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.

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 in the range of 50 to 100 ppb. The proposal also requests comment on standard levels ranging up to a high of 150 ppb. This RIA analyzes alternative primary standards of 50 parts per billion (ppb), 75 ppb, 100 ppb, and 150 ppb.

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. As stated above, we chose 50 ppb as an analytic lower bound, and 150 ppb as an upper bound. (We chose 50 ppb as an analytic lower bound before decisions were made about either the proposed range, or the range for requesting public comment.)

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 proposed 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

[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.

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 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 <u>Summary of Analytic Approach</u>

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. 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 2002 National Emissions Inventory (NEI), and baseline SO_2 concentration values from 2005-2007 across the community-wide monitoring network. We used results from the community multi-scale air quality model (CMAQ) simulations from the ozone NAAQS RIA to calculate the expected reduction in ambient SO_2 concentrations between the 2002 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 2002 and modeled air quality projections for 2020, countywide emissions inventory data for 2002 and 2005-7, 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 33 monitors in 57 counties were projected to exceed a 50 ppb lower bound target NAAQS in 2020, and 5 monitors in 5 counties were projected to exceed a 150 ppb upper bound target 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 revisions to the $PM_{2.5}$ NAAQS, reconsideration of the Ozone NAAQS, the maximum achieveable control technology (MACT) rule for utility boilers, revisions to the Clean Air Interstate Rule, 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 a range from 33 monitors in 57 counties with projected design values exceeding 50 ppb, down to 5 monitors in 5 counties which were projected to exceed a 150 ppb upper bound target 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 each alternative primary standard by 2020. Controls for four 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 four alternative SO_2 NAAQS levels: 50 ppb, 75 ppb, 100 ppb, and 150 ppb (99th 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 primary 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. Although BenMAP has been used extensively in previous RIAs to estimate the health benefits of reducing exposure to $PM_{2.5}$ and ozone, this is the first RIA to use BenMAP to estimate the health benefits of reducing exposure to SO_2 to support a change in the NAAQS.

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 12km by 12km 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 exising 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 then selected health endpoints to be consistent with the conclusions of the Integrated Science Assessment (ISA) for SO_2 . 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_x is also a precursor to $PM_{2.5,}$ reducing SO_x 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 results reflect EPA's most current interpretation of the scientific literature and include three key changes from the 2008 ozone NAAQS RIA: (1) a no-threshold model for PM2.5 that calculates incremental benefits down to the lowest modeled air quality levels; (2) a different Value of Statistical Life (VSL); (3) two technical updates to the population dataset and aggregation method. 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 SOx emission controls. Higher or lower estimates of benefits are possible using other assumptions. Despite methodological limitations that 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, we have included a qualitative evaluation of these benefits. 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.

NonEGU and area source controls largely include measures from the AirControlNET control technology database. For these sources, we estimated costs based on the cost equations included in AirControlNET. The identified controls strategy for nonEGU Point and Area sources incorporated annualized engineering cost per ton caps. These caps were defined as less than the upper cost per ton for controls of nonEGU point and area sources. The caps used were originally developed for the Ozone NAAQS analysis. The number of applied control measures was much larger for that analysis, and therefore provides a more robust estimate of what a potential cap on SO_2 costs would look like.

The EGU analysis included in this RIA utilizes the integrated planning model (IPM) v3.0 as part of the updated modeling platform.[1] IPM v3.0 includes input and model assumption updates in modeling the power sector and incorporates Federal and State rules and regulations adopted before September 2006 and various new source review (NSR) settlements. The SO_2 control technology options used in IPM v3.0 includes flue gas desulfurization (FGD), also known as “scrubbers”. It is important to note that beyond these emission control options, IPM offers other compliance options for meeting emission limits. These include fuel switching, re-powering, and adjustments in the dispatching of electric generating units.

Finally, 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

1 http://www.epa.gov/airmarkets/progsregs/epa-ipm/past-modeling.html.

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, 100, and 150 ppb alternative NAAQS target levels in 2020.

Alternative standard (ppb)	Number of monitors	Number of counties
50	74	57
75	30	24
100	17	14
150	6	6

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, b] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb	150 ppb
Total Emission Reductions from Identified Controls	760,000	439,000	343,000	162,000
EGUs	550,000	317,000	256,000	119,000
Non-EGUs	209,000	122,000	87,000	44,000
Area Sources	1,000	100	0	0

[a] All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b] All estimates provided reflect the application of the identified control strategy analysis and the necessary emission reductions estimated for attainment as shown in Chapter 2 for the areas covered by this analysis.
[c] 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 SO_2 Emission Reductions and those from Extrapolated[1] Controls in 2020 in Total and by Sector (Tons)[a] for Each Alternative Standard

	50 ppb	75 ppb	100 ppb	150 ppb
Total Emission Reductions from Identified and Unidentified Controls	1,061,000	566,000	404,000	165,000
Total Emission Reductions from Unidentified Controls	301,000	127,000	61,000	2,600
Unidentified Reductions from EGUs	217,000	91,000	46,000	1,900
Unidentified Reductions from non-EGUs	84,000	36,000	15,000	700
Unidentified Reductions from Area Sources	75	30	0	0

[a] All estimates rounded to two significant figures.

Benefit and Cost Estimates

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 separates the portion of benefits associated with reduced levels of SO2 from the additional reductions in health effects that come with the implementation of the control strategy – (i.e., the $PM_{2.5}$ co-benefits). For instance, for an alternative standard of 100 ppb, $1.9 million in benefits are associated with reductions in SO2 while between 16,000 M and 39,000 M are associated with the $PM_{2.5}$ co-benefits.

[1] We use the term "extrapolated cost" to refer to the portion of full attainment costs not attributable to identified controls. The term is not meant to refer to a specific methodology for determining costs from unidentified controls.

