scientific evidence that would support the development of differential effects estimates by particle type. Reductions in SO_2 emissions from multiple sectors to meet the SO_2 NAAQS would primarily reduce the sulfate fraction of $PM_{2.5}$. Because this rule targets a specific particle precursor (i.e., SO_2), this introduces some uncertainty into the results of the analysis.

Table 5.14: Summary of Reductions in Health Incidences from SO_2 and $PM_{2.5}$ to attain Alternate Standard Levels*

	50 ppb	75 ppb	100 ppb
Avoided Premature Mortality			
Pope	5,100	2,300	1,100
Laden	13,000	5,900	2,900
Woodruff (Infant Mortality)	20	9	5
Avoided Morbidity			
Chronic Bronchitis	3,500	1,600	780
Acute Myocardial Infarction	8,600	3,900	1,900
Hospital Admissions, Respiratory	1,400	570	280
Hospital Admissions, Cardiovascular	2,800	1,300	620
Emergency Room Visits, Respiratory	5,800	2,500	1,200
Acute Bronchitis	8,200	3,700	1,800
Work Loss Days	650,000	290,000	150,000
Asthma Exacerbation	150,000	54,000	24,000
Acute Respiratory Symptoms	3,900,000	1,700,000	870,000
Lower Respiratory Symptoms	98,000	44,000	22,000
Upper Respiratory Symptoms	74,000	33,000	17,000

*All estimates are for the analysis year (2020) and are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but each $PM_{2.5}$ precursor pollutant has a different propensity to form $PM_{2.5}$. These results reflect full attainment with the various standard levels, including extrapolated tons, which were spread across the sectors in proportion to the emissions in the county.

Figure 5.8: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Fully Attaining 75 ppb in 2020*



* This graphs shows the estimated total monetized benefits in 2020 for the selected standard of 75 ppb using the no-threshold model at discount rates of 3% and 7% using effect coefficients derived from the Pope et al. study and the Laden et al. study, as well as 12 effect coefficients derived from EPA's expert elicitation on PM mortality. The results shown are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response function provided in those studies. Graphs for alternative standards would show a similar pattern.

5.9 Unquantified Welfare Benefits

The monetized benefits estimated in this RIA only reflect the portion of benefits attributable to the health effect reductions associated with ambient fine particles and direct exposure to SO_2. Data, resource, and methodological limitations prevented EPA from quantifying or monetizing the benefits from several important benefit categories, including benefits from reducing ecosystem effects and visibility impairment. In this section, we provide a qualitative assessment of two welfare benefit categories: ecosystem benefits of reducing sulfur deposition and visibility improvements.

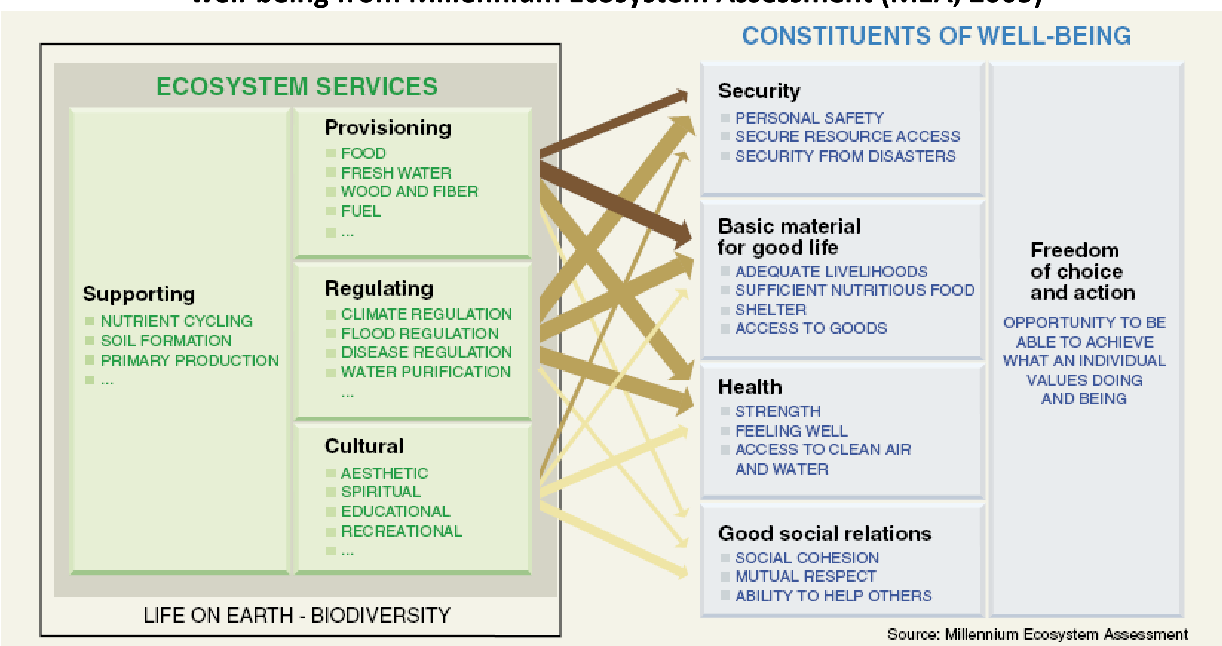
5.9.1 Ecosystem Benefits of Reduced Sulfur Deposition

Ecosystem services can be generally defined as the benefits that individuals and organizations obtain from ecosystems. EPA has defined ecological goods and services as the "outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some outputs may be bought and sold, but most are not marketed" (U.S. EPA, 2006c). Figure 5.9 provides the Millennium Ecosystem Assessment's schematic demonstrating the connections between the categories of ecosystem services and human well-being. The interrelatedness of these categories means that any one ecosystem may provide multiple services. Changes in these services can affect human well-being by affecting security, health, social relationships, and access to basic material goods (MEA, 2005).

In the Millennium Ecosystem Assessment (MEA, 2005), ecosystem services are classified into four main categories:

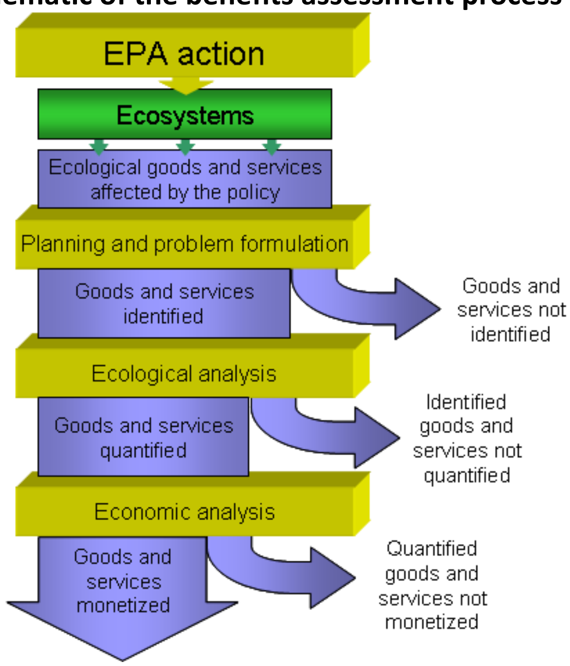
1. Provisioning: Products obtained from ecosystems, such as the production of food and water
2. Regulating: Benefits obtained from the regulation of ecosystem processes, such as the control of climate and disease
3. Cultural: Nonmaterial benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences
4. Supporting: Services necessary for the production of all other ecosystem services, such as nutrient cycles and crop pollination

Figure 5.9. Linkages between categories of ecosystem services and components of human well-being from Millennium Ecosystem Assessment (MEA, 2005)



The monetization of ecosystem services generally involves estimating the value of ecological goods and services based on what people are willing to pay (WTP) to increase ecological services or by what people are willing to accept (WTA) in compensation for reductions in them (U.S. EPA, 2006c). There are three primary approaches for estimating the monetary value of ecosystem services: market-based approaches, revealed preference methods, and stated preference methods (U.S. EPA, 2006c). Because economic valuation of ecosystem services can be difficult, nonmonetary valuation using biophysical measurements and concepts also can be used. An example of a nonmonetary valuation method is the use of relative-value indicators (e.g., a flow chart indicating uses of a water body, such as boatable, fishable, swimmable, etc.). It is necessary to recognize that in the analysis of the environmental responses associated with any particular policy or environmental management action, only a subset of the ecosystem services likely to be affected are readily identified. Of those ecosystem services that are identified, only a subset of the changes can be quantified. Within those services whose changes can be quantified, only a few will likely be monetized, and many will remain nonmonetized. The stepwise concept leading up to the valuation of ecosystems services is graphically depicted in Figure 5.10.

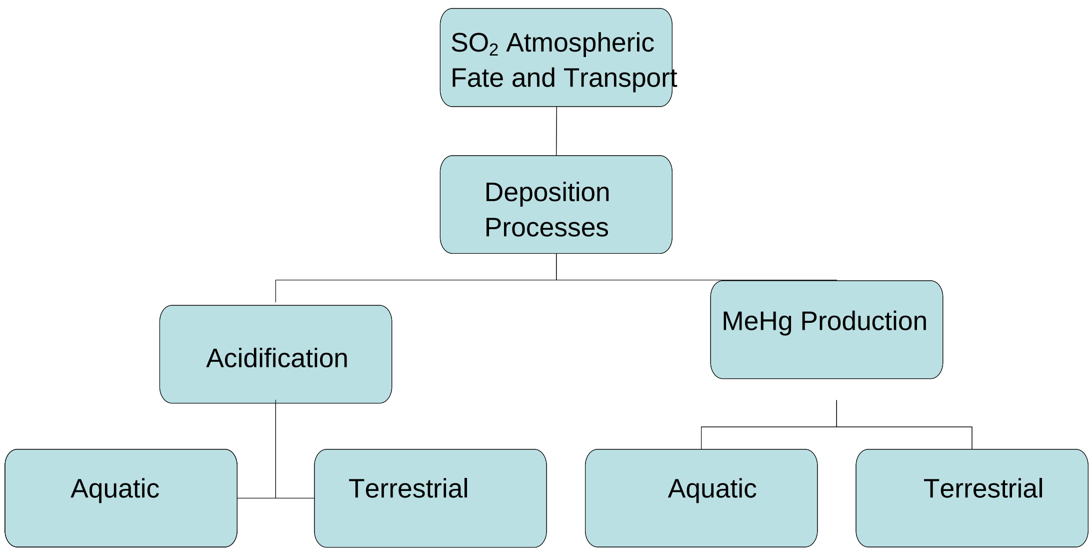
Figure 5.10: Schematic of the benefits assessment process (U.S. EPA, 2006c)



Science of Sulfur Deposition

Sulfur emissions occur over large regions of North America. Once these pollutants are lofted to the middle and upper troposphere, they typically have a much longer lifetime and, with the generally stronger winds at these altitudes, can be transported long distances from their source regions. The length scale of this transport is highly variable owing to differing chemical and meteorological conditions encountered along the transport path (U.S. EPA, 2008f). Sulfur is primarily emitted as SO_2, and secondary particles are formed from SO_X gaseous emissions and associated chemical reactions in the atmosphere. Deposition can occur in either a wet (i.e., rain, snow, sleet, hail, clouds, or fog) or dry form (i.e., gases or particles). Together these emissions are deposited onto terrestrial and aquatic ecosystems across the U.S., contributing to the problems of acidification, nutrient enrichment, and methylmercury production as represented in Figure 5-11.

Figure 5-11: Schematic of Ecological Effects of Sulfur Deposition



The lifetimes of particles vary with particle size. Accumulation-mode particles such as sulfates are kept in suspension by normal air motions and have a lower deposition velocity than coarse-mode particles; they can be transported thousands of kilometers and remain in the atmosphere for a number of days. They are removed from the atmosphere primarily by cloud processes. Particulates affect acid deposition by serving as cloud condensation nuclei and contribute directly to the acidification of rain. In addition, the gas-phase species that lead to the dry deposition of acidity are also precursors of particles. Therefore, reductions in SO_2 emissions will decrease both acid deposition and PM concentrations, but not necessarily in a linear fashion (U.S. EPA, 2008f). Sulfuric acid is also deposited on surfaces by dry deposition and can contribute to environmental effects (U.S. EPA, 2008f).

Ecological Effects of Acidification

Deposition of sulfur can cause acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. Soil acidification is a natural process, but is often accelerated by acidifying deposition, which can decrease concentrations of exchangeable base cations in soils (U.S. EPA, 2008f). Major terrestrial effects include a decline in sensitive tree species, such as red spruce (*Picea rubens*) and sugar maple (*Acer saccharum*) (U.S. EPA, 2008f). Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations (U.S. EPA, 2008f). Decreases in the acid neutralizing capacity and increases in inorganic aluminum concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems (U.S. EPA, 2008f).

Geology (particularly surficial geology) is the principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from sulfur deposition (U.S. EPA, 2008f). Geologic formations having low base cation supply generally underlie the watersheds of acid-sensitive lakes and streams. Other factors contribute to the sensitivity of soils and surface waters to acidifying deposition, including topography, soil chemistry, land use, and hydrologic flow path (U.S. EPA, 2008f).

Aquatic Ecosystems

Aquatic effects of acidification have been well studied in the U.S. and elsewhere at various trophic levels. These studies indicate that aquatic biota have been affected by acidification at virtually all levels of the food web in acid sensitive aquatic ecosystems. Effects have been most clearly documented for fish, aquatic insects, other invertebrates, and algae. Biological effects are primarily attributable to a combination of low pH and high inorganic aluminum concentrations. Such conditions occur more frequently during rainfall and snowmelt that cause high flows of water and less commonly during low-flow conditions, except where chronic acidity conditions are severe. Biological effects of episodes include reduced fish condition factor[15], changes in species composition and declines in aquatic species richness across multiple taxa, ecosystems and regions. These conditions may also result in direct fish mortality (Van Sickle et al., 1996). Biological effects in aquatic ecosystems can be divided into two major categories: effects on health, vigor, and reproductive success; and effects on biodiversity. Surface water with ANC values greater than 50 μeq/L generally provides moderate protection for most fish (i.e., brook trout, others) and other aquatic organisms (U.S. EPA, 2009c). Table 5-15 provides a summary of the biological effects experienced at various ANC levels.

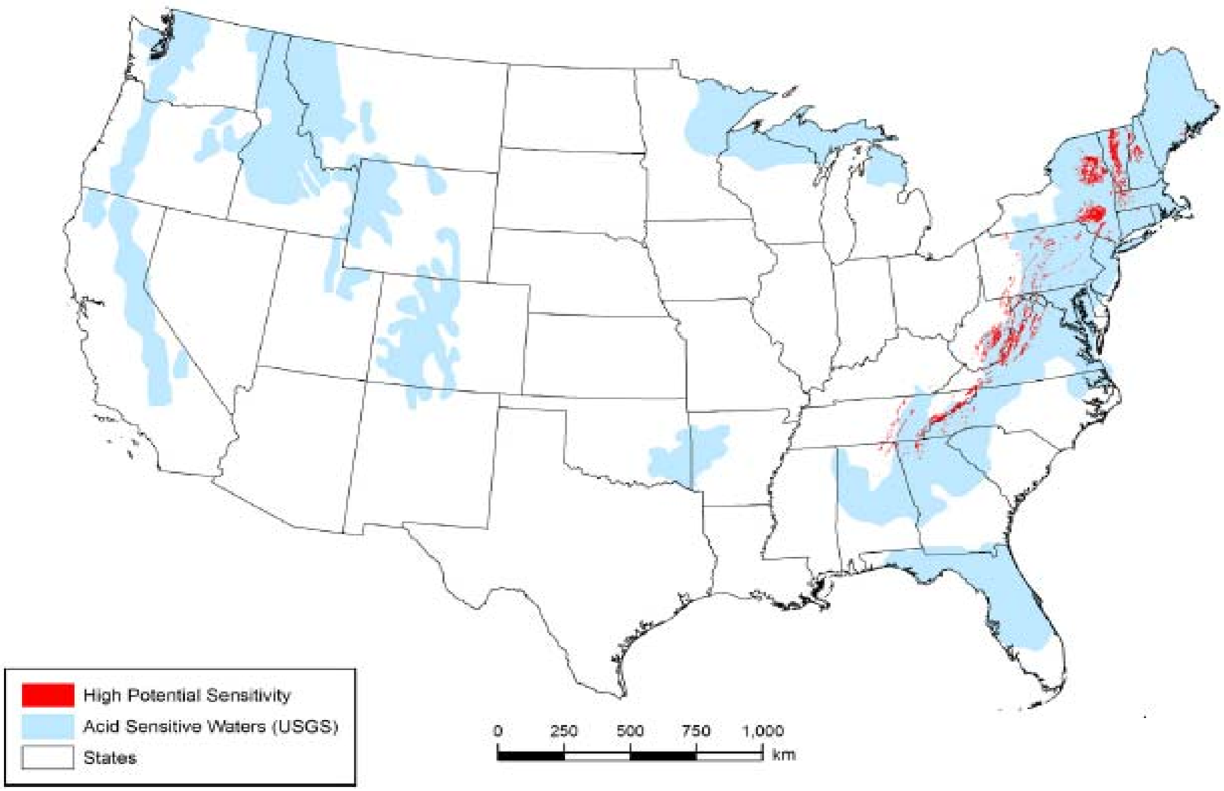
[15] Condition factor is an index that describes the relationship between fish weight and length, and is one measure of sublethal acidification stress that has been used to quantify effects of acidification on an individual fish (U.S.EPA, 2008f).

Table 5-15: Aquatic Status Categories

Category Label	ANC Levels	Expected Ecological Effects
Acute Concern	<0 micro equivalent per Liter (µeq/L)	Near complete loss of fish populations is expected. Planktonic communities have extremely low diversity and are dominated by acidophilic forms. The number of individuals in plankton species that are present is greatly reduced.
Severe Concern	0–20 µeq/L	Highly sensitive to episodic acidification. During episodes of high acidifying deposition, brook trout populations may experience lethal effects. Diversity and distribution of zooplankton communities decline sharply.
Elevated Concern	20–50 µeq/L	Fish species richness is greatly reduced (i.e., more than half of expected species can be missing). On average, brook trout populations experience sublethal effects, including loss of health, reproduction capacity, and fitness. Diversity and distribution of zooplankton communities decline.
Moderate Concern	50–100 µeq/L	Fish species richness begins to decline (i.e., sensitive species are lost from lakes). Brook trout populations are sensitive and variable, with possible sublethal effects. Diversity and distribution of zooplankton communities also begin to decline as species that are sensitive to acidifying deposition are affected.
Low Concern	>100 µeq/L	Fish species richness may be unaffected. Reproducing brook trout populations are expected where habitat is suitable. Zooplankton communities are unaffected and exhibit expected diversity and distribution.

A number of national and regional assessments have been conducted to estimate the distribution and extent of surface water acidity in the U.S (U.S. EPA, 2008f). As a result, several regions of the U.S. have been identified as containing a large number of lakes and streams that are seriously impacted by acidification. Figure 5-12 illustrates those areas of the U.S. where aquatic ecosystems are at risk from acidification.

Figure 5-12: Areas Potentially Sensitive to Aquatic Acidification (U.S. EPA, 2008f)



Because acidification primarily affects the diversity and abundance of aquatic biota, it also affects the ecosystem services that are derived from the fish and other aquatic life found in these surface waters.

While acidification is unlikely to have serious negative effects on, for example, water supplies, it can limit the productivity of surface waters as a source of food (i.e., fish). In the northeastern United States, the surface waters affected by acidification are not a major source of commercially raised or caught fish; however, they are a source of food for some recreational and subsistence fishermen and for other consumers. For example, there is evidence that certain population subgroups in the northeastern United States, such as the Hmong and Chippewa ethnic groups, have particularly high rates of self-caught fish consumption (Hutchison and Kraft, 1994; Peterson et al., 1994). However, it is not known if and how their consumption patterns are affected by the reductions in available fish populations caused by surface water acidification.