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 Health Benefits	Monetized $PM_{2.5}$ Health Co-benefits	Costs	Monetized Net Benefits
Partial attainment (identified controls)	**50 ppb**	31	3%	--[b]	$29,000 to $76,000	$2,000	$27,000 to $74,000
			7%	--[b]	$27,000 to $69,000	$2,300	$25,000 to $67,000
	75 ppb	12	3%	--[b]	$17,000 to $41,000	$1,000	$16,000 to $40,000
			7%	--[b]	$15,000 to $37,000	$1,100	$14,000 to $36,000
	100 ppb	6	3%	--[b]	$13,000 to $33,000	$840	$12,000 to $32,000
			7%	--[b]	$12,000 to $29,000	$900	$11,000 to $28,000
	150 ppb	4	3%	--[b]	$6,300 to $15,000	$340	$6,000 to $16,000
			7%	--[b]	$5,700 to $14,000	$370	$5,300 to $14,000
Extrapolated portion (uUnidentified Controls	**50 ppb**	26	3%	--[b]	$12,000 to $24,000	$4,500	$7,500 to $20,000
			7%	--[b]	$10,000 to $21,000	$4,500	$5,500 to $17,000
	75 ppb	12	3%	--[b]	$5,000 to $12,000	$1,900	$3,100 to $10,000
			7%	--[b]	$5,000 to $11,000	$1,900	$3,100 to $9,100
	100 ppb	8	3%	--[b]	$3,000 to $5,000	$920	$2,000 to $4,000
			7%	--[b]	$2,000 to $5,000	$920	$1,100 to $4,000
	150 ppb	2	3%	--[b]	$100 to $250	$39	$60 to $180
			7%	--[b]	$90 to $220	$39	$50 to $180
Full attainment	**50 ppb**	57	3%	$12	$41,000 to $100,000	$6,500	$34,000 to $94,000
			7%	$12	$37,000 to $90,000	$6,800	$30,000 to $83,000
	75 ppb	24	3%	$4.6	$22,000 to $53,000	$2,900	$19,000 to $50,000
			7%	$4.6	$20,000 to $48,000	$3,000	$17,000 to $45,000
	100 ppb	14	3%	$1.9	$16,000 to $38,000	$1,800[c]	$14,000 to $36,000
			7%	$1.9	$14,000 to $35,000	$1,800[c]	$12,000 to $33,000
	150 ppb	6	3%	$0.6	$6,400 to $16,000	$380	$6,000 to $16,000
			7%	$0.6	$5,800 to $14,000	$410	$5,400 to $14,000

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates. Benefits are shown as a range from Pope et al (2002) to Laden et al. (2006). Estimates reflect full attainment with the alternate standards, including emission reductions from known and unidentified controls. Monetized benefits do not include unquantified benefits, such as other health effects, reduced sulfur deposition, or improvements in visibility.

[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 potion of the SO_2 benefits are attributable to the known controls and a portion of the SO_2 benefits are attributable to the extrapolated controls. Because all SO_2-related benefits are short-term effects, the results are identical for all discount rates.

[c] Although the costs appear the same for full attainment of 100 ppb due to rounding, the unrounded costs are actually $67,000 higher at a 7% discount rate.

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.

- *Current PM2.5 Controls in Baseline*: Our 2020 analysis year baseline assumes that States will put in place the necessary control strategies to attain the current $PM_{2.5}$ standards. As States develop their plans for attaining these standards, their SO_2 control strategies may differ significantly from our analysis.

- *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 gradient of ambient SO_2 concentrations is difficult to estimate due to the sparsity of the monitoring network in some areas. The 12km 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 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.
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'Conner et al. (2007). 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 (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. This is primary due to 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 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.

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 proposed 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. The Integrated Science Assessment (ISA) and Risk and Exposure Assessment (REA), discussed in section 1.3 below, summarize available monitoring information further.

[1] There are 488 monitors. Currently 169 monitors (representing 119 counties) exceed the most stringent target NAAQS level in this analysis (50 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." NO_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 NO_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 99^{th} percentile of 1-hour daily maximum concentrations, establishing a new standard within the range of 50 to 100 ppb. The proposal also requests comment on standard levels ranging up to a high of 150 ppb. This RIA analyzes alternative primary standards of 50 parts per billion (ppb), 75 ppb, 100 ppb, and 150 ppb. (We chose 50 ppb as an analytic lower bound before decisions were made about either the proposed range, or the range for requesting public comment.)

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,

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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>.

market power, and inadequate or asymmetric information. Correcting market failures is one reason for regulation, but it is not the only reason. Other possible justifications include improving the function of government, removing distributional unfairness, or promoting privacy and personal freedom.

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.

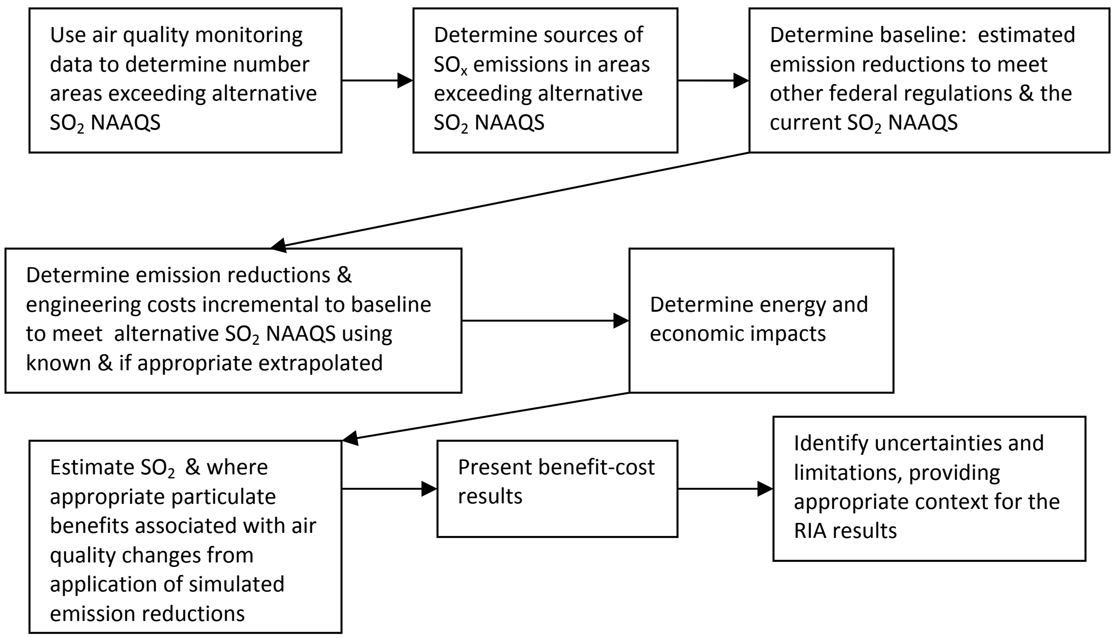
The illustrative goals of this RIA are somewhat different from other EPA analyses of national rules, or the implementation plans states develop, and the distinctions are worth brief mention. This RIA does not assess the regulatory impact of an EPA-prescribed national or regional rule such as the Clean Air Interstate 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 the revised particulate matter (PM) and NAAQS standard, 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. Since SO_2 is a precursor of PM, it is important that we account for the impact on SO_2 concentrations of the NO_2 and PM controls used in the hypothetical control scenario in the PM NAAQS RIA, so as to avoid double counting the benefits and costs of these controls.

1.3.2 Control Scenarios Considered in this RIA

In this RIA we analyzed target NAAQS levels of 50, 75, 100, and 150 ppb. Hypothetical control strategies were developed for each target NAAQS level. First, we used outputs from CMAQ model runs developed for the ozone RIA analysis 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 three technical documents EPA produced to prepare for promulgation of the SO_2 NAAQS. The first was a Criteria Document created by EPA's Office of Research and Development (published in 2007), which presented the latest available pertinent information on atmospheric science, air quality, exposure, health effects, and environmental effects of SO_2. The second was an Integrated Science Assessment (ISA) published in 2008 that evaluated the

[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.

policy implications of the key studies and scientific information contained in the Criteria Document. The third was a risk and exposure assessment (REA) for various standard levels. The REA also includes staff conclusions and recommendations to the Administrator regarding potential revisions to the standards.

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, 100, and 150 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 proposed SO_2 standard.

1.5 References

U.S. EPA. 1970. Clean Air Act. 40 CFR 50.

U.S. EPA. 2007, Integrated Review Plan and the Health Assessment Plan, U.S. Environmental Protection Agency, Washington, DC, available at http://www.epa.gov/ttn/naaqs/standards/nox/s_nox_cr_pd.html.

U.S. EPA. 2007. Review of the National Ambient Air Quality Standards for NO_2: Integrated Science Assessment. Office of Air Quality Planning and Standards, RTP, NC, available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=194645.

U.S. EPA. 2008. Review of the National Ambient Air Quality Standards for NO_2: Risk and Exposure Assessment. Office of Air Quality Planning and Standards, RTP, NC, available at http://www.epa.gov/ttn/naaqs/standards/nox/s_nox_cr_rea.html.

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 controls 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, principle 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.

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, 100, and 150 ppb based on design values calculated using the 3-year average of the 98th and 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, 2008a).

3.1 2005-2007 Design Values

The proposed standard is based on the 3-year average of the 98th or 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 98th and 99th percentile values of the daily 1-hour maximum concentrations for each year
- Average the 98th percentile values for the three years. 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 98th and 99th percentile daily 1-hour maximum concentrations are shown in Figures 3.1 and 3.2 respectively for 229 monitored counties. Counties in blue, green, yellow, and scarlet would exceed the lowest alternative standard considered in the RIA, 50 ppb. The

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

counties are color-coded based on the alternative standards; i.e. counties in green exceed 75 ppb but not 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. Concentrations 50.5 ppb and higher are considered exceeding the lowest alternative standard. Similar rounding is done for the 75, 100, and 150 ppb alternative standards (75.4, 100.4, and 150.4 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 98th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

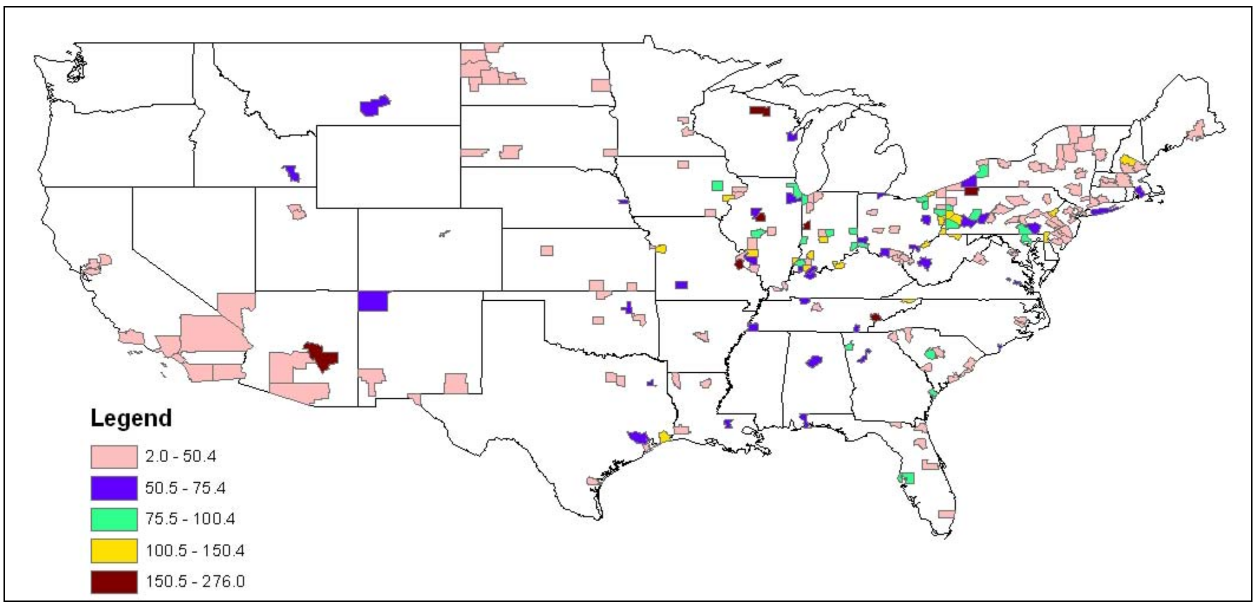


Figure 3.2. 2005-2007 3-year averaged design values (ppb) for 99th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