Inland surface waters support several cultural services, including aesthetic and educational services and recreational fishing. Recreational fishing in lakes and streams is among the most popular outdoor recreational activities in the northeastern United States.

Based on studies conducted in the northeastern United States, Kaval and Loomis (2003) estimated average consumer surplus values per day of $36 for recreational fishing (in 2007 dollars); therefore, the implied total annual value of freshwater fishing in the northeastern United States was $5.1 billion in 2006.[16] For recreation days, consumer surplus value is most commonly measured using recreation demand, travel cost models.

Another estimate of the overarching ecological benefits associated with reducing lake acidification levels in Adirondacks National Park can be derived from the contingent valuation (CV) survey (Banzhaf et al., 2006), which elicited values for specific improvements in acidification-related water quality and ecological conditions in Adirondack lakes. The survey described a base version with minor improvements said to result from the program, and a scope version with large improvements due to the program and a gradually worsening status quo. After adapting and transferring the results of this study and converting the 10-year annual payments to permanent annual payments using discount rates of 3% and 5%, the WTP estimates ranged from $48 to $107 per year per household (in 2004 dollars) for the base version and $54 to $154 for the scope version. Using these estimates, the aggregate annual benefits of eliminating all anthropogenic sources of NO_x and SO_x emissions were estimated to range from $291 million to $829 million (U.S. EPA, 2009c).[17]

In addition, inland surface waters provide a number of regulating services associated with hydrological and climate regulation by providing environments that sustain aquatic food webs. These services are disrupted by the toxic effects of acidification on fish and other aquatic life. Although it is difficult to quantify these services and how they are affected by acidification, some of these services may be captured through measures of provisioning and cultural services.

Terrestrial Ecosystems

Acidifying deposition has altered major biogeochemical processes in the U.S. by increasing the nitrogen and sulfur content of soils, accelerating nitrate and sulfate leaching from soil to drainage waters, depleting base cations (especially calcium and magnesium) from soils, and increasing the mobility of aluminum. Inorganic aluminum is toxic to some tree roots. Plants affected by high levels of aluminum from the soil often have reduced root growth, which restricts the ability of the plant to take up water and nutrients, especially calcium (U. S. EPA, 2008f). These direct effects can, in turn, influence the response of these plants to climatic

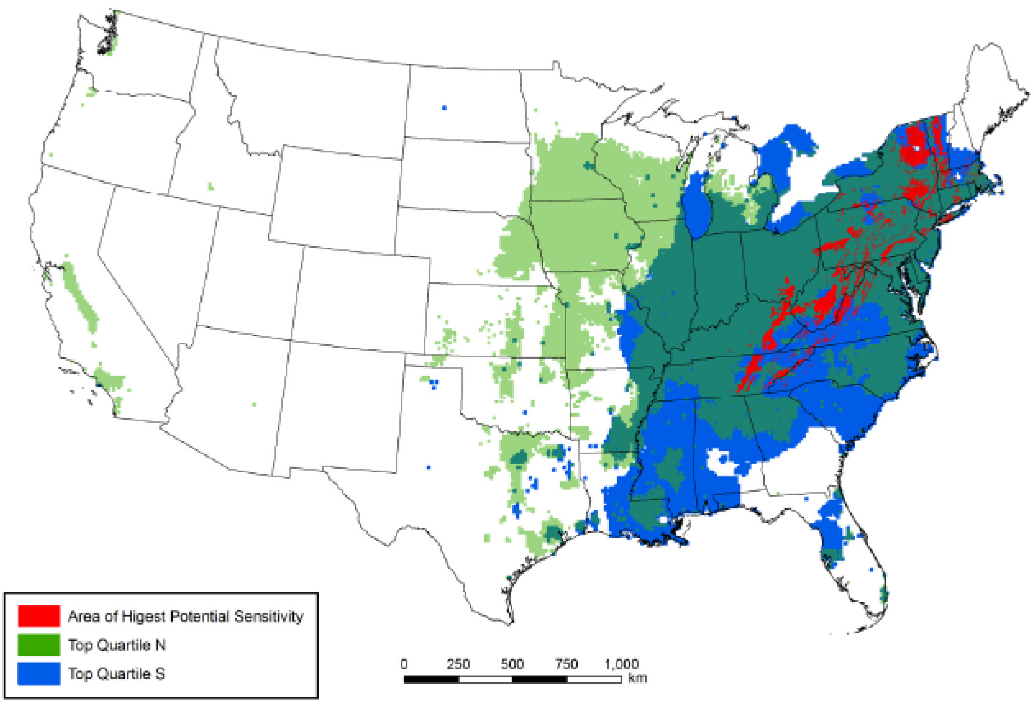
[16] These estimates reflect the total value of the service, not the marginal change in the value of the service as a result of the emission reductions achieved by this rule.

[17] These estimates reflect the total value of the service, not the marginal change in the value of the service as a result of the emission reductions achieved by this rule.

stresses such as droughts and cold temperatures. They can also influence the sensitivity of plants to other stresses, including insect pests and disease (Joslin et al., 1992) leading to increased mortality of canopy trees. In the U.S., terrestrial effects of acidification are best described for forested ecosystems (especially red spruce and sugar maple ecosystems) with additional information on other plant communities, including shrubs and lichen (U.S. EPA, 2008f).

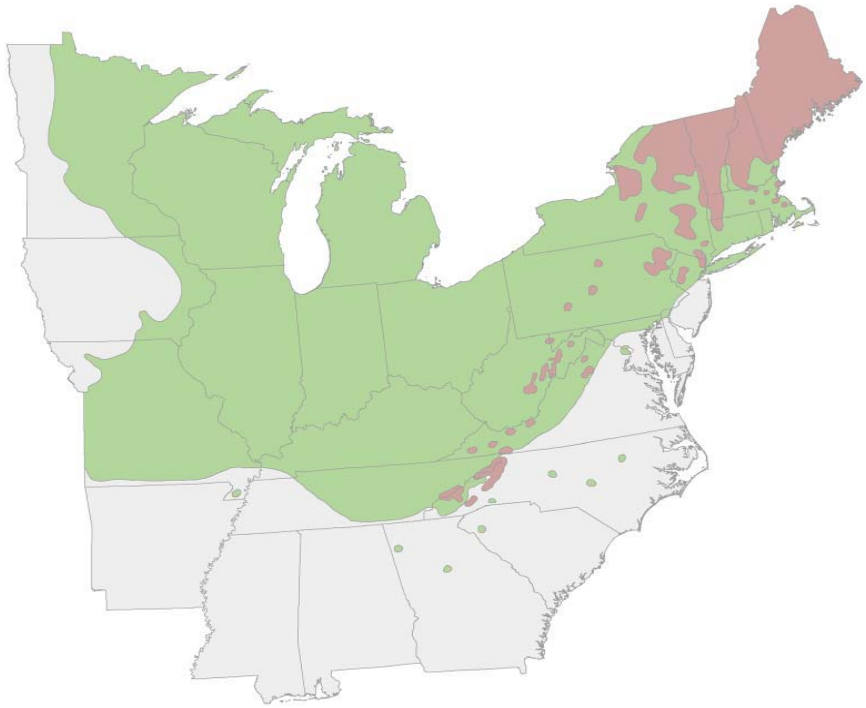
Certain ecosystems in the continental U.S. are potentially sensitive to terrestrial acidification, which is the greatest concern regarding sulfur deposition U.S. EPA (2008f). Figure 5-13 depicts the areas across the U.S. that are potentially sensitive to terrestrial acidification.

Figure 5-13: Areas Potentially Sensitive to Terrestrial Acidification (U.S. EPA, 2008f)



Both coniferous and deciduous forests throughout the eastern U.S. are experiencing gradual losses of base cation nutrients from the soil due to accelerated leaching for acidifying deposition. This change in nutrient availability may reduce the quality of forest nutrition over the long term. Evidence suggests that red spruce and sugar maple in some areas in the eastern U.S. have experienced declining health because of this deposition. For red spruce, (*Picea rubens*) dieback or decline has been observed across high elevation landscapes of the northeastern U.S., and to a lesser extent, the southeastern U.S., and acidifying deposition has been implicated as a causal factor (DeHayes et al., 1999). Figure 5-14 shows the distribution of red spruce (brown) and sugar maple (green) in the eastern U.S.

Figure 5-14: Distribution of Red Spruce (pink) and Sugar Maple (green) in the Eastern U.S. (U.S. EPA, 2008f)



Terrestrial acidification affects several important ecological endpoints, including declines in habitat for threatened and endangered species (cultural), declines in forest aesthetics (cultural), declines in forest productivity (provisioning), and increases in forest soil erosion and reductions in water retention (cultural and regulating).

Forests in the northeastern United States provide several important and valuable provisioning services in the form of tree products. Sugar maples are a particularly important commercial hardwood tree species, providing timber and maple syrup. In the United States, sugar maple saw timber was nearly 900 million board feet in 2006 (USFS, 2006), and annual production of maple syrup was nearly 1.4 million gallons, accounting for approximately 19% of worldwide production. The total annual value of U.S. production in these years was approximately $160 million (NASS, 2008). Red spruce is also used in a variety of products including lumber, pulpwood, poles, plywood, and musical instruments. The total removal of red spruce saw timber from timberland in the United States was over 300 million board feet in 2006 (USFS, 2006).

Forests in the northeastern United States are also an important source of cultural ecosystem services—nonuse (i.e., existence value for threatened and endangered species), recreational, and aesthetic services. Red spruce forests are home to two federally listed species and one delisted species:

1. Spruce-fir moss spider (*Microhexura montivaga*)—endangered
2. Rock gnome lichen (*Gymnoderma lineare*)—endangered
3. Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*)—delisted, but important

Forestlands support a wide variety of outdoor recreational activities, including fishing, hiking, camping, off-road driving, hunting, and wildlife viewing. Regional statistics on recreational activities that are specifically forest based are not available; however, more general data on outdoor recreation provide some insights into the overall level of recreational services provided by forests. More than 30% of the U.S. adult population visited a wilderness or primitive area during the previous year and engaged in day hiking (Cordell et al., 2005). From 1999 to 2004, 16% of adults in the northeastern United States participated in off-road vehicle recreation, for an average of 27 days per year (Cordell et al., 2005). The average consumer surplus value per day of off-road driving in the United States was $25 (in 2007 dollars), and the implied total annual value of off-road driving recreation in the northeastern United States was more than $9 billion (Kaval and Loomis, 2003). More than 5% of adults in the northeastern United States participated in nearly 84 million hunting days (U.S. FWS and U.S. Census Bureau, 2007). Ten percent of adults in northeastern states participated in wildlife viewing away from home on 122 million days in 2006. For these recreational activities in the northeastern United States, Kaval and Loomis (2003) estimated average consumer surplus values per day of $52 for hunting and $34 for wildlife viewing (in 2007 dollars). The implied total annual value of hunting and wildlife viewing in the northeastern United States was, therefore, $4.4 billion and $4.2 billion, respectively, in 2006.

As previously mentioned, it is difficult to estimate the portion of these recreational services that are specifically attributable to forests and to the health of specific tree species. However, one recreational activity that is directly dependent on forest conditions is fall color viewing. Sugar maple trees, in particular, are known for their bright colors and are, therefore, an essential aesthetic component of most fall color landscapes. A survey of residents in the Great Lakes area found that roughly 30% of residents reported at least one trip in the previous year involving fall color viewing (Spencer and Holecek, 2007). In a separate study conducted in Vermont, Brown (2002) reported that more than 22% of households visiting Vermont in 2001 made the trip primarily for viewing fall colors.

Two studies estimated values for protecting high-elevation spruce forests in the southern Appalachian Mountains. Kramer et al. (2003) conducted a contingent valuation study estimating households' WTP for programs to protect remaining high-elevation spruce forests from damages associated with air pollution and insect infestation. Median household WTP was estimated to be roughly $29 (in 2007 dollars) for a smaller program, and $44 for the more extensive program. Jenkins et al. (2002) conducted a very similar study in seven Southern Appalachian states on a potential program to maintain forest conditions at status quo levels. The overall mean annual WTP for the forest protection programs was $208 (in 2007 dollars). Multiplying the average WTP estimate from these studies by the total number of households in the seven-state Appalachian region results in an aggregate annual range of $470 million to $3.4 billion for avoiding a significant decline in the health of high-elevation spruce forests in the Southern Appalachian region.

Forests in the northeastern United States also support and provide a wide variety of valuable regulating services, including soil stabilization and erosion control, water regulation, and climate regulation. The total value of these ecosystem services is very difficult to quantify in a meaningful way, as is the reduction in the value of these services associated with total sulfur deposition. As terrestrial acidification contributes to root damages, reduced biomass growth, and tree mortality, all of these services are likely to be affected; however, the magnitude of these impacts is currently very uncertain.

Ecological Effects of Associated with Sulfate in the Mercury Methylation Process

Mercury is a highly neurotoxic contaminant that enters the food web as a methylated compound, methylmercury (U.S. EPA, 2008f). The contaminant is concentrated in higher trophic levels, including fish eaten by humans. Experimental evidence has established that only inconsequential amounts of methylmercury can be produced in the absence of sulfate (U.S. EPA, 2008f). Many variables influence how much mercury accumulates in fish, but elevated mercury levels in fish can only occur where substantial amounts of methylmercury are present (U.S. EPA, 2008f). Current evidence indicates that in watersheds where mercury is present, increased sulfate deposition very likely results in methylmercury accumulation in fish (Drevnick et al., 2007; Munthe et al., 2007). The ISA for Oxides of Nitrogen and Sulfur: Ecological Criteria ISA concluded that evidence is sufficient to infer a casual relationship between sulfur deposition and increased mercury methylation in wetlands and aquatic environments (U.S. EPA, 2008f).

Establishing the quantitative relationship between sulfate and mercury methylation in natural settings is difficult because of the presence of multiple interacting factors in aquatic and terrestrial environments, including wetlands, aquatic environments where sulfate, sulfur-reducing bacteria (SRB), and inorganic mercury are present (U.S. EPA, 2008f). These are the three primary requirements for bacterially-mediated conversion to methylmercury. Additional factors affecting conversion include the presence of anoxic conditions, temperature, the presence and types of organic matter, the presence and types of mercury-binding species, and watershed effects (e.g., watershed type, land cover, water body limnology, and runoff loading). With regard to methylmercury, the highest concentrations in the environment generally occur at or near the sedimentary surface, below the oxic–anoxic boundary. Although mercury methylation can occur within the water column, there is generally a far greater contribution of mercury methylation from sediments because of anoxia and of greater concentrations of SRB, substrate, and sulfate. Figure 5-15 depicts the mercury cycle.

Figure 5-15: The mercury cycle in an ecosystem (USGS, 2006)

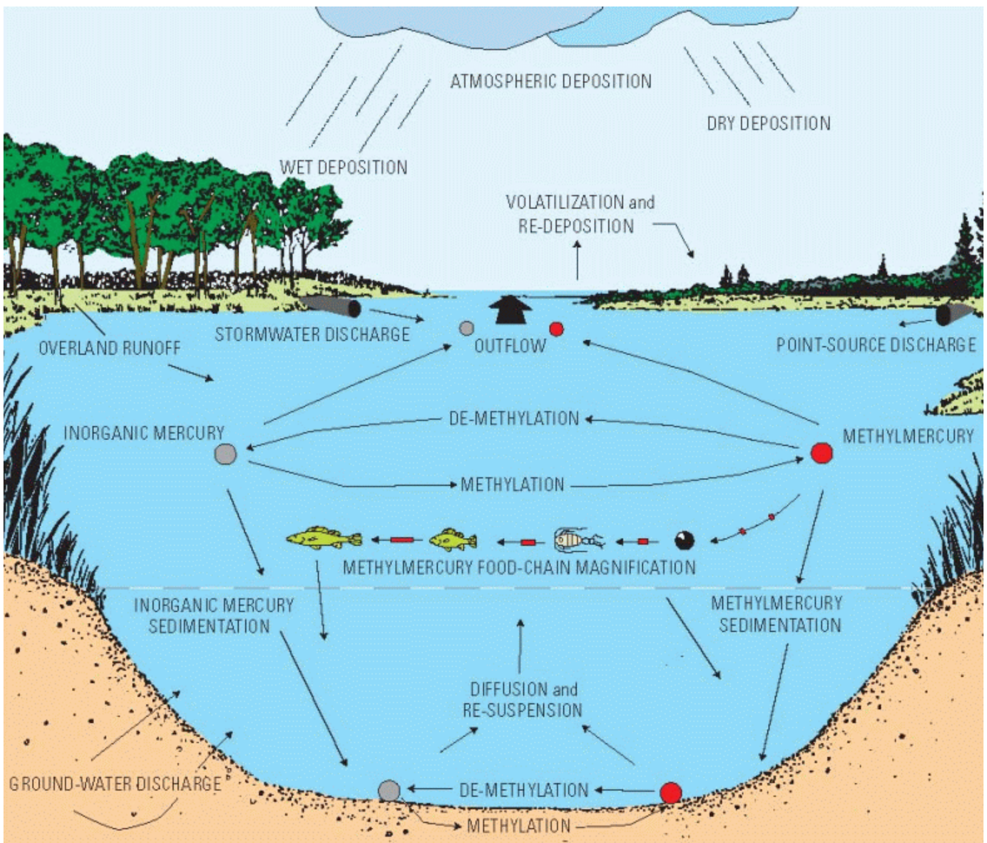
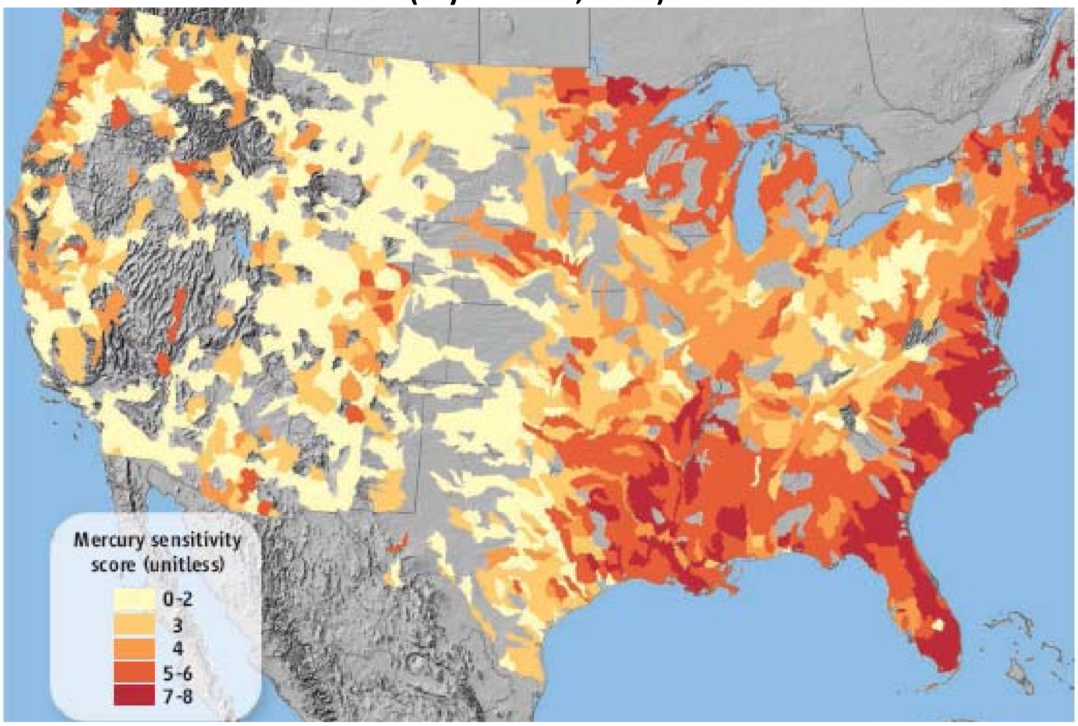


Figure 5-16 illustrates a map of mercury-sensitive watersheds based on sulfate concentrations, ANC, levels of dissolved organic carbon and pH, mercury species concentrations, and soil types to gauge the methylation sensitivity (Myers et al., 2007).