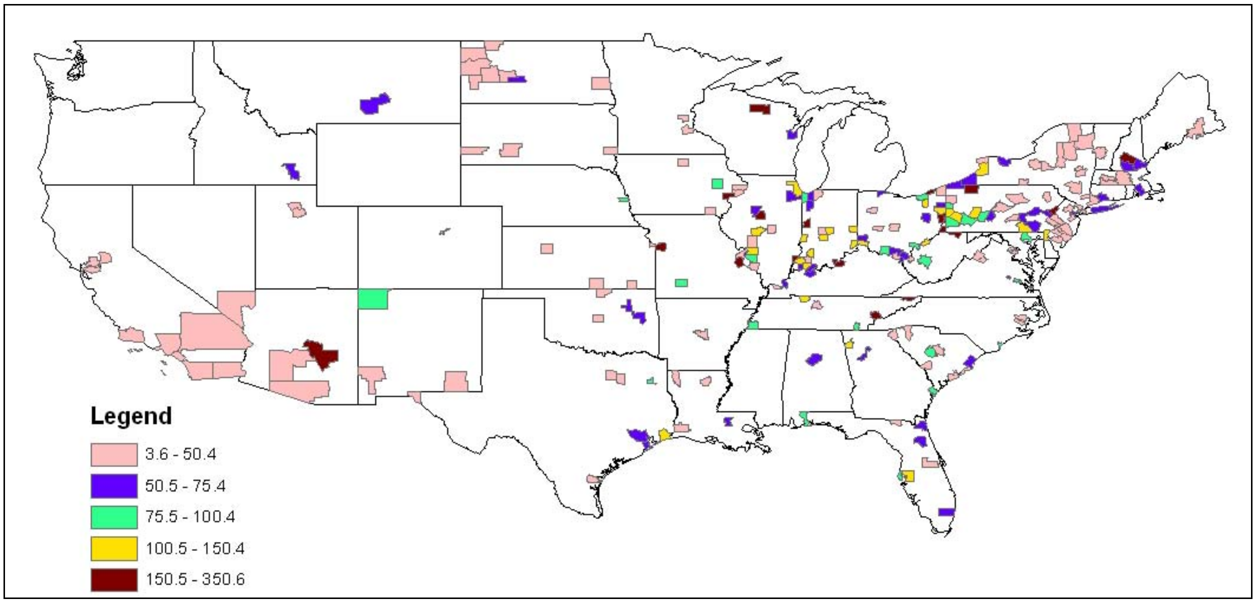


Table 3.1. Number of monitors and counties exceeding 50, 75, 100, and 150 ppb alternative standards for 98^{th} and 99^{th} percentile design values for 2005-07.

Alternative standard (ppb)	Percentile	Number of monitors	Number of counties
50	98^{th}	132	93
	99^{th}	169	119
75	98^{th}	69	54
	99^{th}	95	70
100	98^{th}	41	39
	99th	59	46
150	98^{th}	7	7
	99^{th}	23	21

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

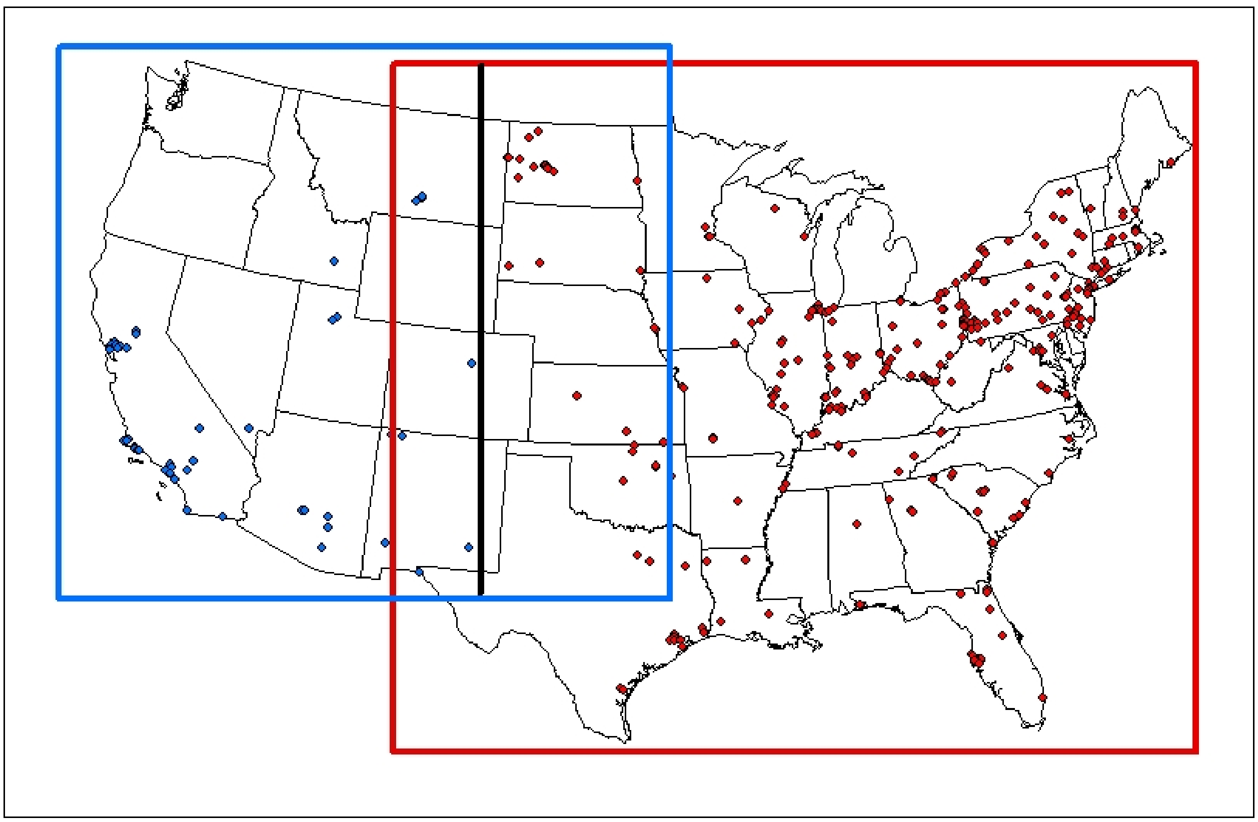
The 2020 baseline design values were determined using CMAQ gridded emissions for 2006 and 2020. Gridded emissions were utilized instead of county emissions because of the influence of stationary sources on SO_2 concentrations. For monitors near county boundaries, stationary sources in a neighboring county may have more influence over the monitor than a stationary source in the monitor's home county. The 2020 emissions were used in CMAQ runs for the ozone RIA (EPA, 2008b). Due to timing and resource issues, we decided to use existing CMAQ inputs for ozone modeling instead of conducting new modeling. The SO_2 emissions in the CMAQ runs reflect reductions from federal programs including the Clean Air Interstate Rule (EPA, 2005a), the Clean Air Mercury Rule (EPA, 2005b), the Clean Air Visibility Rule (EPA, 2005c), the Clean Air Nonroad Diesel Rule (EPA, 2004), the Light-Duty Vehicle Tier 2 Rule (EPA, 1999), the Heavy Duty Diesel Rule (EPA, 2000); proposed rules for Locomotive and Marine Vessels (EPA, 2007a) and for Small Spark-Ignition Engines (EPA, 2007b); and national, state and local level mobile and stationary source controls identified for additional reductions in emissions for the purpose of attaining the current PM 2.5 and Ozone standards. It should be noted that the emission reductions modeled for the PM2.5 and Ozone standards represent one possible control scenario, while the actual control strategies and resulting levels of emission reductions will be determined as part of the process of developing and implementing state implementation plans over the coming years. The 2006 emissions also reflect emissions as part of the Category 3 (engines with 30 liter or more cylinder displacement) marine diesel engine Rule (EPA, 2009).

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 3.3. For 2020 we used CMAQ SO_2 emissions from the Ozone NAAQS RIA "2020_070" control case.