Figure 5.16: Preliminary USGS map of mercury methylation–sensitive watersheds (Myers et al., 2007)



Decreases in sulfate deposition/emissions have already shown reductions in methylmercury (U.S. EPA, 2008f). Observed decreases in methylmercury fish tissue concentrations have been linked to decreased acidification and declining sulfate and mercury deposition (Hrabik and Watras, 2002; Drevnick et al., 2007).

In the U.S., consumption of fish and shellfish are the main sources of methylmercury exposure to humans. Methylmercury builds up more in some types of fish and shellfish than in others. The levels of methylmercury in high and shellfish vary widely depending on what they eat, how long they live, and how high they are in the food chain. Most fish, including ocean species and local freshwater fish, contain some methylmercury. For example, in recent studies by EPA and the U.S. Geological Survey (USGS) of fish tissues, every fish samples contained some methylmercury.

State-level fish consumption advisories for mercury are based on state criteria, many of which are based on EPA's fish tissue criterion for methylmercury (U.S. EPA, 2001) or on U.S. Food and Drug Administration's action levels (U.S. FDA, 2001). In 2008, there were 3,361 fish advisories issued at least in part for mercury contamination (80% of all fish advisories), covering

16.8 million lake acres (40% of total lake acreage) and 1.3 million river miles (35% of total river miles) over all 50 states, one U.S. territory, and 3 tribes (U.S. EPA, 2009f). Recently, the U.S. Geological Survey (USGS) examined mercury levels in top-predator fish, bed sediment, and water from 291 streams across the U.S. (Scudder et al., 2009). USGS detected mercury contamination in every fish sampled, and the concentration of mercury in fish exceeded EPA's criterion in 27% of the sites sampled.

The ecosystem service most directly affected by sulfate-mediated mercury methylation is the provision of fish for consumption as a food source. This service is of particular importance to groups engaged in subsistence fishing, pregnant women and young children. While it is not possible to quantify the reduction in fish consumption due to the presence of methylmercury in fish from sulfur deposition, it is likely, given the number of state advisories and the EPA/FDA guidelines (U.S. EPA/FDA, 2004) on consumption for pregnant women and young children, that this service is negatively affected.

Research shows that most people's fish consumption does not cause a mercury-related health concern. However, certain people may be at higher risk because of their routinely high consumption of fish (e.g., tribal and other subsistence fishers and their families who rely heavily on fish for a substantial part of their diet). It has been demonstrated that high levels of methylmercury in the bloodstream of unborn babies and young children may harm the developing nervous system, making the child less able to think and learn. Moreover, mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages. The majority of fish consumed in the U.S. are ocean species. The methylmercury concentrations in ocean fish species are primarily influences by the global mercury pool. However, the methylmercury found in local fish can be due, at least partly, to mercury emissions from local sources.

Several studies suggest that the methylmercury content of fish may reduce these cardio-protective effects of fish consumption. Some of these studies also suggest that methylmercury may cause adverse effects to the cardiovascular system. For example, the NRC (2000) review of the literature concerning methylmercury health effects took note of two epidemiological studies that found an association between dietary exposure to methylmercury and adverse cardiovascular effects.[18] Moreover, in a study of 1,833 males in Finland aged 42 to 60 years, Solonen et al. (1995) observed a relationship between methylmercury exposure via

[18] National Research Council (NRC). 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology. National Academies Press. Washington, DC. pp.168-173.

fish consumption and acute myocardial infarction (AMI or heart attacks), coronary heart disease, cardiovascular disease, and all-cause mortality.[19] The NRC also noted a study of 917 seven year old children in the Faroe Islands, whose initial exposure to methylmercury was *in utero* although post natal exposures may have occurred as well. At seven years of age, these children exhibited an increase in blood pressure and a decrease in heart rate variability.[20] Based on these and other studies, NRC concluded in 2000 that, while "the data base is not as extensive for cardiovascular effects as it is for other end points (i.e. neurologic effects) the cardiovascular system appears to be a target for methylmercury toxicity."[21]

Since publication of the NRC report there have been some 30 published papers presenting the findings of studies that have examined the possible cardiovascular effects of methylmercury exposure. These studies include epidemiological, toxicological, and toxicokinetic investigations. Over a dozen review papers have also been published. If there is a causal relationship between methylmercury exposure and adverse cardiovascular effects, then reducing exposure to methylmercury would result in public health benefits from reduced cardiovascular effects.

In early 2010, EPA sponsored a workshop in which a group of experts were asked to assess the plausibility of a causal relationship between methylmercury exposure and cardiovascular health effects and to advise EPA on methodologies for estimating population level cardiovascular health impacts of reduced methylmercury exposure. The report from that workshop is in preparation.

Because establishing the quantitative relationship between sulfate and mercury methylation in natural settings is difficult, we were unable to model the changes in the methylation process, bioaccumulation in fish tissue, and human consumption of mercury-contaminated fish that would be needed in order to estimate the human health benefits from reducing sulfate emissions in this rule.

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[19] Salonen, J.T., Seppanen, K. Nyyssonen et al. 1995. "Intake of mercury from fish lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular and any death in Eastern Finnish men." Circulation, 91 (3):645-655.

[20] Sorensen, N, K. Murata, E. Budtz-Jorgensen, P. Weihe, and Grandjean, P., 1999. "Prenatal Methylmercury Exposure As A Cardiovascular Risk Factor At Seven Years of Age", Epidemiology, pp370-375.

[21] National Research Council (NRC). 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology. National Academies Press. Washington, DC. p. 229.

Ecological Effects Associated with Gaseous Sulfur Dioxide

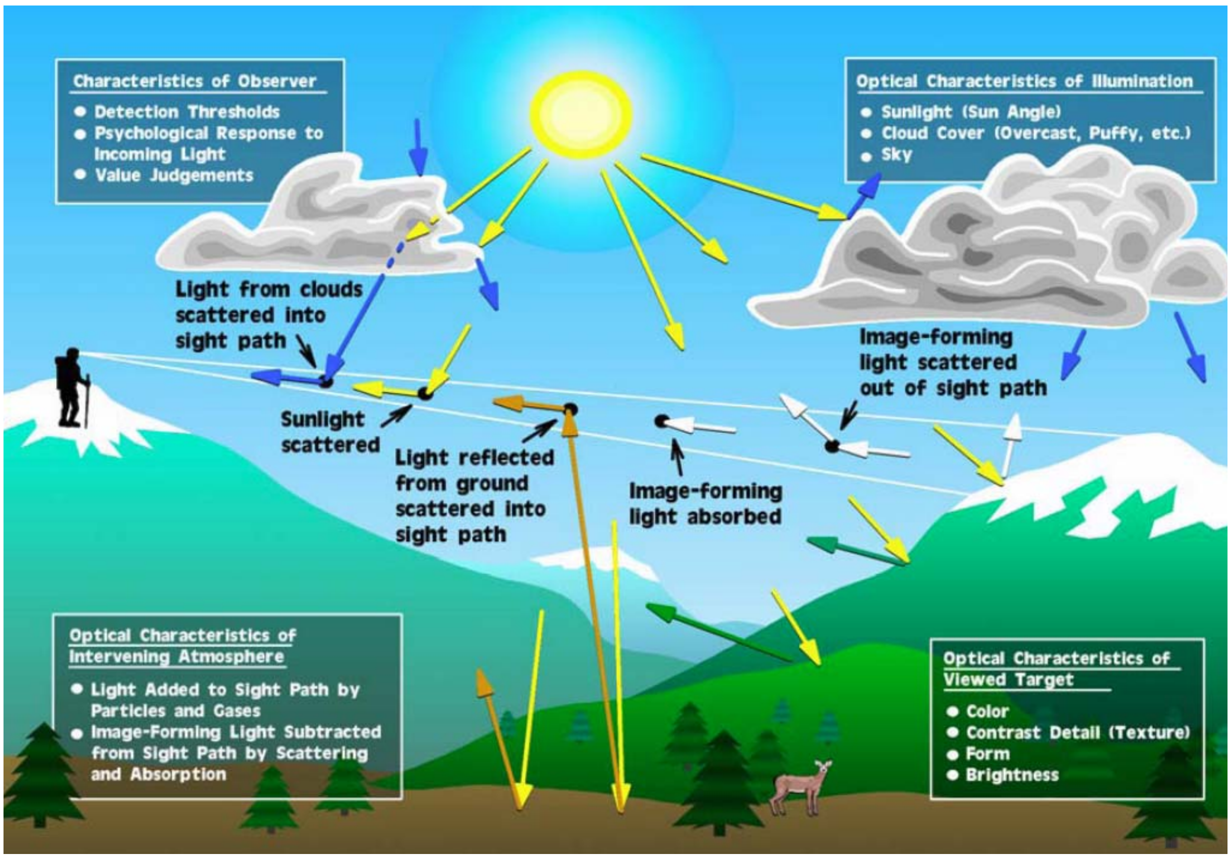
Uptake of gaseous sulfur dioxide in a plant canopy is a complex process involving adsorption to surfaces (leaves, stems, and soil) and absorption into leaves. SO_2 penetrates into leaves through to the stomata, although there is evidence for limited pathways via the cuticle. Pollutants must be transported from the bulk air to the leaf boundary layer in order to get to the stomata. When the stomata are closed, as occurs under dark or drought conditions, resistance to gas uptake is very high and the plant has a very low degree of susceptibility to injury. In contrast, mosses and lichens do not have a protective cuticle barrier to gaseous pollutants or stomates and are generally more sensitive to gaseous sulfur than vascular plants (U.S. EPA, 2008f). Acute foliar injury usually happens within hours of exposure, involves a rapid absorption of a toxic dose, and involves collapse or necrosis of plant tissues. Another type of visible injury is termed chronic injury and is usually a result of variable SO_2 exposures over the growing season. Besides foliar injury, chronic exposure to low SO_2 concentrations can result in reduced photosynthesis, growth, and yield of plants (U.S. EPA, 2008f). These effects are cumulative over the season and are often not associated with visible foliar injury. As with foliar injury, these effects vary among species and growing environment. SO_2 is also considered the primary factor causing the death of lichens in many urban and industrial areas (Hutchinson et al., 1996).

5.9.2 Visibility Improvements

Reductions in SO_2 emissions and secondary formation of $PM_{2.5}$ due to the alternative standards will improve the level of visibility throughout the United States. These suspended particles and gases degrade visibility by scattering and absorbing light. 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. Without the necessary air quality data, we were unable to calculate the predicted change in visibility due to control strategy to attain various alternate standard levels. However, in this section, we describe the process by which SO_2 emissions impair visibility and how this impairment affects the public.

Visual air quality (VAQ) is commonly measured as either light extinction, which is defined as the loss of light per unit of distance in terms of inverse megameters (Mm^{-1}) or the deciview (dv) metric (Pitchford and Malm, 1993), which is a logarithmic function of extinction. Extinction and deciviews are physical measures of the amount of visibility impairment (e.g., the amount of "haze"), with both extinction and deciview increasing as the amount of haze increases. Pitchford and Malm characterize a change of one deciview as "a small but perceptible scenic change under many circumstances." Light extinction is the optical characteristic of the atmosphere that occurs when light is either scattered or absorbed, which converts the light to heat. Particulate matter and gases can both scatter and absorb light. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil (Sisler, 1996). The extent to which any amount of light extinction affects a person's ability to view a scene depends on both scene and light characteristics. For example, the appearance of a nearby object (i.e. a building) is generally less sensitive to a change in light extinction than the appearance of a similar object at a greater distance. See Figure 5-17 for an illustration of the important factors affecting visibility.

Figure 5-17: Important factors involved in seeing a scenic vista (Malm, 1999)



In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., the U.S. EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network known as IMPROVE (Interagency Monitoring of Protected Visual Environments) now includes 150 sites that represent almost all of the Class I areas across the country (see Figure 5-18) (U.S. EPA, 2009d).

Figure 5-18: Mandatory Class I Areas in the U.S.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. (U.S. EPA, 2009d). The rural East generally has higher levels of impairment than remote sites in the West, with the exception of urban-influenced sites such as San Gorgonio Wilderness (CA) and Point Reyes National Seashore (CA), which have annual average levels comparable to certain sites in the Northeast (U.S. EPA, 2004). Higher visibility impairment levels in the East are due to generally higher concentrations of fine particles, particularly sulfates, and higher average relative humidity levels. While visibility trends have improved in most Class I areas, the recent data show that these areas continue to suffer from visibility impairment. In eastern parks, average visual range has decreased from 90 miles to 15-25 miles, and in the West, visual range has decreased from 140 miles to 35-90 miles (U.S. EPA, 2004; U.S. EPA, 1999b).

Visibility has direct significance to people's enjoyment of daily activities and their overall sense of wellbeing (U.S. EPA, 2009d). Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities. When the necessary AQ data is available, EPA generally considers benefits from these two categories of visibility changes: residential visibility (i.e., the visibility in and around the locations where people live) and recreational visibility (i.e., visibility at Class I national parks and wilderness areas.) 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 bird watching. Nonuse values are based on people's beliefs that the environment ought to exist free of human-induced haze. Nonuse values may be more important for recreational areas, particularly national parks and monuments. In addition, evidence suggests 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 (Chestnut and Rowe, 1990). 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. EPA generally uses a contingent valuation study as the basis for monetary estimates of the benefits of visibility changes in recreational areas (Chestnut and Rowe, 1990). To estimate the monetized value of visibility changes, an analyst would multiply the willingness-to-pay estimates by the amount of visibility impairment, but this information in unavailable for this analysis.

5.10 Limitations and Uncertainties

The National Research Council (NRC) (2002) concluded that EPA's general methodology for calculating the benefits of reducing air pollution is reasonable and informative in spite of inherent uncertainties. To address these inherent uncertainties, NRC highlighted the need to conduct rigorous quantitative analysis of uncertainty and to present benefits estimates to decisionmakers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that strategy include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

In this analysis, we use three methods to assess uncertainty quantitatively: Monte Carlo analysis, sensitivity analysis, and alternate concentration-response functions for PM mortality. We also provide a qualitative assessment for those aspects that we are unable to address quantitatively in this analysis. Each of these analyses is described in detail in the following sections.

This analysis includes many data sources as inputs, including emission inventories, air quality data from models (with their associated parameters and inputs), population data, health effect estimates from epidemiology studies, and economic data for monetizing benefits. Each of these inputs may be uncertain and would affect the benefits estimate. When the uncertainties from each stage of the analysis are compounded, small uncertainties can have large effects on the total quantified benefits. In this analysis, we are unable to quantify the cumulative effect of all of these uncertainties, but we provide the following analyses to characterize many of the largest sources of uncertainty.

5.10.1 Monte Carlo analysis

Similar to other recent RIAs, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions and economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of morbidity. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates, as shown in Table 5.6 for SO_2 benefits. Unfortunately, the associated confidence intervals are not available for the $PM_{2.5}$ co-benefits due to limitations in the benefit-per-ton methodology.

5.10.2 Sensitivity analyses

We performed a variety of sensitivity analyses on the benefits results to assess the sensitivity of the primary results to various data inputs and assumptions. We then changed each default input one at a time and recalculated the total monetized benefits to assess the percent change from the default. In Tables 5.6 and 5.12, we provided the results of this sensitivity analysis. We indicate each input parameter, the value used as the default, and the values for the sensitivity analyses, and then we provide the total monetary benefits for each input and the percent change from the default value. This sensitivity analysis indicates that the results are most sensitive to assumptions regarding the attainment status and the threshold assumption in the PM-mortality relationship, and the results are less sensitive to alternate assumptions regarding the interpolation method, discount rate, and various assumptions regarding SO_2 exposure. To account for the large difference in magnitude between benefits from reduced SO_2 exposure and $PM_{2.5}$ exposure, we provide separate sensitivity analyses. We show the sensitivity analysis for selected standard (75 ppb), but other standard levels would show similar sensitivity to these perturbations, albeit with smaller magnitudes. Descriptions of the sensitivity analyses are provided in the relevant sections of this chapter.

5.10.3 Alternate concentration-response functions for PM mortality

$PM_{2.5}$ mortality co-benefits are the largest benefit category that we monetized in this analysis. To better understand the concentration-response relationship between $PM_{2.5}$ exposure and premature mortality, EPA conducted an expert elicitation in 2006 (Roman et al., 2008; IEc, 2006). In general, the results of the expert elicitation support the conclusion that the benefits of $PM_{2.5}$ control are very likely to be substantial. In previous RIAs, EPA presented benefits estimates using concentration response functions derived from the $PM_{2.5}$ Expert Elicitation as a range from the lowest expert value (Expert K) to the highest expert value (Expert E). However, this approach did not indicate the agency's judgment on what the best estimate of PM benefits may be, and EPA's Science Advisory Board described this presentation as misleading. Therefore, we began to present the cohort-based studies (Pope et al, 2002; and Laden et al., 2006) as our core estimates in the Portland Cement RIA (U.S. EPA, 2009a). Using alternate relationships between $PM_{2.5}$ and premature mortality supplied by experts, higher and lower benefits estimates are plausible, but most of the expert-based estimates fall between the two epidemiology-based estimates (Roman et al., 2008).

In this analysis, we present the results derived from the expert elicitation as indicative of the uncertainty associated with a major component of the health impact functions, and we provide the independent estimates derived from each of the twelve experts to better characterize the degree of variability in the expert responses. In this chapter, we provide the results using the concentration-response functions derived from the expert elicitation in both tabular (Table 5.11) and graphical form (Figure 5.1). Please note that these results are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response function provided in those studies. Because in this RIA we estimate PM co-benefits using benefit-per-ton estimates, technical limitations prevent us from providing the associated credible intervals with the expert functions.

5.10.4 Qualitative assessment of uncertainty and other analysis limitations

Although we strive to incorporate as many quantitative assessments of uncertainty, there are several aspects for which we are only able to address qualitatively. These aspects are important factors to consider when evaluating the relative benefits of the attainment strategies for each of the alternative standards:

1. The 12 km by 12 km resolution of the air quality modeling grid may be too coarse to accurately estimate the potential near-field health benefits of reducing SO_2 emissions. These uncertainties likely result in an underestimate of the SO_2-related benefits.
2. The interpolation techniques used to estimate the full attainment benefits from reduced SO_2 exposure of the alternative standards contributed some uncertainty to the analysis. The great majority of benefits estimated for the various standard levels were derived through interpolation. As noted previously in this chapter, these benefits are likely to be more uncertain than if we had modeled the air quality scenario for both SO_2 and $PM_{2.5}$. In general, the VNA interpolation approach will underestimate benefits because it does not account for the broader spatial distribution of air quality changes that may occur due to the implementation of a regional emission control program.
3. There are many uncertainties associated with the health impact functions used in this modeling effort. These include: within study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of C-R functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the C-R function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.
4. Co-pollutants present in the ambient air may have contributed to the health effects attributed to SO_2 in single pollutant models. Risks attributed to SO_2 might be overestimated where concentration-response functions are based on single pollutant models. If co-pollutants are highly correlated with SO_2, their inclusion in an SO_2 health effects model can lead to misleading conclusions in identifying a specific causal pollutant. Because this collinearity exists, many of the studies reported statistically insignificant effect estimates for both SO_2 and the co-pollutants; this is due in part to the loss of statistical power as these models control for co-pollutants. Where available, we have selected multipollutant effect estimates to control for the potential confounding effects of co-pollutants; these include NYDOH (2006), Schwartz et al. (1994) and O'Connor et al. (2008). The remaining studies include single pollutant models.
5. This analysis is for the year 2020, and projecting key variables introduces uncertainty. 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.

6. This analysis omits certain unquantified effects due to lack of data, time and resources. These unquantified endpoints include other health effects, ecosystem effects, and visibility. EPA will continue to evaluate new methods and models and select those most appropriate for estimating the benefits of reductions in air pollution. Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, ecologists, and economists should result in a more tightly integrated analytical framework for measuring benefits of air pollution policies.