3.2.1 2020 Design Value Calculation Methodology

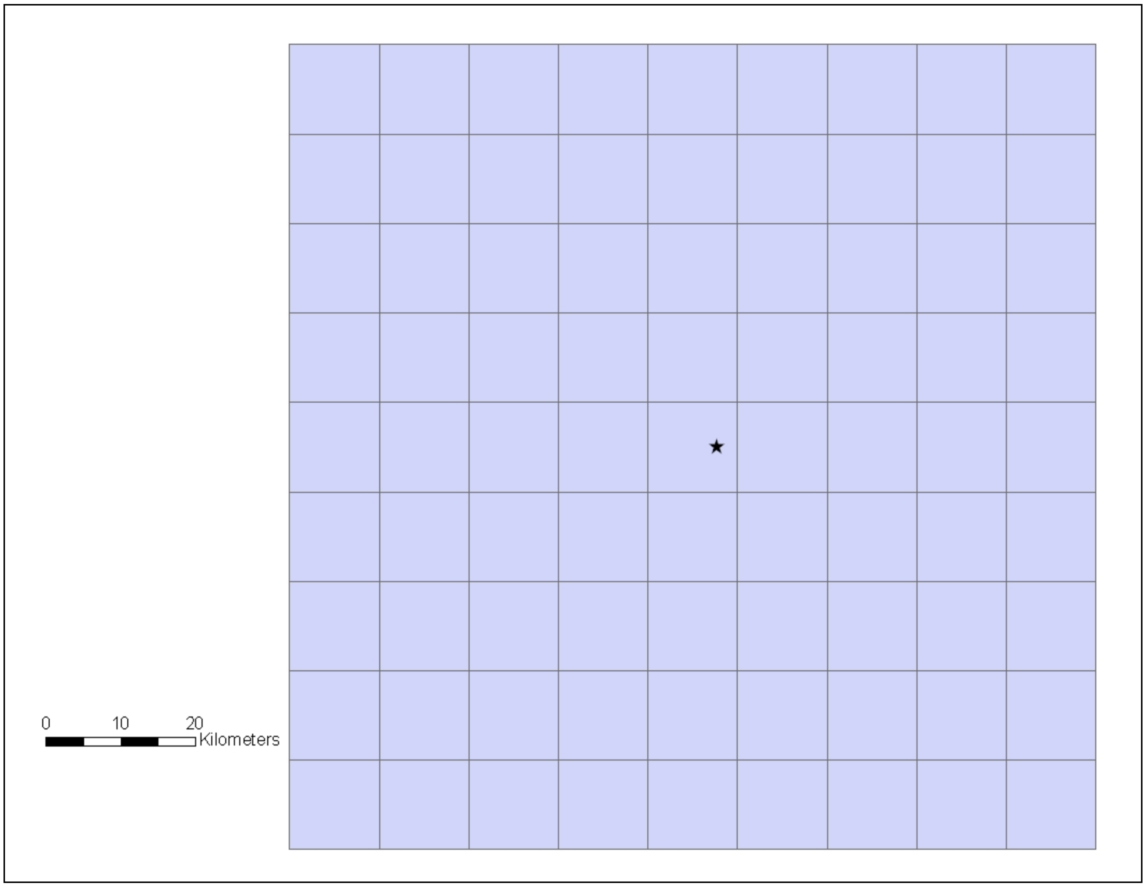
Ambient monitored data were assigned to CMAQ grid cells using ArcGIS. Since there were areas of the country where the eastern and western domains overlapped, monitors in these overlapping areas were assigned to the eastern or western grid cells by using a "combined grid." This combined grid was a mesh 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 3.3. Figure 3.3 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 3.3. 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.



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. An example is shown in Figure 3.4. 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 3.4. 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 2006 and 2020 gridded emissions were summed separately across the 81 grid cells to result in total 2006 and 2020 emissions for each monitor. The summed 2020 emissions were then divided by the 2006 emissions to get an emissions change ratio:

$$E_{ratio} = \frac{E_{2020}}{E_{2006}} \qquad (3.1)$$

Where E_{2020} are the summed 81 grid cell emissions for 2020, E_{2006} are the summed 81 grid cell emissions for 2006 and E_{ratio} is the ratio of 2020 emissions to 2006 emissions.

The 2005-2007 98th and 99th percentile design value concentrations were then multiplied by the emissions ratio to calculate the 2020 design values.

$$DV_{2020"P} = DV_{2005-2007:P} \times E_{ratio} \quad (3.2)$$

Where E_{ratio} is as defined above, $DV_{2005\text{-}2007:P}$ is the 2005-2007 3-year averaged design value for percentile P (98th or 99th), and $DV_{2020:P}$ is the projected 2020 design value for percentile P (98th or 99th).

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

$$ppb/ton_P = \left(DV_{20205:P} - DV_{2005-2007:P}\right) \Big/ \left(E_{2020} - E_{2006}\right) \quad (3.3)$$

Where E_{2020} and E_{2006} are the summed emissions as defined for Equation 3.1, $DV_{2005\text{-}2007:P}$ and $DV_{2020:P}$ are as defined above and ppb/ton_P is the ppb/ton estimate for percentile P (98th or 99th).

Residual nonattainment estimates for the four alternative standards of 50, 75, 100, and 150 ppb were calculated by subtracting the alternative standard from the 2020 design value (98th and 99th percentiles). The absolute values of the alternative standards (50, 75, 100, or 150 ppb) were not subtracted but rather the highest value that would meet the standards (50.4, 75.4, 100.4 and 150.4 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:

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

Where ppb/ton_P is as defined above, $NA_{P:AS}$ is the residual nonattainment for alternative standard AS (50, 75, 100, or 150 ppb) for percentile P (98th or 99th), and $Tons_{P:AS}$ are the tons needed to reach attainment for alternative standard AS for percentile P.

3.3 Results

3.3.1. Nonattainment results

Table 3.3 lists the number of monitors and counties exceeding the four alternative standards for the 98th and 99th percentile 2020 design values. The number of counties exceeding each of the alternative standards decreased from 2005-2007 to 2020. Figures 3.5 and 3.6 show the maximum 2020 design value for monitored counties for the 98th and 99th percentile design values. Counties in blue, green, yellow, and scarlet exceed the 50 ppb alternative standard. Table 3.4 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 3.3. Number of monitors and counties exceeding 50, 75, 100, and 150 ppb alternative standards for 98th and 99th percentile design values for 2020.

Alternative standard (ppb)	Percentile	Number of monitors	Number of counties
50	98^{th}	43	33
	99^{th}	74	57
75	98^{th}	21	16
	99^{th}	30	24
100	98^{th}	13	11
	99th	17	14
150	98^{th}	5	5
	99^{th}	6	6

Figure 3.5. 2020 design values (ppb) for 98th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

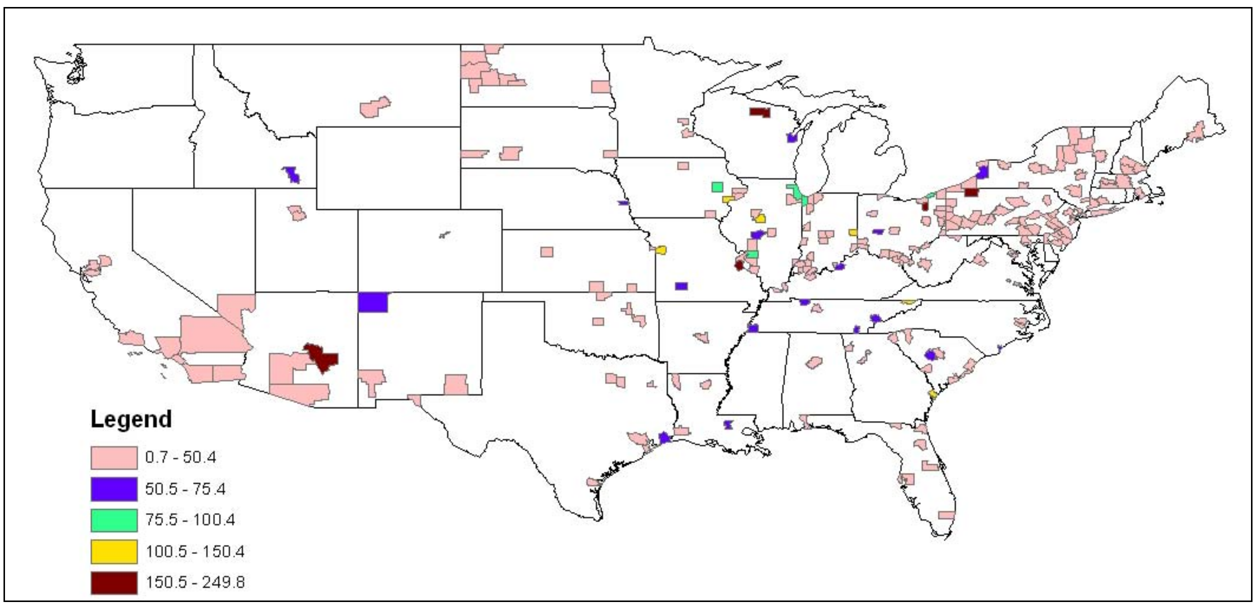


Figure 3.6. 2020 design values (ppb) for 99th percentile daily 1-hour maximum SO_2 concentrations. Values shown are county maxima.