7. $PM_{2.5}$ co-benefits represent a substantial proportion of total monetized benefits (over 99% of total monetized benefits), and these estimates are subject to a number of assumptions and uncertainties.

    a. $PM_{2.5}$ co-benefits were derived through benefit per-ton estimates, which do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an over-estimate or under-estimate of the actual benefits of controlling directly emitted fine particulates.

    b. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.

    c. We assume that the health impact function for fine particles is linear down to the lowest air quality levels modeled in this analysis. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.

    d. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality, we include a set of twelve estimates based on results of the expert elicitation study in addition to our core estimates. Even these multiple characterizations omit the uncertainty in air quality estimates, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the $PM_{2.5}$ estimates.

This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis. For more information on the uncertainties associated with $PM_{2.5}$ co-benefits, please consult the $PM_{2.5}$ NAAQS RIA (Table 5.5).

5.11 Discussion

The results of this benefits analysis suggest that fully attaining the selected SO_2 standard of 75 ppb would produce important health benefits from reduced SO_2 exposure in the form of fewer respiratory hospitalizations, respiratory emergency department visits and cases of acute respiratory symptoms. In addition, attaining the selected SO_2 standard standards would also produce substantial health co-benefits from reducing $PM_{2.5}$ exposure in the form of avoided premature mortality and other morbidity effects.

The proposal version of this analysis was the first time that EPA has estimated the monetized human health benefits of reducing exposure to SO_2 to support a change in the NAAQS. In contrast to recent $PM_{2.5}$ and ozone-related benefits assessments, there was far less analytical precedent on which to base this assessment. For this reason, we developed entirely new components of the health impact analysis, including the identification of health endpoints to be quantified and the selection of relevant effect estimates within the epidemiology literature. Because we did not receive any substantive comments on this approach during the comment period, we duplicated this methodology using the updated air quality estimates for the final RIA. As the SO_2 health literature continues to evolve, EPA will reassess the health endpoints and risk estimates used in this analysis.

While the monetized benefits of reduced SO_2 exposure appear small when compared to the monetized benefits of reduced $PM_{2.5}$ exposure, readers should not necessarily infer that the total monetized benefits of attaining a new SO_2 standard are minimal. As shown in Table 5.13, the monetized $PM_{2.5}$ co-benefits represent over 99% of the total monetized benefits. This result is consistent with other recent RIAs, where the $PM_{2.5}$ co-benefits represent a large proportion of total monetized benefits. This result is amplified in this RIA by the decision not to quantify SO_2-related premature mortality and other morbidity endpoints due to the uncertainties associated with estimating those endpoints. Studies have shown that there is a relationship between SO_2 exposure and premature mortality, but that relationship is limited by potential confounding. Because premature mortality generally comprises over 90% of the total monetized benefits, this decision may substantially underestimate the monetized health benefits of reduced SO_2 exposure.

We were unable to quantify the benefits from several welfare benefit categories. We lacked the necessary air quality data to quantify the benefits from improvements in visibility from reducing light-scattering particles. Previous RIAs for ozone (U.S. EPA, 2008a) and $PM_{2.5}$ (U.S. EPA, 2006a) indicate that visibility is an important benefit category, and previous efforts to monetize those benefits have only included a subset of visibility benefits, excluding benefits in urban areas and many national and state parks. Even this subset accounted for up to 5% of total monetized benefits in the Ozone NAAQS RIA (U.S. EPA, 2008a).

We were also unable to quantify the ecosystem benefits of reduced sulfur deposition because we lacked the necessary air quality data and resources to run the ecosystem benefits models. Previous assessments (U.S. EPA, 1999a; U.S. EPA, 2005; U.S. EPA, 2009e) indicate that ecosystem benefits are also an important benefits category, but those efforts were only able to monetize a tiny subset of ecosystem benefits in specific geographic locations, such as recreational fishing effects from lake acidification in the Adirondacks. We were also unable to quantify the benefits of decreased mercury methylation from sulfate deposition. Quantifying the relationship between sulfate and mercury methylation in natural settings is difficult, but some studies have shown that decreasing sulfate deposition can also decrease methylmercury.

In section 5.7 of this RIA, we discuss the revised presentation using benefits based on Pope et al. and Laden et al. as the core estimates instead of using the range based on the low and high end of the expert elicitation. This change was incorporated in direct response to recommendations from EPA's Science Advisory Board (U.S.EPA-SAB, 2008). Although using benefit-per-ton estimates limited our ability to incorporate all of their suggestions fully, we have incorporated the following recommendations into this analysis:

- Added "bottom line" statements where appropriate
- Clarified that the benefits results shown are not the actual judgments of the experts
- Acknowledged uncertainties exist at each stage of the analytic process, although difficult to quantify when using benefit-per-ton estimates
- Did not use the expert elicitation range to characterize the uncertainty as it focuses on the most extreme judgments with zero weight to all the others,
- Described the rationale for using expert elicitation in the context of the regulatory process (to characterize uncertainty)
- Identified results based on epidemiology studies and expert elicitation separately
- Showed central mass of expert opinion using graphs
- Presented the quantitative results using diverse tables and more graphics

5.12 References

Abt Associates. 2008. Environmental Benefits and Mapping Program (Version 3.0). Bethesda, MD. Prepared for U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC. Available on the Internet at <http://www.epa.gov/air/benmap>.

Agency for Healthcare Research and Quality (AHRQ). 2000. HCUPnet, Healthcare Cost and Utilization Project.

Banzhaf, S., D. Burtraw, D. Evans, and A. Krupnick. 2006. "Valuation of Natural Resource Improvements in the Adirondacks." Land Economics 82:445-464.

Brown, L.H. 2002. Profile of the Annual Fall Foliage Tourist in Vermont: Travel Year 2001. Report prepared for the Vermont Department of Tourism and Marketing and the Vermont Tourism Data Center in association with the University of Vermont, Burlington, VT.

Chestnut, L.G., and R.D. Rowe. 1990. A New National Park Visibility Value Estimates. In Visibility and Fine Particles, Transactions of an AWMA/EPA International Specialty Conference, C.V. Mathai, ed. Air and Waste Management Association, Pittsburgh.

Cordell, H.K., C.J. Betz, G. Green, and M. Owens. 2005. Off-Highway Vehicle Recreation in the United States, Regions and States: A National Report from the National Survey on Recreation and the Environment (NSRE). Prepared for the U.S. Department of Agriculture Forest Service, Southern Research Station, National OHV Policy and Implementation Teams, Athens, GA. Available on the Internet at <http://www.fs.fed.us/recreation/programs/ohv/OHV_final_report.pdf>.

Cropper, M. L. and A. J. Krupnick. 1990. The Social Costs of Chronic Heart and Lung Disease. Resources for the Future. Washington, DC. Discussion Paper QE 89-16-REV.

DeHayes, D.H., P.G. Schaberg, G.J. Hawley, and G.R. Strimbeck. 1999. Acid rain impacts on calcium nutrition and forest health. Bioscience 49(10):789–800.

Delfino, R. J., H. Gong, Jr., W. S. Linn, E. D. Pellizzari and Y. Hu. 2003. Asthma symptoms in Hispanic children and daily ambient exposures to toxic and criteria air pollutants. Environ Health Perspect. Vol. 111 (4): 647-56.

Dewanji, A. and S. H. Moolgavkar. 2000. A Poisson process approach for recurrent event data with environmental covariates. Environmetrics. Vol. 11: 665-673.

Dewanji, A. and S. H. Moolgavkar. 2002. Choices of stratification in Poisson process analysis of recurrent event data with environmental covariates. Stat. Med. Vol. 21: 3383-3393.

Drevnick, P.E., D.E. Canfield, P.R. Gorski, A.L.C. Shinneman, D.R. Engstrom, D.C.G. Muir, G.R. Smith, P.J. Garrison, L.B. Cleckner, J.P. Hurley, R.B. Noble, R.R. Otter, and J.T.Oris. 2007. Deposition and cycling of sulfur controls mercury accumulation in Isle Royale fish. Environmental Science and Technology 41(21):7266–7272.

Fann, N., C.M. Fulcher, B.J. Hubbell. 2009. The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health (2009) 2:169–176.

Fung, K. Y., S. Khan, D. Krewski and Y. Chen. 2006. Association between air pollution and multiple respiratory hospitalizations among the elderly in Vancouver, Canada. Inhal Toxicol. Vol. 18 (13): 1005-11.

Guallar, et. al., 2002. "Mercury, Fish Oils, and the Risk of Myocardial Infarction." New England Journal of Medicine, Vol. 374, No. 22, November.

Hallgren et al. 2001. "Markers of high fish intake are associated with decreased risk of a first myocardial infarction," British Journal of Nutrition, 86, 397-404.

Hrabik, T.R., and C.J. Watras. 2002. Recent declines in mercury concentration in a freshwater fishery: isolating the effects of de-acidification and decreased atmospheric mercury deposition in Little Rock Lake. Science of the Total Environment 297:229–237.

Hutchison, R., and C.E. Kraft. 1994. Hmong Fishing Activity and Fish Consumption. Journal of Great Lakes Research 20(2):471–487.

Industrial Economics, Incorporated (IEc). March 31., 1994. Memorandum to Jim DeMocker, Office of Air and Radiation, Office of Policy Analysis and Review, U.S. Environmental Protection Agency.

Industrial Economics, Inc. 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between $PM_{2.5}$ Exposure and Mortality. Prepared for the U.S. EPA, Office of Air Quality Planning and Standards, September. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf>.

Ito, K., G. D. Thurston and R. A. Silverman. 2007. Characterization of $PM_{2.5,}$ gaseous pollutants, and meteorological interactions in the context of time-series health effects models. J Expo Sci Environ Epidemiol. Vol. 17 Suppl 2: S45-60.

Jenkins, D.H., J. Sullivan, and G.S. Amacher. 2002. Valuing high altitude spruce-fir forest improvements: Importance of forest condition and recreation activity. Journal of Forest Economics 8:77–99.

Joslin, J.D., Kelly, J.M., van Miegroet, H. 1992. Soil chemistry and nutrition of North American spruce-fir stands: evidence for recent change. Journal of Environmental Quality, 21, 12-30.

Kaval, P., and J. Loomis. 2003. Updated Outdoor Recreation Use Values With Emphasis On National Park Recreation. Final Report October 2003, under Cooperative Agreement CA 1200-99-009, Project number IMDE-02-0070.

Kochi, I., B. Hubbell, and R. Kramer. 2006. An Empirical Bayes Approach to Combining Estimates of the Value of Statistical Life for Environmental Policy Analysis. Environmental and Resource Economics. 34: 385-406.

Kramer, A., T. Holmes, and M. Haefel. 2003. Contingent valuation of forest ecosystem protection. Pp. 303–320 in Forests in a Market Economy. Edited by E.O. Sills and K.L. Abt. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Krupnick, A.J., and M.L. Cropper. 1992. The Effect of Information on Health Risk Valuations. Journal of Risk and Uncertainty 5(2):29-48.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. “Reduction in Fine Particulate Air Pollution and Mortality.” American Journal of Respiratory and Critical Care Medicine 173:667-672. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

Luginaah, I. N., K. Y. Fung, K. M. Gorey, G. Webster and C. Wills. 2005. Association of ambient air pollution with respiratory hospitalization in a government-designated "area of concern": the case of Windsor, Ontario. Environ Health Perspect. Vol. 113 (3): 290-6.

Malm, WC. 1999. Introduction to visibility. Colorado State University, Fort Collins, CO, USA, 1983, Revised edition, 1999. Available on the Internet at <vista.cira.colostate.edu/improve/Education/IntroToVisinstr.htm>.

Michaud, J. P., J. S. Grove and D. Krupitsky. 2004. Emergency department visits and "vog"-related air quality in Hilo, Hawai'i. Environ Res. Vol. 95 (1): 11-9.

Millennium Ecosystem Assessment Board (MEA). 2005. Ecosystems and Human Well-being: Synthesis. Washington, DC: World Resources Institute.

Mortimer, K. M., L. M. Neas, D. W. Dockery, S. Redline and I. B. Tager. 2002. The effect of air pollution on inner-city children with asthma. Eur Respir J. Vol. 19 (4): 699-705.

Mrozek, J.R., and L.O. Taylor. 2002. “What Determines the Value of Life? A Meta-Analysis.” Journal of Policy Analysis and Management 21(2):253-270.

Munthe, J., R.A. Bodaly, B.A. Branfireun, C.T. Driscoll, C.C. Gilmour, R. Harris, M. Horvat, M. Lucotte, and O. Malm. 2007. Recovery of mercury-contaminated fisheries. AMBIO:A Journal of the Human Environment 36:33–44.

Myers, M.D., M.A. Ayers, J.S. Baron, P.R. Beauchemin, K.T. Gallagher, M.B. Goldhaber, D.R. Hutchinson, J.W. LaBaugh, R.G. Sayre, and S.E. Schwarzbach. 2007. USGS goals for the coming decade. Science 318:200–201.

National Agricultural Statistics Service (NASS). 2008. Maple Syrup – June 12, 2008: Maple Syrup Production Up 30 Percent Nationwide. U.S. Department of Agriculture, National Agricultural Statistics Service, New England Agricultural Statistics, Concord, NH.

National Center for Health Statistics (NCHS). 1999a. Health Interview Survey (HIS). National Vital Statistics Reports. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. Washington, DC. Volume 47, Number 19. June 30.

National Center for Health Statistics (NCHS). 1999b. National Hospital Discharge Survey (NHDS). Available on the internet at <ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS>.

National Center for Health Statistics (NCHS). 2000. National Hospital Ambulatory Medical Care Survey (NHAMCS). Available on the internet at <ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS>.

National Research Council (NRC). 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology. National Academies Press. Washington, DC.

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

Neumann, J.E., M.T. Dickie, and R.E. Unsworth. March 31, 1994. “Linkage Between Health Effects Estimation and Morbidity Valuation in the Section 812 Analysis—Draft Valuation Document.” Industrial Economics Incorporated (IEc) Memorandum to Jim DeMocker, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy Analysis and Review.

New York Department of Health (NYDOH). 2006. A Study of Ambient Air Contaminants and Asthma in New York City. New York State Department of Health Center for Environmental Health.

O'Connor, G. T., L. Neas, B. Vaughn, M. Kattan, H. Mitchell, E. F. Crain, R. Evans, 3rd, R. Gruchalla, W. Morgan, J. Stout, G. K. Adams and M. Lippmann. 2008. Acute respiratory health effects of air pollution on children with asthma in US inner cities. J Allergy Clin Immunol. Vol. 121 (5): 1133-1139 e1.

Peel, J. L., P. E. Tolbert, M. Klein, K. B. Metzger, W. D. Flanders, K. Todd, J. A. Mulholland, P. B. Ryan and H. Frumkin. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology. Vol. 16 (2): 164-74.

Peterson, D.E., M.S. Kanarek, M.A. Kuykendall, J.M. Diedrich, H.A. Anderson, P.L. Remington, and T.B. Sheffy. 1994. Fish Consumption Patterns and Blood Mercury Levels in Wisconsin Chippewa Indians. Archives of Environmental Health 49(1):53–58.

Pitchford, M. and W. Malm. 1993. Development and applications of a standard visual index. Atmospheric Environment 28(5):1049-1054.

Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132-1141.

Rissanen, T., S Voutilainen, T.A. Lakka, and J.T. Salonen. 2000. "Fish oil-derived fatty acids, docasahexaenoic acid and docosapentainoic acid, and the risk of acute coronary events: The Kuopio ischaemic heart disease risk factor study", Circulation. 102(22), pp2677-2679.

Roman, Henry A., Katherine D. Walker, Tyra L. Walsh, Lisa Conner, Harvey M. Richmond, Bryan J. Hubbell, and Patrick L. Kinney. 2008. Expert Judgment Assessment of the Mortality Impact of Changes in Ambient Fine Particulate Matter in the U.S. Environ. Sci. Technol., 42(7):2268-2274.

Rowe, R. D. and L. G. Chestnut. 1986. Oxidants and Asthmatics in Los Angeles: A Benefits Analysis -- Executive Summary. Prepared for U.S. Environmental Protection Agency, Office of Policy Analysis. Prepared by Energy and Resource Consultants, Inc. Washington, DC. EPA-230-09-86-018. March.

Russell, M.W., D.M. Huse, S. Drowns, E.C. Hamel, and S.C. Hartz. 1998. "Direct Medical Costs of Coronary Artery Disease in the United States." American Journal of Cardiology 81(9):1110-1115.

Salonen, J.T., Seppanen, K. Nyyssonen et al. 1995. "Intake of mercury from fish lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular and any death in Eastern Finnish men." Circulation, 91 (3):645-655.

Salonen, J.T., Seppanen,T.A. Lakka, R. Salonen and G.A. Kaplan. 2000. "Mercury accumulation and accelerated progression of carotid atherosclerosis: A population-based prospective 4-year follow-up study in men in Eastern Finland. Atherosclerosis. 148: pp265-273.

Schildcrout, J. S., L. Sheppard, T. Lumley, J. C. Slaughter, J. Q. Koenig and G. G. Shapiro. 2006. Ambient air pollution and asthma exacerbations in children: an eight-city analysis. Am J Epidemiol. Vol. 164 (6): 505-17.

Schwartz, J., D. W. Dockery, L. M. Neas, D. Wypij, J. H. Ware, J. D. Spengler, P. Koutrakis, F. E. Speizer and B. G. Ferris. 1994. Acute Effects of Summer Air Pollution on Respiratory Symptom Reporting in Children. Am J Respir Crit Care Med. Vol. 150 (5): 1234-1242.

Schwartz, J., C. Spix, G. Touloumi, L. Bacharova, T. Barumamdzadeh, A. le Tertre, T. Piekarksi, A. Ponce de Leon, A. Ponka, G. Rossi, M. Saez and J. P. Schouten. 1996. Methodological issues in studies of air pollution and daily counts of deaths or hospital admissions. J Epidemiol Community Health. Vol. 50 Suppl 1: S3-11.

Scudder, B.C., Chasar, L.C., Wentz, D.A., Bauch, N.J., Brigham, M.E., Moran, P.W., and Krabbenhoft, D.P. 2009. Mercury in fish, bed sediment, and water from streams across the United States, 1998–2005: U.S. Geological Survey Scientific Investigations Report 2009–5109, 74 p.

Sisler, J.F. 1996. Spatial and seasonal patterns and long-term variability of the composition of the haze in the United States: an analysis of data from the IMPROVE network. CIRA Report, ISSN 0737-5352-32, Colorado State University.

Smith, D. H., D. C. Malone, K. A. Lawson, L. J. Okamoto, C. Battista and W. B. Saunders. 1997. A national estimate of the economic costs of asthma. Am J Respir Crit Care Med. Vol. 156 (3 Pt 1): 787-93.

Sorensen, N. , K. Murata, E. Budtz-Jorgensen, P. Weihe, and Grandjean, P., 1999. “Prenatal Methylmercury Exposure As A Cardiovascular Risk Factor At Seven Years of Age”, Epidemiology, pp370-375.

Spencer, D.M., and D.F. Holecek. 2007. Basic characteristics of the fall tourism market. Tourism Management 28:491–504.

Stanford, R., T. McLaughlin and L. J. Okamoto. 1999. The cost of asthma in the emergency department and hospital. Am J Respir Crit Care Med. Vol. 160 (1): 211-5.

Stern, A. 2005, “A review of the studies of the cardiovascular health effects of methylmercury with consideration of their suitability for risk assessment,” Environmental Research, 98 133-142.

Tolley, G.S. et al. 1986. Valuation of Reductions in Human Health Symptoms and Risks. University of Chicago. Final Report for the U.S. Environmental Protection Agency. January

U.S. Environmental Protection Agency (U.S. EPA). 1999a. The Benefits and Costs of the Clean Air Act 1990 to 2010: EPA Report to Congress. EPA-410-R-99-001. Office of Air and Radiation, Office of Policy, Washington, DC. November. Available on the Internet at < http://www.epa.gov/air/sect812/1990-2010/fullrept.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 1999b. Regional Haze Regulations, July 1, 1999. (64 FR 35714, July 1, 1999).

U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury (Final). Office of Science and Technology. Office of Water. January. Washington, DC. Available on the Internet at <http://www.epa.gov/waterscience/criteria/methylmercury/document.html>.

U.S. Environmental Protection Agency (U.S. EPA). 2002. Letter to Recipients of Third Draft EPA PM Criteria Document. National Center for Environmental Assessment, Research Triangle Park, NC. June 5, 2002. Available on the Internet at <http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=42380>.

U.S. Environmental Protection Agency (U.S. EPA). 2004. Air Quality Criteria for Particulate Matter. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

U.S. Environmental Protection Agency (U.S. EPA). 2005. Regulatory Impact Analysis for the Final Clean Air Interstate Rule. Office of Air and Radiation. March. Available on the Internet at < http://www.epa.gov/cair/pdfs/finaltech08.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2006a. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for Particulate Matter, Chapter 5. Office of Air Quality Planning and Standards, Research Triangle Park, NC. October. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2006c. Ecological Benefits Assessment Strategic Plan. EPA-240-R-06-001. Office of the Administrator. Washington, DC. October. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/EcologBenefitsPlan.html>.

U.S. Environmental Protection Agency (U.S. EPA). 2008a. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air

Quality Planning and Standards, Research Triangle Park, NC. March. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2008b. Technical Support Document: Calculating Benefit Per-Ton estimates, Ozone NAAQS Docket #EPA-HQ-OAR-2007-0225-0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at <http://www.regulations.gov>.

U.S. Environmental Protection Agency (U.S. EPA). 2008c. Integrated Science Assessment for Sulfur Oxides - Health Criteria (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. September. Available on the Internet at < http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843>.

U.S. Environmental Protection Agency (U.S. EPA). 2008d. Guidelines for Preparing Economic Analyses: External Review Draft. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2008f. Integrated Science Assessment for Oxides of Nitrogen and Sulfur –Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.

U.S. Environmental Protection Agency (U.S. EPA). 2009a. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2009c. Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards: Final Report. Office of Air Quality Planning and Standards, Research Triangle Park, NC. August. Available on the Internet at <http://www.epa.gov/ttn/naaqs/standards/so2/data/Risk%20and%20Exposure%20Assessment%20to%20Support%20the%20Review%20of%20the%20SO2%20Primary%20National%20Ambient%20Air%20Quality%20Standards-%20Final%20Report.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2009d. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment – RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

U.S. Environmental Protection Agency (U.S. EPA). 2009e. Risk and Exposure Assessment for Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Oxides of Sulfur (Final). EPA-452/R-09-008a. Office of Air Quality Planning and Standards, Research Triangle Park, NC. September. Available on the Internet at <http://www.epa.gov/ttn/naaqs/standards/no2so2sec/data/NOxSOxREASep2009MainContent.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2009f. 2008 National Listing of Fish Advisories. Fish Advisory Program. EPA-823-F-09-007. September. Available on the Internet at < http://www.epa.gov/waterscience/fish/advisories/tech2008.pdf>.

U.S. Environmental Protection Agency (U.S. EPA) 2010a. Regulatory Impact Analysis, National Ambient Air Quality Standards for Ozone, Office of Air Quality Planning and Standards, Research Triangle Park, NC. October. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2010b. Final Regulatory Impact Analysis (RIA) for the NO_2 National Ambient Air Quality Standards (NAAQS). Office of Air Quality Planning and Standards, Research Triangle Park, NC. January. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf>.

U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2007. SAB Advisory on EPA's Issues in Valuing Mortality Risk Reduction. EPA-SAB-08-001. October. Available on the Internet at <http://yosemite.epa.gov/sab/sabproduct.nsf/4128007E7876B8F0852573760058A978/$File/sab-08-001.pdf>.

U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2008. Characterizing Uncertainty in Particulate Matter Benefits Using Expert Elicitation. EPA-COUNCIL-08-002. July. Available on the Internet at < http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/43B91173651AED9E85257487004EA6CB/$File/EPA-COUNCIL-08-002-unsigned.pdf>.

U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2009a. Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008). EPA-COUNCIL-09-008. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf>.

U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2009b. Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment. EPA-COUNCIL-09-009. May. Available on the Internet at

<http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf>.

U.S. Environmental Protection Agency and U.S. Food and Drug Administration (U.S. EPA/FDA). 2004. What You Need to Know About Mercury in Fish and Shellfish: Advice for Women Who Might Become Pregnant Women, Who are Pregnant, Nursing Mothers, Young Children. EPA-823-F-04-009. Available on the Internet at <http://www.epa.gov/waterscience/fish/files/MethylmercuryBrochure.pdf>.

U.S. Fish and Wildlife Service (FWS) and U.S. Census Bureau. 2007. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. FHW/06-NAT. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, DC, and U.S. Department of Commerce, U.S. Census Bureau, Washington, DC.

U.S. Food and Drug Administration (U.S. FDA). 2001. Fish and Fisheries Products Hazards and Controls Guidance: Chapter 10: Methyl Mercury. Third Edition. June. Available on the Internet at < http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/Seafood/ucm092041.htm>.

U.S. Forest Service (USFS). 2006. Forest Inventory and Analysis National Program: Forest Inventory Data Online. Online database. U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis, Arlington, VA. Available on the Internet at <http://fia.fs.fed.us/tools-data>.

U.S. Geological Survey (USGS). 2006. Investigations and Monitoring of Mercury in Indiana by the U.S. Geological Survey. U.S. Department of the Interior, U.S. Geological Survey, Indiana Water Science Center, Indianapolis, IN. Available athttp://in.water.usgs.gov/mercury.

Van Sickle, J., Baker, J.P., Simonin, H.A., Baldigo, B.P., Kretser, W.A., Sharpe, W.E. 1996. Episodic acidification of small streams in the northeastern United States: Fish mortality in field bioassays. Ecological Applications, 6, 408-421.

Villeneuve, P. J., L. Chen, B. H. Rowe and F. Coates. 2007. Outdoor air pollution and emergency department visits for asthma among children and adults: a case-crossover study in northern Alberta, Canada. Environ Health. Vol. 6 (1): 40.

Viscusi, W.K., W.A. Magat, and J. Huber. 1991. “Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis.” Journal of Environmental Economics and Management 21:32-51.

Virtanen JK, S Voutilainen, T.H. Rissanen, J Mursu, T.P.Tuomainen, M.J. Korhonen, V.P.Walkonen, K. Seppanen,J.A. Laukkanen, J.T.Salonen.Grandjean, P., K. Murata, E. Budtz-Jorgensen, and P.Weihe. 2004. “Autonomic Activity in Methylmercury Neurotoxicity:14-Year Follow-Up of a Faroese Birth Cohort”, The Journal of Pediatrics, February, pp169-176.

Viscusi, V.K., and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." Journal of Risk and Uncertainty 27(1):5-76.

Wilson, A. M., C. P. Wake, T. Kelly and J. C. Salloway. 2005. Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environ Res. Vol. 97 (3): 312-21.

Wittels, E.H., J.W. Hay, and A.M. Gotto, Jr. 1990. Medical Costs of Coronary Artery Disease in the United States. American Journal of Cardiology 65(7):432-440.

Yang, Q., Y. Chen, D. Krewski, R. T. Burnett, Y. Shi and K. M. McGrail. 2005. Effect of short-term exposure to low levels of gaseous pollutants on chronic obstructive pulmonary disease hospitalizations. Environ Res. Vol. 99 (1): 99-105.

Yang, Q., Y. Chen, Y. Shi, R. T. Burnett, K. M. McGrail and D. Krewski. 2003. Association between ozone and respiratory admissions among children and the elderly in Vancouver, Canada. Inhal Toxicol. Vol. 15 (13): 1297-308.

Yoshizawa, K et. al. 2002. Mercury and the Risk of Coronary Heart Disease in Men, New England Journal of Medicine, Vol. 374, No. 22, November.

Chapter 6: Cost Analysis Approach and Results

Synopsis

This chapter describes our illustrative analysis of the engineering costs and monitoring costs associated with attaining the final and alternative standards for the National Ambient Air Quality Standard (NAAQS) for SO_2. We present our analysis of these costs in four separate sections. Section 6.1 presents the cost estimates. Sections 6.2 and 6.3 summarize the illustrative economic and energy impacts of these standards, respectively, while Section 6.4 outlines the main limitations of the analysis. As mentioned previously, the analysis is presented here for the final standard of 75 ppb, and two alternative standards: 50 ppb and 100 ppb in the year 2020.

Section 6.1 breaks out discussion of cost estimates into five subsections. The first subsection summarizes the data and methods that we employed to estimate the costs associated with the control strategies outlined in Chapter 4. The second subsection presents county level estimates of the costs of identified controls associated with the regulatory alternatives examined in this RIA. Following this discussion, the third subsection describes the approach used to estimate the extrapolated costs of unspecified emission reductions that may be needed to comply with the final and alternative standards. The fourth subsection provides a brief discussion of the monitoring costs associated with the final NAAQS. The fifth subsection provides the estimated total costs of the regulatory alternatives examined. This section concludes with a discussion of technological innovation and how that affects regulatory cost estimates.

This analysis does not estimate the projected attainment status of areas of the country other than those counties currently served by one of the approximately 349 monitors with complete data in the current network. It is important to note that the final rule will require a monitoring network wholly comprised of monitors sited at locations of expected maximum hourly concentrations. Only about one third of the existing SO_2 network may be source-oriented and/or in the locations of maximum concentration required by the final rule because the current network is focused on population areas and community-wide ambient levels of SO_2. Actual monitored levels using the new monitoring network may be higher than levels measured using the existing network. We recognize that once a network of monitors located at maximum-concentration is put in place, more areas could find themselves exceeding the new SO_2 NAAQS. However for this RIA analysis, we lack sufficient data to predict which counties might exceed the new NAAQS after implementation of the new monitoring network. Therefore we lack a credible analytic path to estimating costs and benefits for such a future scenario.

In addition, this chapter presents cost estimates associated with both identified control measures and unspecified emission reductions needed to reach attainment. Identified control measures include known measures for known sources that may be implemented to attain the alternative standard, whereas the achievement of unspecified emission reductions requires implementation of hypothetical additional measures in areas that would not attain the selected standard following the implementation of identified controls to known sources.

Note that the universe of sources achieving unspecified emission reductions beyond identified controls is not completely understood; therefore we are not able to identify known control devices, work practices, or other control measures to achieve these reductions. We calculated extrapolated costs for unspecified emission reductions using a fixed cost per ton approach. The analysis presents hypothetical costs of attaining the SO_2 NAAQS, subject to States' abilities to find emission reductions whose costs are finite, although likely to be higher than those of the identified control measures we believe to exist. Section 6.1 below describes in more detail our approaches for estimating both the costs of identified controls and the extrapolated costs of unspecified emission reductions needed beyond identified controls.

As is discussed throughout this RIA, the technologies and control strategies selected for this analysis are illustrative of one approach that nonattainment areas may employ to comply with the revised SO_2 standard. Potential control programs may be designed and implemented in a number of ways, 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 annualized costs of purchasing, installing, and operating the referenced technologies. We also present monitoring costs. Because we are uncertain of the specific actions that State Agencies will take to design State Implementation Plans to meet the revised standard, we do not estimate the costs that government agencies may incur to implement these control strategies.

6.1 Engineering Cost Estimates

6.1.1 Data and Methods: Identified Control Costs

Consistent with the emissions control strategy analysis presented in Chapter 4, our analysis of the costs associated with the final SO_2 NAAQS focuses SO_2 emission controls for EGU sources first, then nonEGU point sources, and then area sources.

6.1.1.1 EGU Sources

We used equations for wet FGD scrubber controls used in the Integrated Planning Model (IPM) to estimate the control cost for SO_2 reductions from EGUs. Equations are available for estimating capital and annual costs, and these equations are dependent on unit capacity and capacity factor (fraction of hours in a year that an EGU operates). Annual costs for control measures applied in IPM include those for fixed and variable operating and maintenance (O&M) items and annualized capital costs calculated using a capital recovery factor and are specifically applicable to EGUs.

6.1.1.2 NonEGU Point and Area Sources

After designing the hypothetical control strategy using the methodology discussed in Chapter 4, EPA used the Control Strategy Tool (CoST) and AirControlNET to estimate engineering control costs for nonEGU and Area sources. CoST calculates engineering costs using three different methods: (1) by multiplying an average annualized cost per ton estimate against the total tons of a pollutant reduced to derive a total cost estimate; (2) by calculating cost using an equation that incorporates key plant information; or (3) by using both cost per ton and cost equations. Most control cost information within CoST has been developed based on the cost per ton approach. This is because estimating engineering costs using an equation requires more data, and parameters used in other non-cost per ton methods may not be readily available or broadly representative across sources within the emissions inventory. The costing equations used in CoST require either plant capacity or stack flow to determine annual, capital and/or operating and maintenance (O&M) costs. Capital costs are converted to annual costs using the capital recovery factor (CRF)[1]. Where possible, cost calculations are used to calculate total annual control cost (TACC) which is a function of the capital (CC) and O&M costs. The capital recovery factor incorporates the interest rate and equipment life (in years) of the control equipment. Operating costs are calculated as a function of annual O&M and other variable costs. The resulting TACC equation is TACC = (CRF * CC) + O&M.

Engineering costs will differ based upon quantity of emissions reduced, plant capacity, or stack flow which can vary by emissions inventory year. Engineering costs will also differ in a nominal sense by the year the costs are calculated for (i.e., 1999$ versus 2006$).[2] For capital

[1] For more information on this cost methodology and the role of AirControlNET in control strategy analysis, see Section 6 of the 2006 PM RIA, AirControlNET 4.1 Control Measures Documentation (Pechan, 2006b), or the EPA Air Pollution Control Cost Manual, Section 1, Chapter 2, found at http://www.epa.gov/ttn/catc/products.html#cccinfo.

[2] The engineering costs will not be any different in a real (inflation-adjusted) sense if calculated in 2006 versus 1999 dollars if properly escalated. For this analysis, all costs are reported in real 2006 dollars.

investment, we do not assume early capital investment in order to attain standards by 2020. For 2020, our estimate of annualized costs represents a “snapshot” of the annualized costs, which include annualized capital and O&M costs, for those controls included in our identified control strategy analysis. Our engineering cost analysis uses the equivalent uniform annual costs (EUAC) method, in which annualized costs are calculated based on the equipment life for the control measure along with the interest rate by use of the CRF as mentioned previously in this chapter. Annualized costs are estimated as equal for each year the control is expected to operate. Hence, our annualized costs for nonEGU point and area sources estimated for 2020 are the same whether the control measure is installed in 2019 or in 2010. We make no presumption of additional capital investment in years beyond 2020. The EUAC method is discussed in detail in the EPA Air Pollution Control Cost Manual[3]. Applied controls and their respective engineering costs are provided in the SO_2 NAAQS docket.

6.1.2 Identified Control Strategy Analysis Engineering Costs

In this section, we provide engineering cost estimates of the control strategies identified in Chapter 4 that include control measures applied to nonEGU sources, area sources, and EGUs. Engineering costs generally refer to the expense of capital equipment installation, the site preparation costs for the application, and annual operating and maintenance costs.

The total annualized cost of control in each geographic area of our analysis for the hypothetical control scenario is provided in Table 6.1. These numbers reflect the engineering costs across all sectors. Estimates are annualized at a discount rate of 7%.

Table 6.1 summarizes these costs in total and by sector nationwide. As indicated in the table, the estimated annualized costs of these controls under the 75 ppb final standard in 2020 are $960 million per year (2006$). For the other 2 alternative standards examined, in 2020 the annualized costs range from $470 million to $2,600 million. Consistent with Chapter 4's summary of the air quality impacts associated with identified controls, the cost estimates in Table 6.1 reflect partial attainment with the alternative standard being examined in this RIA. Consistent with the identified control strategy analysis emission reductions presented in Chapter 4, a majority of the costs are from controls applied to EGU sources, but a relatively large share of costs is borne by nonEGU point sources.

The costs of the EGU strategy reflect application of controls (described in Chapter 4) where needed to obtain as much reductions as possible to attain each alternative standard.

[3] http://epa.gov/ttn/catc/products.html#cccinfo

Table 6.2 presents the identified control costs in 2020 by county for each alternative standard. These costs are shown for a 7 percent discount rate.

Table 6.1: Annual Control Costs of Identified Controls in 2020 in Total and by Sector (Millions of 2006$) [a, b]

	50 ppb	75 ppb	100 ppb
Total Costs for Identified Controls[c, d]	$ 2,600	$ 960	$ 470
EGUs	$ 1,700	$ 700	$ 300
nonEGUs	$ 900	$ 260	$ 170
Area Sources	$ 40	$ 0.55	$ 0.24

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] Total annualized costs were calculated using a 7% discount rate
[d]These values represent partial attainment costs for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

Table 6.2: Identified Controls – Total Annual Cost by County in 2020 (Millions of 2006$)[a,b,c,d]

state	county	50 ppb	75 ppb	100 ppb
Arizona	Gila Co	$8.8	$8.8	$8.8
Colorado	Denver Co	$39.0		
Connecticut	New Haven Co	$8.2		
Florida	Duval Co	$24.0		
Florida	Hillsborough Co	$3.2		
Georgia	Chatham Co	$42.0	$12.0	
Idaho	Bannock Co	$0.6		
Illinois	Cook Co	$16.0		
Illinois	Madison Co	$65.0	$31.0	
Illinois	St Clair Co			
Illinois	Sangamon Co	$60.0	$30.0	
Illinois	Tazewell Co	$120.0	$27.0	
Indiana	Floyd Co	$0.14		
Indiana	Fountain Co	$19.0		
Indiana	Jasper Co			
Indiana	Lake Co	$210.0	$49.0	
Indiana	Morgan Co	$10.0		
Indiana	Porter Co			
Indiana	Wayne Co	$47.0	$47.0	$35.0
Iowa	Linn Co	$26.0	$18.0	
Iowa	Muscatine Co	$89.0	$65.0	$31.0
Kentucky	Jefferson Co	$85.0		
Kentucky	Livingston Co	$11.0		
Louisiana	East Baton Rouge Par	$29.0		

state	county	50 ppb	75 ppb	100 ppb
Missouri	Greene Co	$16.0		
Missouri	Jackson Co	$59.0	$26.0	
Missouri	Jefferson Co	$310.0	$280.0	$280.0
Montana	Yellowstone Co	$12.0		
Nebraska	Douglas Co	$17.0	$17.0	
New Hampshire	Merrimack Co	$19.0		
New York	Erie Co	$38.0	$14.0	
New York	Monroe Co	$7.5		
New York	Suffolk Co	$50.0	$21.0	
North Carolina	New Hanover Co	$19.0		
Ohio	Clark Co	$19.0		
Ohio	Jefferson Co	$18.0		
Ohio	Lake Co	$110.0	$47.0	
Ohio	Summit Co	$76.0	$19.0	$3.0
Oklahoma	Kay Co	$28.0		
Oklahoma	Muskogee Co	$78.0	$51.0	$25.0
Oklahoma	Tulsa Co	$24.0		
Pennsylvania	Allegheny Co	$160.0		
Pennsylvania	Blair Co	$38.0		
Pennsylvania	Northampton Co	$61.0	$28.0	
Pennsylvania	Warren Co	$29.0	$29.0	$29.0
South Carolina	Lexington Co	$22.0		
Tennessee	Blount Co	$36.0		
Tennessee	Bradley Co	$39.0	$2.9	
Tennessee	Montgomery Co	$38.0	$38.0	$38.0
Tennessee	Shelby Co	$16.0		
Tennessee	Sullivan Co	$110.0	$47.0	
Texas	Harris Co	$66.0		
Texas	Jefferson Co	$61.0	$28.0	
West Virginia	Hancock Co	$30.0		
Wisconsin	Brown Co	$40.0		
Wisconsin	Oneida Co	$22.0	$22.0	$22.0

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] Total annualized costs were calculated using a 7% discount rate.
[d]These values represent partial attainment costs for the identified control strategy analysis. There were locations not able to attain the alternative standard being analyzed with identified controls only.