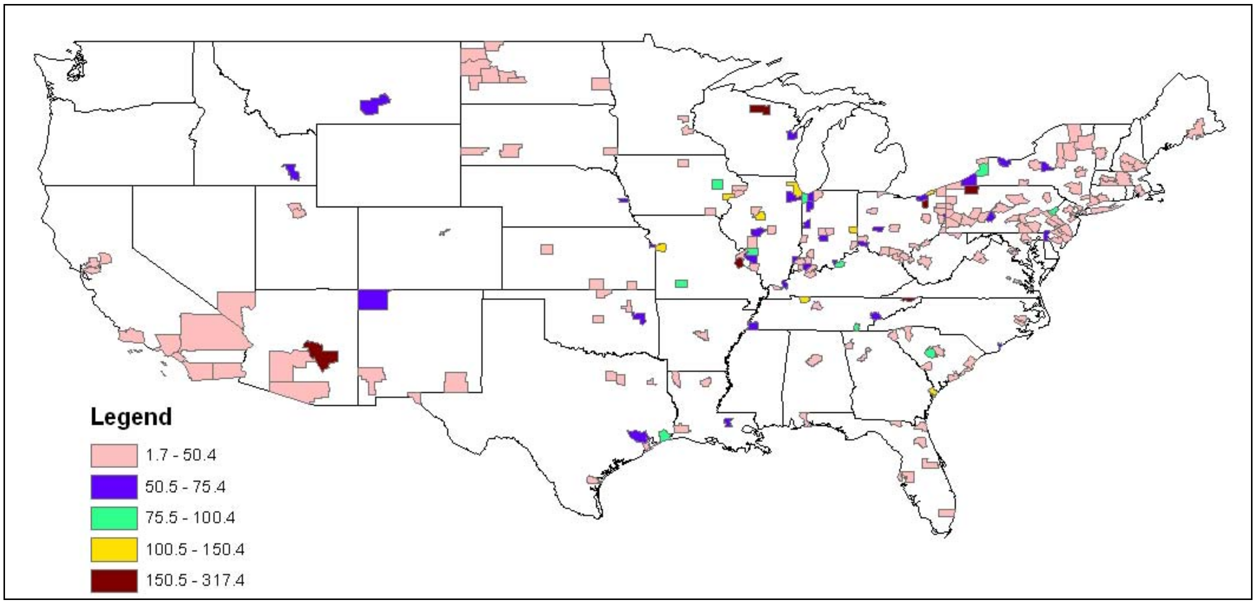


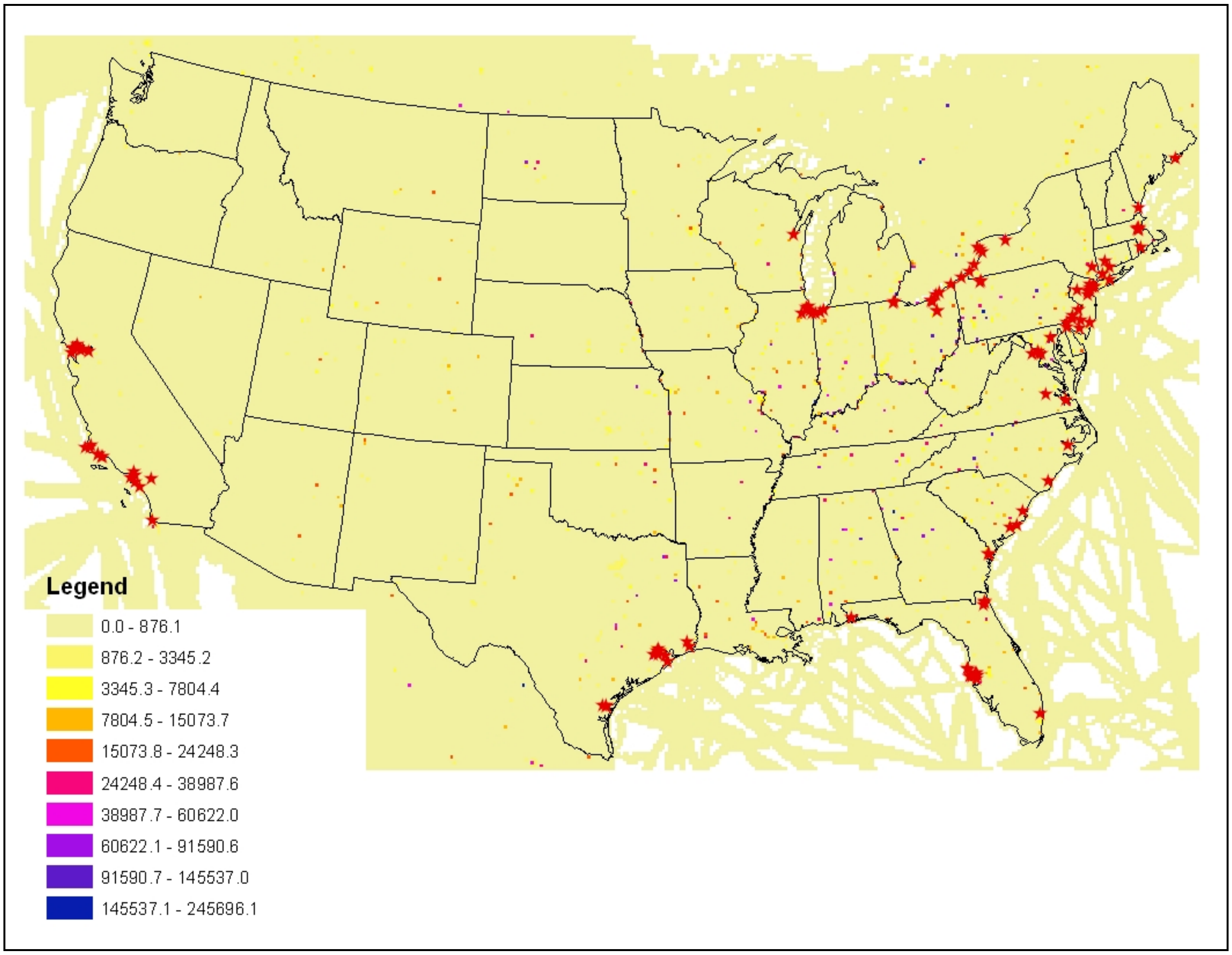
Table 3.4. Top 10 2020 counties 99th percentile design values.

State	County	2020 DV	Alternative standards (ppb)							
			50		75		100		150	
			Residual nonattainment	Tons for control	Residual nonattainment	Tons for control	Residual nonattainment	Tons for control	Residual nonattainment	Tons for control
MO	Jefferson	317.4	267	135,586	242	122,891	217	110,195	167	84,805
AZ	Gila	296.5	246.1	16,193	221.1	14,548	196.1	12,903	146.1	9,613
PA	Warren	245.7	195.3	14,150	170.3	12,338	145.3	10,527	95.3	6,905
WI	Oneida	183.1	132.7	7,427	107.7	6,028	82.7	4,628	32.7	1,830
OH	Summit	170.6	120.2	41,312	95.2	32,720	70.2	24,127	20.2	6,943
TN	Sullivan	169.2	118.8	66,461	93.8	52,475	68.8	38,489	18.8	10,517
IL	Tazewell	149.3	98.9	41,589	73.9	31,076	48.9	20,563	-	-
TN	Montgomery	143	92.6	21,081	67.6	15,390	42.6	9,698	-	-
MO	Jackson	138.5	88.1	44,567	63.1	31,920	38.1	19,273	-	-
GA	Chatham	134.8	84.4	29,929	59.4	21,064	34.4	12,199	-	-

3.3.2 2006 ocean-going vessel emissions

The 2006 inventory contained oceangoing SO_2 emissions as part of the proposed Category 3 marine diesel engine rule (EPA, 2009). These can be seen in Figure 3.7 as lines radiating out from port areas. These emissions were not in the 2020 inventory as used in the final ozone RIA. For monitors affected by the oceangoing vessel emissions, the lack of oceangoing vessel emissions in 2020 could lead to an underestimation of 2020 design values. Of the 349 monitors used in this RIA, approximately 119 monitors, based on visual analysis, contained these oceangoing vessel emissions in their 9x9 matrix of 2006 emissions. These monitors were located near ports or the coast. Analyses of emissions for these receptors indicated that the oceangoing vessel emissions did not play a large role in the emissions change from 2006 to 2020 and subsequently did not play a large role in 2020 projected design values. For seventy of these monitors, the 2005-2007 design values were already below 50 ppb and were often well below 50 ppb. This further indicated that oceangoing vessels may not play a large role in the monitor design values. For most monitors, the land-based emissions (point sources or other sources) were bigger contributors to monitor emissions. Even though the 2020 inventory did not contain the emissions associated with the ocean-going vessels, 2020 emissions were projected to decrease (EPA, 2009) and design values would decrease from 2006 to 2020.

Figure 3.7. 2006 12km gridded emissions (tons) and monitors (stars) located near coastal regions or ports.



3.3.3 Example monitors

This section describes the emissions changes for two monitors 99th percentile design values shown Figure 3.8. One monitor's design value, Tazewell County, IL decreased from 2005-2007 to 2020 (Figure 3.8a) and the other monitor's design value increased from 2005-2007 to 2020, Gila County, AZ (Figure 3.8b). Emissions in the 81 cell matrices for both monitors are shown in Table 3.5.

Figure 3.8. Locations of monitors in a) Tazewell County, IL and b) Gila County, AZ.