6.1.3 Extrapolated Costs

Prior to presenting the methodology for estimating costs for unspecified emission reductions, it is important to provide information from EPA's Science Advisory Board (SAB) Council Advisory on the issue of estimating costs of unidentified control measures.[4]

> *812 Council Advisory, Direct Cost Report, Unidentified Measures (charge question 2.a):*
>
> *"The Project Team has been unable to identify measures that yield sufficient emission reductions to comply with the National Ambient Air Quality Standards (NAAQS) and relies on unidentified pollution control measures to make up the difference. Emission reductions attributed to unidentified measures appear to account for a large share of emission reductions required for a few large metropolitan areas but a relatively small share of emission reductions in other locations and nationwide.*
>
> *"The Council agrees with the Project Team that there is little credibility and hence limited value to assigning costs to these unidentified measures. It suggests taking great care in reporting cost estimates in cases where unidentified measures account for a significant share of emission reductions. At a minimum, the components of the total cost associated with identified and unidentified measures should be clearly distinguished. In some cases, it may be preferable to not quantify the costs of unidentified measures and to simply report the quantity and share of emissions reductions attributed to these measures.*
>
> *"When assigning costs to unidentified measures, the Council suggests that a simple, transparent method that is sensitive to the degree of uncertainty about these costs is best. Of the three approaches outlined, assuming a fixed cost/ton appears to be the*

[4] U.S. Environmental Protection Agency, Advisory Council on Clean Air Compliance Analysis (COUNCIL), *Council Advisory on OAR's Direct Cost Report and Uncertainty Analysis Plan*, Washington, DC. June 8, 2007.

simplest and most straightforward. Uncertainty might be represented using alternative fixed costs per ton of emissions avoided."

EPA has considered this advice and the requirements of E.O. 12866 and OMB circular A-4, which provides guidance on the estimation of benefits and costs of regulations.

As indicated above the identified control costs do not result in attainment of the selected or alternative standards in four areas. In these areas, unspecified emission reductions needed beyond identified controls will likely be necessary to reach attainment.

Taking into consideration the above SAB advice, we estimated the costs of unspecified future emission reductions using a fixed (annualized) cost per ton approach. In previous analyses we have estimated the extrapolated costs using other marginal cost based approaches in addition to the fixed cost per ton approach. We examine the data available for each analysis and determine on a case by case basis the appropriate extrapolation technique. Due to the limited number of control measures applied in this analysis across all sectors, we concluded that it would not be credible to establish a marginal cost-based approach or a representative value for the costs of further SO_2 emission reductions. We also recognize that the emissions from EGUs are the largest for these areas. In addition, there is also limited information on SO_2 controls applied to non-EGUs beyond the scope of this analysis, especially for small sources. For these reasons, we have relied upon a simple fixed cost approach utilized for that analysis to represent the fixed cost of unspecified emission reductions for this analysis. The primary estimate presented is $15,000 (2006$), with sensitivities of $10,000/ton and $20,000/ton. Use of $15,000/ton as a fixed cost estimate is commensurate with the cost of nonEGU SO_2 control measures as applied in the $PM_{2.5}$ RIA three years ago. This fixed costs is also much higher than reported costs for SO_2 controls such as wet FGD scrubbers for industrial boilers are reported to be up to at least $5,200/ton (2006$).[5] Also, this estimate is considerably greater than the current and futures prices for SO_2 emissions allowances traded for compliance with the CAIR program.[6] Finally, as

[5] Applicability and Feasibility of NOx, SO_2, and PM Emissions Control Technologies for Industrial, Commercial, and Institutional (ICI) Boilers. NESCAUM, November 2008. Available on the Internet at http://www.nescaum.org/documents/ici-boilers-20081118-final.pdf/.

[6] The Evolving SO2 Allowance Market: Title IV, CAIR, and Beyond. Palmer, Karen, Resources for the Future and Evans, David, US EPA/OPEI, July 13, 2009. Available on the Internet at http://www.rff.org/Publications/WPC/Pages/090713-Evolving-SO2-Allowance-Market.aspx.

mentioned above, the use of a fixed cost per ton of $15,000/ton is consistent with what an advisory committee to the Section 812 second prospective analysis on the Clean Air Act Amendments suggested in June 2007 for estimating the costs of reductions from unidentified controls.

The estimation of costs for emission reductions needed to reach attainment many years in the future is inherently difficult. We expect that additional control measures that we were not able to identify may be developed by 2020. As described later in this chapter, our experience with Clean Air Act implementation shows that technological advances and development of innovative strategies can make possible cost effective emissions reductions that are unforeseen today, and can reduce costs of some emerging technologies over time. But we cannot precisely predict the amount of technology advance in the future. The relationship of the cost of additional future controls to the cost of control options available today is not at all clear. Available, currently known control measures increase in costs per ton beyond the range of what has ever been implemented and because they are not currently required can not serve as an accurate representation of expected costs of implementation. Such measures would still not provide the needed additional control for full attainment in the analysis year 2020. History has shown that when faced with potentially costly controls requirements, firms could adapt by changing their production process or innovate to develop more cost effective ways of meeting control requirements. We recognize that a single fixed cost of control of $15,000 per ton of emissions reductions does not account for the significant emissions cuts that are necessary in some areas and so its use provides an estimate that is likely to differ from actual future costs. Yet, the limited emission controls dataset applied for the identified control strategy analysis significantly limits our ability to estimate full attainment costs using more sophisticated methods.

In the economics literature there are a variety of theoretical ways to estimate the cost of more stringent emissions reductions than can be achieved by known technologies. One method would be to estimate the cost of reducing all remaining tons by simply extrapolating the cost curve using data on cost and effectiveness of all known controls. This method can imply the last ton of reductions costs an amount which is thousands of times higher than the fixed cost presumed above (i.e., $15,000 per ton). This result is highly unlikely given the uncertainty surrounding the assumptions implicit in this estimate (e.g. projecting 10 years into the future, not including factors for technological innovation and improvements, not including societal and economy wide changes from dealing with climate change). Such a result does not necessarily mean that such costs will be incurred, because of uncertainties about future control technology, economic activity and the possibility of deferment of full attainment dates. Another variant on this approach is to develop a method which simulates technological change by causing shifts in the cost curve over time to reflect that innovation can reduce costs of control.

In addition, it is theoretically possible to consider the cost of a geographic area changing to a different type of economic structure over time (e.g. moving from a one type of manufacturing to another or from manufacturing to a more service oriented economy) as another way to predict the cost of meeting a tighter standard. This would be a challenging, data intensive exercise that would be very area specific. Nationwide estimates would have to be built from an area by area basis. In some areas, mobile sources may be a significant source of emissions; some areas are experimenting with congestion pricing as a means of restructuring how people and goods travel to reduce emissions.

In the absence of more robust methods for estimating these costs, EPA is following the SAB advice to keep the approach simple and transparent. If commentors have different assumptions about the cost of attainment, it is easy for them to calculate the cost of attaining a tighter standard using the fixed cost formula. EPA is going to continue to work on most robust methods of developing these estimates. EPA will continue to improve methods of estimating the costs of full attainment when health-based standards require emissions cuts greater than can be achieved by all known engineering controls. Over the course of the next several months EPA, in partnership with OMB and interested federal agencies will be investigating different ways of estimating these extrapolated full attainment costs, including consideration of ways of incorporating technological change and other factors. In addition, EPA is looking into developing approaches to characterize different future states of the world. These scenarios (similar to the goal of the IPCC scenarios for the outcome of climate change, for example) would allow us to consider a range of possibilities. Many criteria pollutant emissions result from combustion processes used to make energy, transport goods and people and other industrial operations. Our alternative futures could represent different types of power generation that could become more prevalent under different circumstances. For example, in one scenario solar or wind power would prevail leading to reductions in the burning of coal for power generation. In contrast, in another scenario coal use remains consistent with current usage but is subject to more emissions reductions. Another could presume significant inroads for electric vehicles. EPA will be considering this approach as another method for projecting a range of possibilities for the cost of attaining a tighter standard. This research will include a review of how best to characterize the likely adoption by 2020 (or similar target years) of new technologies (e.g., solar, wind and others unrelated to fossil fuel combustion, as well as more fuel-efficient vehicles), that are expected to have the ancillary benefit of facilitating compliance with new standards for criteria air pollutants. It will also include consideration of control measures that depend on behavioral change (such as congestion pricing) rather than simply the adoption of engineering controls.

The approach outlined above represents a significant amount of theoretical and applied analysis and the development of new methodologies for doing this analysis. Data supporting our cost approach is in the SO2 NAAQS RIA docket and we welcome ideas from the public on suggestions for analytical methods to estimate these future costs and plans to hopefully utilize portions of it in the proposed PM2.5 NAAQS RIA to be released with the rest of the material accompanying the standard.

Table 6.3 presents the extrapolated costs for each alternative standard analyzed. See Chapter 4 for a complete discussion of the air quality projections for these counties.

Table 6.3: Extrapolated Costs Estimated for the Alternative Standards (Millions of 2006$) [a, b]

	50 ppb	75 ppb	100 ppb
Total Extrapolated Costs ($10,000/ton):	$ 1,200	$ 330	$ 180
Total Extrapolated Costs ($15,000/ton):	**$ 1,800**	**$ 500**	**$ 260**
Total Extrapolated Costs ($20,000/ton):	$ 2,400	$ 670	$ 350

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] Estimates of extrapolated costs are assumed using a 7% discount rate. Given the fixed cost per ton approach used here, 3% discount rate estimates could not be calculated.

6.1.4 Monitoring Costs

The final amendments would revise the technical requirements for SO_2 monitoring sites; require the siting and operation of additional SO_2 ambient air monitors, and the reporting of the collected ambient monitoring data to EPA's Air Quality System (AQS). We have estimated the burden based on the monitoring requirements of this rule. Details of the burden estimate are contained in the information collection request (ICR) accompanying the final rule.[7] The ICR estimates annualized costs of a new monitoring network at approximately $15 million per year (2006 dollars).

6.1.5 Summary of Cost Estimates

Table 6.4 provides a summary of total costs to achieve the alternative standards in the year 2020, and this summary includes the sensitivity estimates. As mentioned previously, we use $15,000/ton as our primary estimate of the extrapolated costs on a per ton reduction basis, and $10,000/ton and $20,000/ton are used as sensitivities. Using that estimate, we find that the total annualized costs for the 75 ppb final standard in 2020 are $1.0 billion (2006$) using seven percent as the discount rate and applying the primary estimate of the extrapolated costs, and the costs for the other alternative standards range from $0.5 billion to $2.6 billion (2006$). The portion of these costs accounted for by identified controls ranges from 59 percent for the 50 ppb standard to 64 percent for the 100 ppb standard. Hence, the portion of these costs accounted for by extrapolated controls ranges from 41 percent for the 50 ppb standard to 36 percent for the 100 ppb standard.

Finally, Table 6.5 present the annual cost/ton for the identified controls by sector as applied for the alternative standards in 2020. For each alternative standard, the annual cost/ton for reductions from the non-EGU sector is the most expensive. For the 75 ppb final standard, reductions from non-EGUs occur at $2,400/ton while the annual cost/ton for EGU sector is $2,700/ton. All of these estimates are for reductions in 2020 in 2006 dollars and using a seven percent discount rate.

The significant difference between the costs of identified controls alone and the cost of achieving attainment (i.e. including both identified controls and emission reductions beyond identified controls) in this and other areas reflects the limited information available to EPA on

[7] ICR 2358.01, May 2009.

the control measures that sources may implement. Although AirControlNET contains information on a large number of different point source controls, we would expect that State and local air quality managers would have access to additional information on the controls available to the most significant sources.

Table 6.4: Total Annual Costs for Alternative Standards (Millions of 2006$)[a, b]

		50 ppb	75 ppb	100 ppb
Identified Control Costs		$ 2,600	$ 960	$ 470
Monitoring Costs		$2.1	$2.1	$2.1
Extrapolated Costs	Fixed Cost ($10,000/ton)	$ 1,200	$ 330	$ 180
	[d]Fixed Cost ($15,000/ton)	**$ 1,800**	**$ 500**	**$ 260**
	Fixed Cost ($20,000/ton)	$ 2,400	$ 670	$ 350
Total Costs	Fixed Cost ($10,000/ton)	$ 3,800	$ 1,300	$ 650
	[d]Fixed Cost ($15,000/ton)	**$ 4,400**	**$ 1,500**	**$ 730**
	Fixed Cost ($20,000/ton)	$ 5,000	$ 1,600	$ 820

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020.
[c] Values reflect a 7% discount rate.
[d] Our primary estimate of extrapolated costs is, as mentioned earlier in this RIA, based on a fixed annual cost of $15,000/ton. This estimate of extrapolated costs is incorporated into our estimate of total costs for the alternative standards.

Table 6.5: Annual Cost per Ton of Identified Controls applied for the Alternative Standards by Emissions Sector (2006$) [a, b]

Emissions Sector	50 ppb	75 ppb	100 ppb
NonEGU	$ 2,400	$ 2,700	$ 2,800
Area	$ 2,500	$ 2,200	$ 2,100
EGU	$ 2,700	$ 2,700	$ 2,800

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.

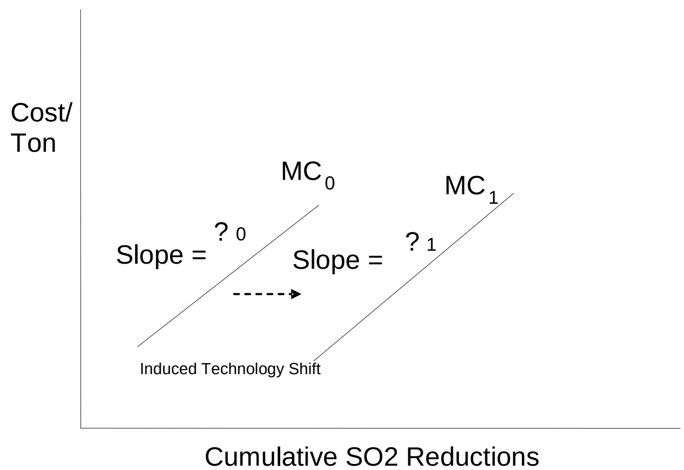
6.1.6 Technology Innovation and Regulatory Cost Estimates

There are many examples in which technological innovation and “learning by doing” have made it possible to achieve greater emissions reductions than had been feasible earlier, or have reduced the costs of emission control in relation to original estimates. Studies[8] have suggested that costs of some EPA programs have been less than originally estimated due in part to inadequate inability to predict and account for future technological innovation in regulatory impact analyses.

Constantly increasing marginal costs are likely to induce the type of innovation that would result in lower costs than estimated early in this chapter. Breakthrough technologies in control equipment could by 2020 result in a rightward shift in the marginal cost curve for such equipment (Figure 6.1)[9] as well as perhaps a decrease in its slope, reducing marginal costs per unit of abatement, and thus deviate from the assumption of a static marginal cost curve. In addition, elevated abatement costs may result in significant increases in the cost of production and would likely induce production efficiencies, in particular those related to energy inputs, which would lower emissions from the production side.

[8] Harrington et al. (2000) and previous studies cited by Harrington.
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.
[9] Figure 6.1 shows a linear marginal abatement cost curve. It is possible that the shape of the marginal abatement cost curve is non-linear.

Figure 6.1: Technological Innovation Reflected by Marginal Cost Shift



6.1.6.1 Examples of Technological Advances in Pollution Control

There are numerous examples of low-emission technologies developed and/or commercialized over the past 15 or 20 years, such as:

- Selective catalytic reduction (SCR) and ultra-low NOx burners for NOx emissions
- Scrubbers which achieve 95% and even greater SO2 control on boilers
- Sophisticated new valve seals and leak detection equipment for refineries and chemical plans
- Low or zero VOC paints, consumer products and cleaning processes
- Chlorofluorocarbon (*CFC)* free air conditioners, refrigerators, and solvents
- Water and powder-based coatings to replace petroleum-based formulations
- Vehicles far cleaner than believed possible in the late 1980s due to improvements in evaporative controls, catalyst design and fuel control systems for light-duty vehicles; and treatment devices and retrofit technologies for heavy-duty engines

- Idle-reduction technologies for engines, including truck stop electrification efforts
- Market penetration of gas-electric hybrid vehicles, and clean fuels
- The development of retrofit technology to reduce emissions from in-use vehicles and non-road equipment

These technologies were not commercially available two decades ago, and some were not even in existence. Yet today, all of these technologies are on the market, and many are widely employed. Several are key components of major pollution control programs and most of the examples are discussed further below.

What is known as “learning by doing” or “learning curve impacts”, which is a concept distinct from technological innovation, has also made it possible to achieve greater emissions reductions than had been feasible earlier, or have reduced the costs of emission control in relation to original estimates. Learning curve impacts can be defined generally as the extent to which variable costs (of production and/or pollution control) decline as firms gain experience with a specific technology. Such impacts have been identified to occur in a number of studies conducted for various production processes. Impacts such as these would manifest themselves as a lowering of expected costs for operation of technologies in the future below what they may have been.

The magnitude of learning curve impacts on pollution control costs has been estimated for a variety of sectors as part of the cost analyses done for the Draft Direct Cost Report for the second EPA Section 812 Prospective Analysis of the Clean Air Act Amendments of 1990.[10] In that report, learning curve adjustments were included for those sectors and technologies for which learning curve data was available. A typical learning curve adjustment example is to reduce either capital or O&M costs by a certain percentage given a doubling of output from that sector or for that technology. In other words, capital or O&M costs will be reduced by some percentage for every doubling of output for the given sector or technology.

T.P. Wright, in 1936, was the first to characterize the relationship between increased productivity and cumulative production. He analyzed man-hours required to assemble successive airplane bodies. He suggested the relationship is a log linear function, since he observed a constant linear reduction in man-hours every time the total number of airplanes assembled was doubled. The relationship he devised between number assembled and assembly

[10] E.H. Pechan and Associates and Industrial Economics, Direct Cost Estimates for the Clean Air Act Second Section 812 Prospective Analysis: Draft Report, prepared for U.S. EPA, Office of Air and Radiation, February 2007. Available at http://www.epa.gov/oar/sect812/mar07/direct_cost_draft.pdf.

time is called Wright's Equation (Gumerman and Marnay, 2004)[11]. This equation, shown below, has been shown to be widely applicable in manufacturing:

$$\text{Wright's Equation: } C_N = C_o * N^b,$$

Where:

N	=	cumulative production
C_N	=	cost to produce N^{th} unit of capacity
C_o	=	cost to produce the first unit
B	=	learning parameter = ln (1-LR)/ln(2), where
LR	=	learning by doing rate, or cost reduction per doubling of capacity or output.

The percentage adjustments to costs can range from 5 to 20 percent, depending on the sector and technology. Learning curve adjustments were prepared in a memo by IEc supplied to US EPA and applied for the mobile source sector (both onroad and nonroad) and for application of various EGU control technologies within the Draft Direct Cost Report.[12] Advice received from the SAB Advisory Council on Clean Air Compliance Analysis in June 2007 indicated an interest in expanding the treatment of learning curves to those portions of the cost analysis for which no learning curve impact data are currently available. Examples of these sectors are non-EGU point sources and area sources. The memo by IEc outlined various approaches by which learning curve impacts can be addressed for those sectors. The recommended learning curve impact adjustment for virtually every sector considered in the Draft Direct Cost Report is a 10% reduction in O&M costs for two doubling of cumulative output, with proxies such as cumulative fuel sales or cumulative emission reductions being used when output data was unavailable.

For this RIA, we do not have the necessary data for cumulative output, fuel sales, or emission reductions for all sectors included in our analysis in order to properly generate control costs that reflect learning curve impacts. Clearly, the effect of including these impacts would be to lower our estimates of costs for our control strategies in 2020, but we are not able to include such an analysis in this RIA.

[11] Gumerman, Etan and Marnay, Chris. Learning and Cost Reductions for Generating Technologies in the National Energy Modeling System (NEMS), Ernest Orlando Lawrence Berkeley National Laboratory, University of California at Berkeley, Berkeley, CA. January 2004, LBNL-52559.

[12] Industrial Economics, Inc. Proposed Approach for Expanding the Treatment of Learning Curve Impacts for the Second Section 812 Prospective Analysis: Memorandum, prepared for U.S. EPA, Office of Air and Radiation, August 13, 2007.

6.1.6.2 Influence on Regulatory Cost Estimates

Studies indicate that it is not uncommon for pre-regulatory cost estimates to be higher than later estimates, in part because of inability to predict technological advances. Over longer time horizons the opportunity for technical advances is greater.

- *Multi-rule study:* Harrington et al. of Resources for the Future[13] conducted an analysis of the predicted and actual costs of 28 federal and state rules, including 21 issued by EPA and the Occupational Safety and Health Administration (OSHA), and found a tendency for predicted costs to overstate actual implementation costs. Costs were considered accurate if they fell within the analysis error bounds or if they fall within 25 percent (greater or less than) the predicted amount. They found that predicted total costs were overestimated for 14 of the 28 rules, while total costs were underestimated for only three rules. Differences can result because of quantity differences (e.g., overestimate of pollution reductions) or differences in per-unit costs (e.g., cost per unit of pollution reduction). Per-unit costs of regulations were overestimated in 14 cases, while they were underestimated in six cases. In the case of EPA rules, the agency overestimated per-unit costs for five regulations, underestimated them for four regulations (three of these were relatively small pesticide rules), and accurately estimated them for four. Based on examination of eight economic incentive rules, "for those rules that employed economic incentive mechanisms, overestimation of per-unit costs seems to be the norm," the study said. It is worth noting here, that the controls applied for this NAAQS do not use an economic incentive mechanism. In addition, Harrington also states that overestimation of total costs can be due to error in the quantity of emission reductions achieved, which would also cause the benefits to be overestimated.

Based on the case study results and existing literature, the authors identified technological innovation as one of five explanations of why predicted and actual regulatory cost estimates differ: "Most regulatory cost estimates ignore the possibility of technological innovation … Technical change is, after all, notoriously difficult to forecast … In numerous case studies actual compliance costs are lower than predicted because of unanticipated use of new technology."

It should be noted that many (though not all) of the EPA rules examined by Harrington had compliance dates of several years, which allowed a limited period for technical innovation.

[13] 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.

- *Acid Rain SO2 Trading Program*: Recent cost estimates of the Acid Rain SO2 trading program by Resources for the Future (RFF) and MIT have been as much as 83 percent lower than originally projected by EPA.[14] As noted in the RIA for the Clean Air Interstate Rule, the ex ante numbers in 1989 were an overestimate in part because of the limitation of economic modeling to predict technological improvement of pollution controls and other compliance options such as fuel switching. The fuel switching from high-sulfur to low-sulfur coal was spurred by a reduction in rail transportation costs due to deregulation of rail rates during the 1990's Harrington et al. report that scrubbing turned out to be more efficient (95% removal vs. 80-85% removal) and more reliable (95% vs. 85% reliability) than expected, and that unanticipated opportunities arose to blend low and high sulfur coal in older boilers up to a 40/60 mixture, compared with the 5/95 mixture originally estimated.

Phase 2 Cost Estimates	
Ex ante estimates	\$2.7 to \$6.2 billion[a]
Ex post estimates	\$1.0 to \$1.4 billion

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

- *EPA Fuel Control Rules:* A 2002 study by EPA's Office of Transportation and Air Quality[15] examined EPA vehicle and fuels rules and found a general pattern that "all ex ante estimates tended to exceed actual price impacts, with the EPA estimates exceeding actual prices by the smallest amount." The paper notes that cost is not the same as price, but suggests that a comparison nonetheless can be instructive.[16] An example focusing on fuel rules is provided in Table 6.6:

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[14] Carlson, Curtis, Dallas R. Burtraw, Maureen, Cropper, and Karen L. Palmer. 2000. "Sulfur Dioxide Control by Electric Utilities: What Are the Gains from Trade?" *Journal of Political Economy* 108(#6):1292-1326.
Ellerman, Denny. January 2003. Ex Post Evaluation of Tradable Permits: The U.S. SO2 Cap-and-Trade Program. Massachusetts Institute of Technology Center for Energy and Environmental Policy Research.

[15] Anderson, J.F., and Sherwood, T., 2002. "Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes," Office of Transportation and Air Quality, U.S. Environmental Protection Agency. Technical Paper published by the Society of Automotive Engineers. SAE 2002-01-1980.

[16] The paper notes: "Cost is not the same as price. This simple statement reflects the fact that a lot happens between a producer's determination of manufacturing cost and its decisions about what the market will bear in terms of price change."

Table 6.6: Comparison of Inflation-Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules[a]

	Inflation-adjusted Cost Estimates (c/gal)				Actual Price Changes (c/gal)
	EPA	DOE	API	Other	
Gasoline					
Phase 2 RVP Control (7.8 RVP—Summer) (1995$)	1.1	1.8		0.5	
Reformulated Gasoline Phase 1 (1997$)	3.1-5.1	3.4-4.1	8.2-14.0	7.4 (CRA)	2.2
Reformulated Gasoline Phase 2 (Summer) (2000$)	4.6-6.8	7.6-10.2	10.8-19.4	12	7.2 (5.1, when corrected to 5yr MTBE price)
30 ppm sulfur gasoline (Tier 2)	1.7-1.9	2.9-3.4	2.6	5.7 (NPRA), 3.1 (AIAM)	N/A
Diesel					
500 ppm sulfur highway diesel fuel (1997$)	1.9-2.4		3.3 (NPRA)	2.2	
15 ppm sulfur highway diesel fuel	4.5	4.2-6.0	6.2	4.2-6.1 (NPRA)	N/A

[a] Anderson, J.F., and Sherwood, T., 2002. "Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes," Office of Transportation and Air Quality, U.S. Environmental Protection Agency. Technical Paper published by the Society of Automotive Engineers. SAE 2002-01-1980.

- Chlorofluorocarbon (*CFC) Phase-Out:* EPA used a combination of regulatory, market based (i.e., a cap-and-trade system among manufacturers), and voluntary approaches to phase out the most harmful ozone depleting substances. This was done more efficiently than either EPA or industry originally anticipated. The phaseout for Class I substances was implemented 4-6 years faster, included 13 more chemicals, and cost 30 percent less than was predicted at the time the 1990 Clean Air Act Amendments were enacted.[17]

The Harrington study states, "When the original cost analysis was performed for the CFC phase-out it was not anticipated that the hydrofluorocarbon HFC-134a could be substituted for CFC-12 in refrigeration. However, as Hammit[18] notes, 'since 1991 most new U.S. automobile air conditioners have contained HFC-134a (a compound for which no commercial production technology was available in 1986) instead of CFC-12" (p.13). He cites a similar story for HCFRC-141b and 142b, which are currently substituting for CFC-11 in important foam-blowing applications."

[17] Holmstead, Jeffrey, 2002. "Testimony of Jeffrey Holmstead, Assistant Administrator, Office of Air and Radiation, U.S. Environmental Protection Agency, Before the Subcommittee on Energy and air Quality of the committee on Energy and Commerce, U.S. House of Representatives, May 1, 2002, p. 10.

[18] Hammit, J.K. (2000). "Are the costs of proposed environmental regulations overestimated? Evidence from the CFC phaseout." *Environmental and Resource Economics*, 16(#3): 281-302.

Additional examples of decreasing costs of emissions controls include: SCR catalyst costs decreasing from \$11k-\$14k/m^3 in 1998 to \$3.5k-\$5k/m^3 in 2004, and improved low NOx burners reduced emissions by 50% from 1993-2003 while the associated capital cost dropped from \$25-\$38/kW to \$15/kW[19]. Also, FGD scrubber capital costs have been estimated to have decreased by more than 50 percent from 1976 to 2005, and the operating and maintenance (O&M) costs decreased by more than 50% from 1982 to 2005. Many process improvements contributed to lowering the capital costs, especially improved understanding and control of process chemistry, improved materials of construction, simplified absorber designs, and other factors that improved reliability.[20]

We cannot estimate the precise interplay between EPA regulation and technology improvement, but it is clear that a *priori* cost estimation often results in overestimation of costs because changes in technology (whatever the cause) make less costly control possible.

6.2 Economic Impacts

The assessment of economic impacts in Table 6.7 was conducted based on those source categories which are assumed in this analysis to become controlled. The impacts presented here are a comparison of the control costs to the revenues for industries affected by control strategies applied for the 75 ppb final standard. Control costs are allocated to specific source categories by North American Industry Classification System (NAICS) code.

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[19] ICF Consulting. October 2005. The Clean Air Act Amendment: Spurring Innovation and Growth While Cleaning the Air. Washington, DC. Available at http://www.icfi.com/Markets/Environment/doc_files/caaa-success.pdf.

[20] Yeh, Sonia and Rubin, Edward. February 2007. "Incorporating Technological Learning in the Coal Utility Environmental Cost (CUECost) Model: Estimating the Future Cost Trends of SO_2, NOx, and Mercury Control Technologies." Prepared for ARCADIS Geraghty and Miller, Research Triangle Park, NC 27711. Available at http://steps.ucdavis.edu/People/slyeh/syeh-resources/Drft%20Fnl%20Rpt%20Lrng%20for%20CUECost_v3.pdf.

Table 6.7: Identified Cost/Revenue Ratios by Affected Industry for Illustrative Control Strategy for the Final SO2 Standard (75 ppb) in 2020 (Millions of 2006$)[a, b, c]

NAICS Code	Industry Description	3% Discount Rate[d]	7% Discount Rate	Industry Revenue in 2007[e]	Cost/Revenue Ratio
2211	Electric Power Generation, Transmission and Distribution	699	699	440,000	0.16%
311	Food Manufacturing	55	19.9	589,000	<0.01%
312	Beverage and Tobacco Product Manufacturing	1.3	7.0	128,000	<0.01%
322	Paper Manufacturing	$143	$31.2	$170,000	< 0.01%
324	Petroleum and Coal Products Manufacturing	$245	$39.5	$590,000	< 0.01%
325	Chemical Manufacturing	$12.8	$12.8	$720,000	< 0.01%
326	Plastics and Rubber Products Manufacturing	6.2	6.2	211,000	<0.01%
327	Nonmetallic Mineral Product Manufacturing	266	43.5	128,000	<0.01%
331	Primary Metal Manufacturing	$	$43.6	$250,000	< 0.01%
332	Fabricated metal product manufacturing	0.4	0.4	344,000	< 0.01%
333	Machinery manufacturing	3.0	3.0	19,700	< 0.01%
336	Transportation equipment manufacturing	2.9	0.8	737,000	< 0.01%
611	Educational services	137	51.9	47,000	0.13%

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] All estimates provided reflect the engineering cost of the identified control strategy analysis, incremental to a 2020 baseline.
[c] NAICS codes were unavailable for area source controls. These controls account for less than 2% of the total identified control strategy costs.
[d] Total annualized costs were calculated using a 3% discount rate for controls which had a capital component and where equipment life values were available. For the identified control strategy, data for calculating annualized costs at a 3% discount was available for point sources. Therefore, the total annualized identified control cost value presented in this referenced cell is an aggregation of engineering costs at 3% and 7% discount rate.
[e] Source: U.S. Census Bureau 2007 Economic Census. Industry-level data on revenues can be found at http://factfinder.census.gov/servlet/IBQTable?_bm=y&-fds_name=EC0700A1&-_skip=0&-ds_name=EC0700A1&-_lang=en.
[f] No data on budget or revenues for this NAICS code is included in the 2007 Economic Census.

6.3 Energy Impacts

This section summarizes the energy consumption impacts associated with control strategies applied for the final SO_2 NAAQS of 75 ppb. The SO_2 NAAQS revisions do not constitute a “significant energy action” as defined in Executive Order 13211; this information merely represents impacts of the illustrative control strategy applied in the RIA. The rule does not prescribe specific 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 as defined in Executive Order 13211.

For this RIA, implementation of the control measures needed for attainment with the alternative standards will likely lead to increased energy consumption among SO_2 emitting facilities. In addition, because the energy consumption and impacts on various energy markets associated with emission reductions beyond identified controls is uncertain, we only consider the energy impacts associated with identified controls.

With respect to energy supply and prices, the analysis in Table 6.7 suggests that at the electric power industry level, the annualized costs associated with the illustrative control strategy for the final standard (75 ppb) represent only about 0.16 percent of its revenues in 2020. In addition, for the other industries affected under the 75 ppb standard, no other industry has annualized costs of more than 0.13 percent of its revenues. As a result we can conclude that impacts to supply and electricity price are small

6.4 Limitations and Uncertainties Associated with Engineering Cost Estimates

- EPA bases its estimates of emissions control costs on the best available information from engineering studies of air pollution controls and has developed a reliable modeling framework for analyzing the cost, emissions changes, and other impacts of regulatory controls. The annualized cost estimates of the private compliance costs 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 conventional and widely-accepted approaches that are commonplace for estimating engineering costs in annual terms. However, our engineering cost analysis is subject to uncertainties and limitations.

- One of these limitations is that we do not have sufficient information for all of our known control measures to calculate cost estimates that vary with an interest rate. We are able to calculate annualized costs at an interest rate other than 7% (e.g., 3% interest rate) where there is sufficient information—available capital cost data, and equipment life—to annualize the costs for individual control measures. For the vast majority of nonEGU point source control measures, we do have sufficient capital cost and equipment life data for individual control measures to prepare annualized capital costs using the standard capital recovery factor. Hence, we are able to provide annualized cost estimates at different interest rates for the point source control measures.

- For area source control measures, the engineering cost information is available only in annualized cost/ton terms. We have extremely limited capital cost and equipment life data for area source control measures. We know that these annualized cost/ton estimates reflect an interest rate of 7% because these estimates are typically products of technical memos and reports prepared as part of rules issued by EPA over the last 10 years or so, and the costs estimated in these reports have followed the policy provided in OMB Circular A-4 that recommends the use of 7% as the interest rate for annualizing regulatory costs. Capital cost information for these area source controls, however, is often limited since these measures are often not the traditional add-on controls where the capital cost is well known and convenient to estimate. The limited availability of useful capital cost data for such control measures has led to our use of annualized cost/ton estimates to represent the engineering costs of these controls in our cost tools and hence in this RIA.

- There are some unquantified costs that are not adequately captured in this illustrative analysis. These costs include the costs of federal and State administration of control programs, which we believe are less than the alternative of States developing approvable SIPs, securing EPA approval of those SIPs, and Federal/State enforcement. The analysis also did not consider transactional costs and/or effects on labor supply in the illustrative analysis.

Chapter 7: Estimates of Costs and Benefits

Synopsis

As discussed above, this RIA analyzes alternative primary standards of 50 parts per billion (ppb), 75 ppb, and 100 ppb. Our assessment of the lower bound SO_2 target NAAQS includes several key elements, including specification of baseline SO_2 emissions and concentrations; development of illustrative control strategies to attain the standard in 2020; and analyses of the control costs and health benefits of reaching the various alternative standards. We also note that because it was not possible, in this analysis, to bring all areas into attainment with the selected standard of 75 ppb in all areas using only identified controls, EPA conducted a second step in the analysis, and estimated the cost of unspecified emission reductions needed to attain the alternative primary NAAQS.

This analysis does not estimate the projected attainment status of areas of the country other than those counties currently served by one of the approximately 488 monitors in the current network. It is important to note that the rule would require a monitoring network wholly comprised of monitors sited at locations of expected maximum hourly concentrations. Only about one third of the existing SO_2 network may be source-oriented and/or in the locations of maximum concentration required by the proposed rule because the current network is focused on population areas and community-wide ambient levels of SO_2. Actual monitored levels using the new monitoring network may be higher than levels measured using the existing network. We recognize that once a network of monitors located at maximum-concentration is put in place, more areas could find themselves exceeding the new SO_2 NAAQS. However for this RIA analysis, we lack sufficient data to predict which counties might exceed the new NAAQS after implementation of the new monitoring network. Therefore we lack a credible analytic path to estimating costs and benefits for such a future scenario.

7.1 Benefits and Costs

We estimated the benefits and costs for four alternative SO_2 NAAQS levels: 50 ppb, 75 ppb, and 100 ppb (99^{th} percentile). These costs and benefits are associated with an incremental difference in ambient concentrations between a baseline scenario and a pollution control strategy. As indicated above and in Chapter 4, several areas of the country may not be able to attain some alternative standard using known pollution control methods. Because some areas require substantial emission reductions from unknown sources to attain the various standards, the results are very sensitive to assuming full attainment. For this reason, we provide the full attainment and the partial attainment results for both benefits and costs.

Costs

Our analysis of the costs associated with the range of alternative NAAQS focuses on SO_2 emission controls for electric generating units (EGU) and nonEGU stationary and area sources. EGU, nonEGU and area source controls largely include measures from the Control Strategy Tool (CoST), and the AirControlNET control technology database. For these sources, we estimated costs based on the cost equations included in AirControlNET.

As indicated in the above discussion on illustrative control strategies, implementation of the SO_2 control measures identified from AirControlNET and other sources does not result in attainment with the selected NAAQS in several areas. In these areas, additional unspecified emission reductions might be necessary to reach some alternative standard levels. In order to bring these monitor areas into attainment, we calculated controls costs using a fixed cost per ton approach similar to that used in the ozone RIA analysis. We recognize that a single fixed cost of control of $15,000 per ton of emissions reductions does not account for the significant emissions cuts that are necessary in some areas, and so its use provides an estimate that is likely to differ from actual future costs.

Benefits

EPA estimated the monetized human health benefits of reducing cases of morbidity among populations exposed to SO_2 and cases of morbidity and premature mortality among populations exposed to $PM_{2.5}$ in 2020 for the selected standard and alternative standard levels in 2006$. Because SO_2 is also a precursor to $PM_{2.5,}$ reducing SO_2 emissions in the projected non-attainment areas will also reduce $PM_{2.5}$ formation, human exposure and the incidence of $PM_{2.5}$-related health effects. For the selected SO_2 standard at 75 ppb (99th percentile, daily 1-hour maximum), the total monetized benefits would be $15 to $37 billion at a 3% discount rate and $14 to $33 billion at a 7% discount rate. For an SO_2 standard at 50 ppb, the total monetized benefits would be $34 to $83 billion at a 3% discount rate and $31 to $75 billion at a 7% discount rate. For an SO_2 standard at 100 ppb, the total monetized benefits would be $7.4 to $18 billion at a 3% discount rate and $6.7 to $16 billion at a 7% discount rate.

These estimates reflect EPA's most current interpretation of the scientific literature and are consistent with the methodology used for the proposal RIA. These benefits are incremental to an air quality baseline that reflects attainment with the 2008 ozone and 2006 $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). More than 99% of the total dollar benefits are attributable to reductions in $PM_{2.5}$ exposure resulting from SO_2 emission reductions. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided in Figure 5.1 for the selected standard of 75 ppb. Methodological limitations prevented EPA from quantifying the impacts to, or monetizing the benefits from several important benefit categories, including ecosystem effects from sulfur deposition, improvements in visibility, and materials damage. Other direct benefits from reduced SO_2 exposure have not been quantified, including reductions in premature mortality.

When estimating the SO_2- and $PM_{2.5}$-related human health benefits and compliance costs in Table 7.1 below, EPA applied methods and assumptions consistent with the state-of-the-science for human health impact assessment, economics and air quality analysis. EPA applied its best professional judgment in performing this analysis and believes that these estimates provide a reasonable indication of the expected benefits and costs to the nation of the selected SO_2 standard and alternatives considered by the Agency. The Regulatory Impacts Analysis (RIA) available in the docket describes in detail the empirical basis for EPA's assumptions and characterizes the various sources of uncertainties affecting the estimates below.

EPA's 2009 Integrated Science Assessment for Particulate Matter concluded, based on the scientific literature, that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship. Nonetheless, consistent with historical practice and our commitment to characterizing the uncertainty in our benefits estimates, EPA has included a sensitivity analysis with an assumed threshold in the PM-mortality health impact function in the RIA. EPA has included a sensitivity analysis in the RIA to help inform our understanding of the health benefits which can be achieved at lower air quality concentration levels. While the primary estimate and the sensitivity analysis are not directly comparable, due to differences in population data and use of different analysis years, as well as the difference in the assumption of a threshold in the sensitivity analysis, comparison of the two results provide a rough sense of the proportion of the health benefits that occur at lower $PM_{2.5}$ air quality levels. Using a threshold of 10 $\mu g/m^3$ is an arbitrary choice (EPA could have assumed 6, 8, or 12 µg/m3 for the sensitivity analysis). Assuming a threshold of 10 $\mu g/m^3$, the sensitivity analysis shows that roughly one-third of the benefits occur at air quality levels below that threshold. Because the primary estimates reflect EPA's current methods and data, EPA notes that caution should be exercised when comparing the results of the primary and sensitivity analyses. EPA appreciates the value of sensitivity analyses in highlighting the uncertainty in the benefits estimates and will continue to work to refine these analyses, particularly in those instances in which air quality modeling data are available.

Table 7.1 presents total national primary estimates of costs and benefits for a 3% discount rate and a 7% discount rate. The net benefits were calculated by subtracting the total cost estimate from the two estimates of total benefits. As indicated above, implementation of the SO_2 control measures identified from AirControlNET and other sources does not result in attainment with the all target NAAQS levels in several areas. In these areas, additional unspecified emission reductions might be necessary to reach some alternative standard levels. The first part of the table, labeled *Partial attainment (known controls)*, shows only those benefits and costs from control measures we were able to identify. The second part of the table, labeled U*nidentified Controls*, shows only additional benefits and costs resulting from unidentified controls. The third part of the table, labeled *Full attainment*, shows total benefits and costs resulting from both identified and unidentified controls. It is important to emphasize that we were able to identify control measures for a significant portion of attainment for many of those counties that would not fully attain the target NAAQS level with identified controls. Note also that in addition to separating full and partial attainment, the table also separates the portion of benefits associated with reduced SO_2 exposure (i.e., SO_2 benefits) from the additional benefits associated with reducing SO_2 emissions, which are precursors to $PM_{2.5}$ formation – (i.e., the $PM_{2.5}$ co-benefits). For instance, for the selected standard of 75 ppb, $2.2 million in benefits are associated with reduced SO_2 exposure while $15 billion to $37 billion are associated with reduced $PM_{2.5}$ exposure.

Table 7.1: Monetized Benefits and Costs to Attain Alternate Standard Levels in 2020 (millions of 2006$) [a]

		# Counties Fully Controlled	Discount Rate	Monetized SO_2 Benefits	Monetized $PM_{2.5}$ Co-Benefits [c,d]	Costs	Net Benefits
Partial Attainment (identified controls)	50 ppb	40	3%	-[b]	$30,000 to $74,000	$2,600	$27,000 to $71,000
			7%		$28,000 to $67,000		$25,000 to $64,000
	75 ppb	20	3%	-[b]	$14,000 to $35,000	$960	$13,000 to $34,000
			7%		$13,000 to $31,000		$12,000 to $30,000
	100 ppb	6	3%	-[b]	$6,900 to $17,000	$470	$6,400 to $17,000
			7%		$6,200 to $15,000		$5,700 to $15,000
Unidentified Controls	50 ppb	16	3%	-[b]	$4,000 to $9,000	$1,800	$2,200 to $7,200
			7%		$3,000 to $8,000		$1,200 to $6,200
	75 ppb	4	3%	-[b]	$1,000 to $3,000	$500	$500 to $1,500
			7%		$1,000 to $3,000		$500 to $2,500
	100 ppb	3	3%	-[b]	$500 to $1,000	$260	$240 to $740
			7%		$500 to $1,000		$240 to $740
Full Attainment	50 ppb	56	3%	$8.50	$34,000 to $83,000	$4,400	$30,000 to $79,000
			7%		$31,000 to $75,000		$27,000 to $71,000
	75 ppb	24	3%	$2.20	$15,000 to $37,000	$1,500	$14,000 to $36,000
			7%		$14,000 to $34,000		$13,000 to $33,000
	100 ppb	9	3%	$0.60	$7,400 to $18,000	$730	$6,700 to $17,000
			7%		$6,700 to $16,000		$6,000 to $15,000

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates.
[b] The approach used to simulate air quality changes for SO_2 did not provide the data needed to distinguish partial attainment benefits from full attainment benefits from reduced SO_2 exposure. Therefore, a portion of the SO_2 benefits is attributable to the known controls and a portion of the SO_2 benefits are attributable to the unidentified controls. Because all SO_2-related benefits are short-term effects, the results are identical for all discount rates.
[c] Benefits are shown as a range from Pope et al (2002) to Laden et al. (2006). Monetized benefits do not include unquantified benefits, such as other health effects, reduced sulfur deposition, or improvements in visibility.
[d] These models assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality because there is no clear scientific evidence that would support the development of differential effects estimates by particle type. Reductions in SO_2 emissions from multiple sectors to meet the SO_2 NAAQS would primarily reduce the sulfate fraction of $PM_{2.5}$. Because this rule targets a specific particle precursor (i.e., SO_2), this introduces some uncertainty into the results of the analysis.

7.2 Discussion of Uncertainties and Limitations

Air Quality, Emissions, and Control Strategies

The estimates of emission reductions associated with the control strategies described above are subject to important limitations and uncertainties. We summarize these limitations as follows:

- *Actual State Implementation Plans May Differ from our Simulation*: In order to reach attainment with the proposed NAAQS, each state will develop its own implementation plan implementing a combination of emissions controls that may differ from those simulated in this analysis. This analysis therefore represents an approximation of the emissions reductions that would be required to reach attainment and should not be treated as a precise estimate.

- *Use of Existing CMAQ Model Runs*: This analysis represents a screening level analysis. We did not conduct new regional scale modeling specifically targets to SO_2; instead we relied upon impact ratios developed from model runs used in the analysis underlying the $PM_{2.5}$ NAAQS.

- *Unidentified controls*: We have limited information on available controls for some of the monitor areas included in this analysis. For a number of small non-EGU and area sources, there is little or no information available on SO_2 controls.

Costs

- We do not have sufficient information for all of our known control measures to calculate cost estimates that vary with an interest rate. We are able to calculate annualized costs at an interest rate other than 7% (e.g., 3% interest rate) where there is sufficient information—available capital cost data, and equipment life—to annualize the costs for individual control measures. For the vast majority of nonEGU point source control measures, we do have sufficient capital cost and equipment life data for individual control measures to prepare annualized capital costs using the standard capital recovery factor. Hence, we are able to provide annualized cost estimates at different interest rates for the point source control measures.

- There are some unquantified costs that are not adequately captured in this illustrative analysis. These costs include the costs of federal and State administration of control programs, which we believe are less than the alternative of States developing approvable SIPs, securing EPA approval of those SIPs, and Federal/State enforcement. Additionally, control measure costs referred to as “no cost” may require limited government agency resources for administration and oversight of the program not included in this analysis; those costs are generally outweighed by the saving to the industrial, commercial, or private sector. The Agency also did not consider transactional costs and/or effects on labor supply in the illustrative analysis.

Benefits

Although we strive to incorporate as many quantitative assessments of uncertainty, there are several aspects for which we are only able to address qualitatively. These aspects are important factors to consider when evaluating the relative benefits of the attainment strategies for each of the alternative standards:

1. The 12 km CMAQ grid, which is the air quality modeling resolution, may be too coarse to accurately estimate the potential near-field health benefits of reducing SO_2 emissions. These uncertainties may under- or over-estimate benefits.
2. The interpolation techniques used to estimate the full attainment benefits of the alternative standards contributed some uncertainty to the analysis. The great majority of benefits estimated for the various standard alternatives were derived through interpolation. As noted previously in this chapter, these benefits are likely to be more uncertain than if we had modeled the air quality scenario for both SO_2 and $PM_{2.5}$. In general, the VNA interpolation approach will under-estimate benefits because it does not account for the broader spatial distribution of air quality changes that may occur due to the implementation of a regional emission control program.
3. There are many uncertainties associated with the health impact functions used in this modeling effort. These include: within study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of C-R functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the C-R function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.
4. Co-pollutants present in the ambient air may have contributed to the health effects attributed to SO_2 in single pollutant models. Risks attributed to SO_2 might be overestimated where concentration-response functions are based on single pollutant models. If co-pollutants are highly correlated with SO_2, their inclusion in an SO_2 health effects model can lead to misleading conclusions in identifying a specific causal pollutant. Because this collinearity exists, many of the studies reported statistically insignificant effect estimates for both SO_2 and the co-pollutants; this is due in part to the loss of statistical power as these models control for co-pollutants. Where available, we

have selected multipollutant effect estimates to control for the potential confounding effects of co-pollutants; these include NYDOH (2006), Schwartz et al. (1994) and O'Connor et al. (2008). The remaining studies include single pollutant models.

5. This analysis is for the year 2020, and projecting key variables introduces uncertainty. 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.
6. This analysis omits certain unquantified effects due to lack of data, time and resources. These unquantified endpoints include other health effects, ecosystem effects, and visibility. EPA will continue to evaluate new methods and models and select those most appropriate for estimating the benefits of reductions in air pollution. Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, ecologists, and economists should result in a more tightly integrated analytical framework for measuring benefits of air pollution policies.
7. $PM_{2.5}$ co-benefits represent a substantial proportion of total monetized benefits (over 99% of total monetized benefits), and these estimates are subject to a number of assumptions and uncertainties.
    a. $PM_{2.5}$ co-benefits were derived through benefit per-ton estimates, which do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an over-estimate or under-estimate of the actual benefits of controlling directly emitted fine particulates.
    b. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.
    c. We assume that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.
    d. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality (which typically accounts for 85% to 95% of total monetized benefits), we include a set of twelve estimates based on results of the expert elicitation study in addition to our core estimates. Even these multiple characterizations

omit the uncertainty in air quality estimates, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the $PM_{2.5}$ estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis. For more information on the uncertainties associated with $PM_{2.5}$ co-benefits, please consult the $PM_{2.5}$ NAAQS RIA (Table 5.5).

While the monetized benefits of reduced SO_2 exposure appear small when compared to the monetized benefits of reduced $PM_{2.5}$ exposure, readers should not necessarily infer that the total monetized benefits of attaining a new SO_2 standard are minimal. For this rule, the monetized $PM_{2.5}$ co-benefits represent over 99% of the total monetized benefits. This result is consistent with other recent RIAs, where the $PM_{2.5}$ co-benefits represent a large proportion of total monetized benefits. This result is amplified in this RIA by the decision not to quantify SO_2-related premature mortality and other morbidity endpoints due to the uncertainties associated with estimating those endpoints. Studies have shown that there is a relationship between SO_2 exposure and premature mortality, but that relationship is limited by potential confounding. Because premature mortality generally comprises over 90% of the total monetized benefits, this decision may substantially underestimate the monetized health benefits of reduced SO_2 exposure.

In addition, we were unable to quantify the benefits from several welfare benefit categories. We lacked the necessary air quality data to quantify the benefits from improvements in visibility from reducing light-scattering particles. Previous RIAs for ozone (U.S. EPA, 2008a) and $PM_{2.5}$ (U.S. EPA, 2006a) indicate that visibility is an important benefit category, and previous efforts to monetize those benefits have only included a subset of visibility benefits, excluding benefits in urban areas and many national and state parks. Even this subset accounted for up to 5% of total monetized benefits in the Ozone NAAQS RIA (U.S. EPA, 2008a).

We were also unable to quantify the ecosystem benefits of reduced sulfur deposition because we lacked the necessary air quality data, and the methodology to estimate ecosystem benefits is still being developed. Previous assessments (U.S. EPA, 1999; U.S. EPA, 2005; U.S. EPA, 2009e) indicate that ecosystem benefits are also an important benefits category, but those efforts were only able to monetize a tiny subset of ecosystem benefits in specific geographic locations, such as recreational fishing effects from lake acidification in the Adirondacks. We were also unable to quantify the benefits of decreased mercury methylation from sulfate deposition. Quantifying the relationship between sulfate and mercury methylation in natural settings is difficult, but some studies have shown that decreasing sulfate deposition can also decrease methylmercury.

Chapter 8: Statutory and Executive Order Reviews

1.0 Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order 12866 (58 FR 51735, October 4, 1993), this 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 submitted this action to the Office of Management and Budget (OMB) for review under EO 12866 and any changes made in response to OMB recommendations have been documented in the docket for this action. In addition, EPA prepared a Regulatory Impact Analysis (RIA) of the potential costs and benefits associated with this action. However, the CAA and judicial decisions make clear that the economic and technical feasibility of attaining the national ambient standards cannot be considered in setting or revising NAAQS, although such factors may be considered in the development of State implementation plans to implement the standards. Accordingly, although an RIA has been prepared, the results of the RIA have not been considered by EPA in developing this final rule.

2.0 Paperwork Reduction Act

The information collection requirements in this final rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 et seq. The Information Collection Request (ICR) document prepared by EPA for these proposed revisions to part 58 has been assigned EPA ICR number 2370.01.

The information collected under 40 CFR part 53 (e.g., test results, monitoring records, instruction manual, and other associated information) is needed to determine whether a candidate method intended for use in determining attainment of the NAAQS in 40 CFR part 50 will meet the design, performance, and/or comparability requirements for designation as a Federal reference method (FRM) or Federal equivalent method (FEM). We do not expect the number of FRM or FEM determinations to increase over the number that is currently used to estimate burden associated with SO_2 FRM/FEM determinations provided in the current ICR for 40 CFR part 53 (EPA ICR numbers 2370.01). As such, no change in the burden estimate for 40 CFR part 53 has been made as part of this rulemaking.

The information collected and reported under 40 CFR part 58 is needed to determine compliance with the NAAQS, to characterize air quality and associated health impacts, to develop emissions control strategies, and to measure progress for the air pollution program. The amendments would revise the technical requirements for SO_2 monitoring sites, require the siting and operation of additional SO_2 ambient air monitors, and the reporting of the collected ambient SO_2 monitoring data to EPA's Air Quality System (AQS). This Information Collection is estimated to involve 102 respondents for a total approximate cost of $15,203,762 (total capital, and labor and non-labor operation and maintenance) and a total burden of 207,662 hours. The labor costs associated with these hours is $11,130,409. Included in the $15,203,762 total are other costs of non-labor operations and maintenance of $1,104,377 and equipment and contract costs of $2,968,975. In addition to the costs at the State and local air quality management agencies, there is a burden to EPA of total of 14,749 hours and $1,060,621. Burden is defined at 5 CFR 1320.3(b). State, local, and tribal entities are eligible for State assistance grants provided by the Federal government under the CAA which can be used for monitors and related activities.

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.

3.0 Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of this 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 this proposed rule on small entities, I certify that this action will not have a significant economic impact on a substantial number of small entities. This final rule will not impose any requirements on small entities. Rather, this rule establishes national standards for allowable concentrations of SO_2 in ambient air as required by section 109 of the CAA. *American Trucking Ass'ns v. EPA,* 175 F. 3d 1027, 1044-45 (D.C. Cir. 1999) (NAAQS do not have significant impacts upon small entities because NAAQS themselves impose no regulations upon small entities). Similarly, the amendments to 40 CFR Part 58 address the requirements for States to collect information and report compliance with the NAAQS and will not impose any requirements on small entities.

4.0 Unfunded Mandates Reform Act

This action is not subject to the requirements of sections 202 and 205 of the UMRA. EPA has determined that this proposed rule does not contain a Federal mandate that may result in expenditures of $100 million or more for State, local, and tribal governments, in the aggregate, or the private sector in any one year. The revisions to the SO_2 NAAQS impose no enforceable duty on any State, local or Tribal governments or the private sector. The expected costs associated with the monitoring requirements are described in EPA's ICR document, but those costs are not expected to exceed $100 million in the aggregate for any year. Furthermore, as indicated previously, in setting a NAAQS, EPA cannot consider the economic or technological feasibility of attaining ambient air quality standards. Because the CAA prohibits EPA from considering the types of estimates and assessments described in section 202 when setting the NAAQS, the UMRA does not require EPA to prepare a written statement under section 202 for the revisions to the SO_2 NAAQS.

With regard to implementation guidance, the CAA imposes the obligation for States to submit SIPs to implement the SO_2 NAAQS. In this final rule, EPA is merely providing an interpretation of those requirements. However, even if this rule did establish an independent obligation for States to submit SIPs, it is questionable whether an obligation to submit a SIP revision would constitute a Federal mandate in any case. The obligation for a State to submit a SIP that arises out of section 110 and section 191 of the CAA is not legally enforceable by a court of law, and at most is a condition for continued receipt of highway funds. Therefore, it is possible to view an action requiring such a submittal as not creating any enforceable duty within the meaning of U.S.C. 658 for purposes of the UMRA. Even if it did, the duty could be viewed as falling within the exception for a condition of Federal assistance under U.S.C. 658.

EPA has determined that this final rule contains no regulatory requirements that might significantly or uniquely affect small governments because it imposes no enforceable duty on any small governments. Therefore, the rule is not subject to the requirements of section 203 of the UMRA.

5.0 Executive Order 13132: Federalism

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 in section E (above) 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.

6.0 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 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, on the relationship between the Federal government and Indian tribes, or on the distribution of power and responsibilities between the Federal government and tribes. The rule does not alter the relationship between the Federal government and tribes as established in the CAA and the TAR. Under section 109 of the CAA, EPA is mandated to establish NAAQS; however, this rule does not infringe existing tribal authorities to regulate air quality under their own programs or under programs submitted to EPA for approval. Furthermore, this rule does not affect the flexibility afforded to tribes in seeking to implement CAA programs consistent with the TAR, nor does it impose any new obligation on tribes to adopt or implement any NAAQS. Finally, as noted in section E (above) on UMRA, this rule does not impose significant costs on tribal governments. Thus, Executive Order 13175 does not apply to this rule.

7.0 Executive Order 13045: Protection of Children from Environmental Health & Safety Risks

This action is subject to Executive Order (62 FR 19885, April 23, 1997) 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 has a disproportionate effect on children. This final rule will establish uniform national ambient air quality standards for SO_2; these standards are designed to protect public health with an adequate margin of safety, as required by CAA section 109. The protection offered by these standards may be especially important for asthmatics, including asthmatic children, because respiratory effects in asthmatics are among the most sensitive health endpoints for SO_2 exposure. Because asthmatic children are considered a sensitive population, we have evaluated the potential health effects of exposure to SO_2 pollution among asthmatic children. These effects and the size of the population affected are discussed in chapters 3 and 4 of the ISA; chapters 3, 4, 7, 8, 9 of the REA, and sections II.A through II.E of the preamble.

8.0 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 revised NAAQS for SO_2. The rule does not prescribe specific 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.

9.0 National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA), Public Law 104-113, section 12(d) (15 U.S.C. 27) 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.

This rulemaking involves technical standards with regard to ambient monitoring of SO_2. The use of this voluntary consensus standard would be impractical because the analysis method does not provide for the method detection limits necessary to adequately characterize ambient SO_2 concentrations for the purpose of determining compliance with the revisions to the SO_2 NAAQS.

10.0 Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order 12898 (59 FR 7629; Feb. 16, 1994) establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States.

EPA has determined that this final rule will not have disproportionately high and adverse human health or environmental effects on minority or low-income populations because it increases the level of environmental protection for all affected populations without having any disproportionately high and adverse human health effects on any population, including any minority or low-income population. The rule will establish uniform national standards for SO_2 in ambient air.