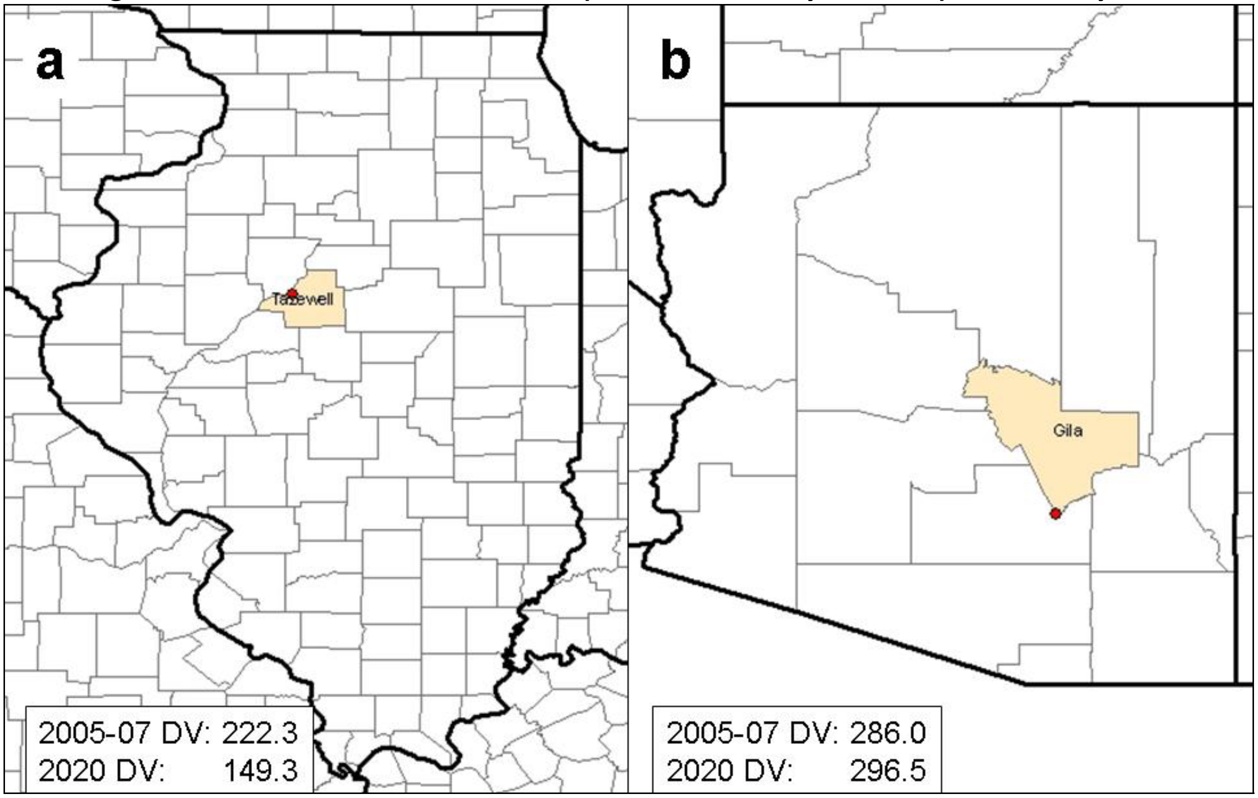


Table 3.5. 2006 and 2020 81-cell emissions for the monitors in Tazewell and Gila Counties by source sector.

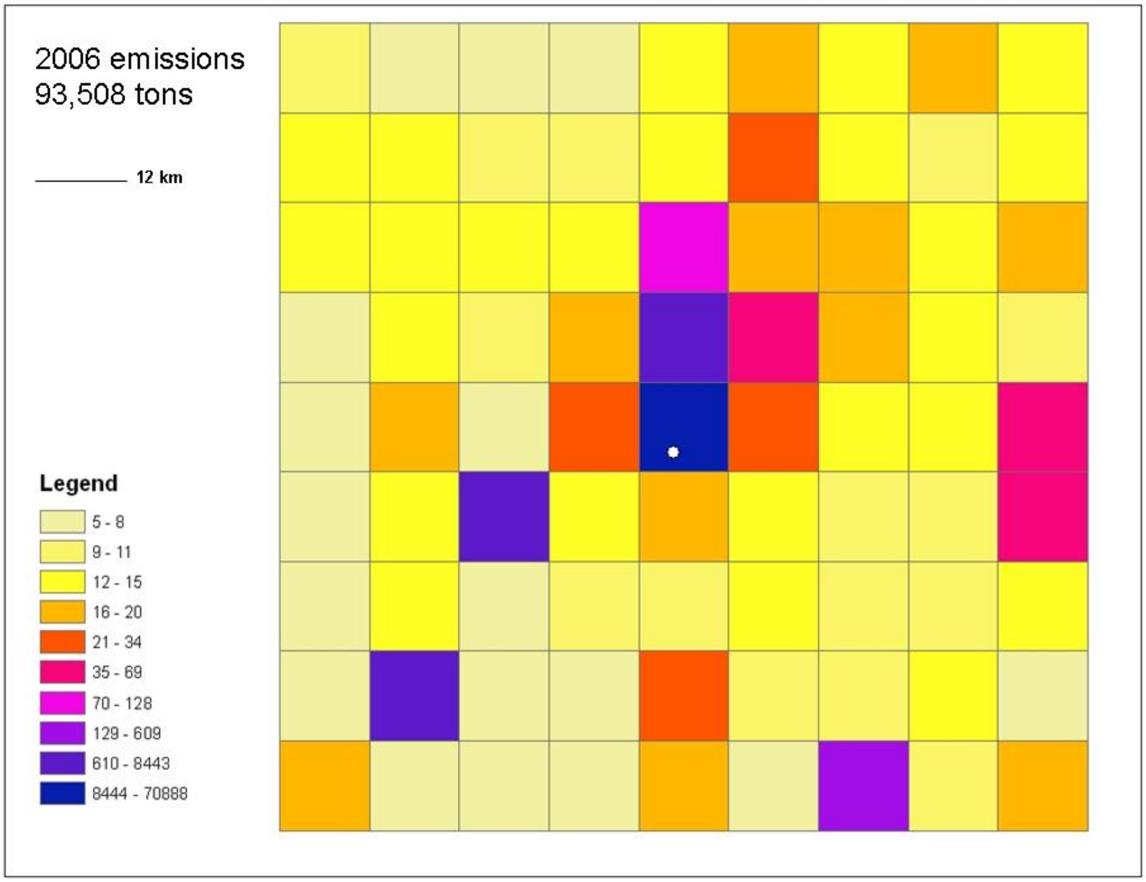
Emissions (tons)	Tazewell		Gila	
	2006	**2020**	**2006**	**2020**
EGU	70,714	38,386	0	0
Non-EGU	21,377	21,369	18,441	18,441
Other*	1,417	3,055	326	1,017
Total	93,508	62,810	18,767	19,458
Emissions ratio (2020/2006)	0.6717		1.0368	

*gridded nonpoint, nonroad, and onroad mobile emissions

3.3.2.1 Tazewell County

Gridded emissions are shown for the monitor in Tazewell County in Figure 3.9 for 2006 and Figure 3.10 for 2020. The overall matrix emissions decreased from 2006 to 2020 with the 2020 emissions being about 67% of the 2006 emissions. The grid cell containing the monitor (denoted by the white circle in Figures 3.9 and 3.10) was the highest emitting grid cell for 2006 in the emissions matrix with 70,888 tons of SO_2, approximately 75% of the matrix emissions (Figure 3.9). The grid cell was also the highest emitting grid cell for EGU point and non-EGU point sources, 58,357 and 12,458 tons respectively. The cell was the second highest, 74 tons, for other sources (excluding EGU and non-EGU point emissions) with the cell just north of it being the highest, 183 tons.

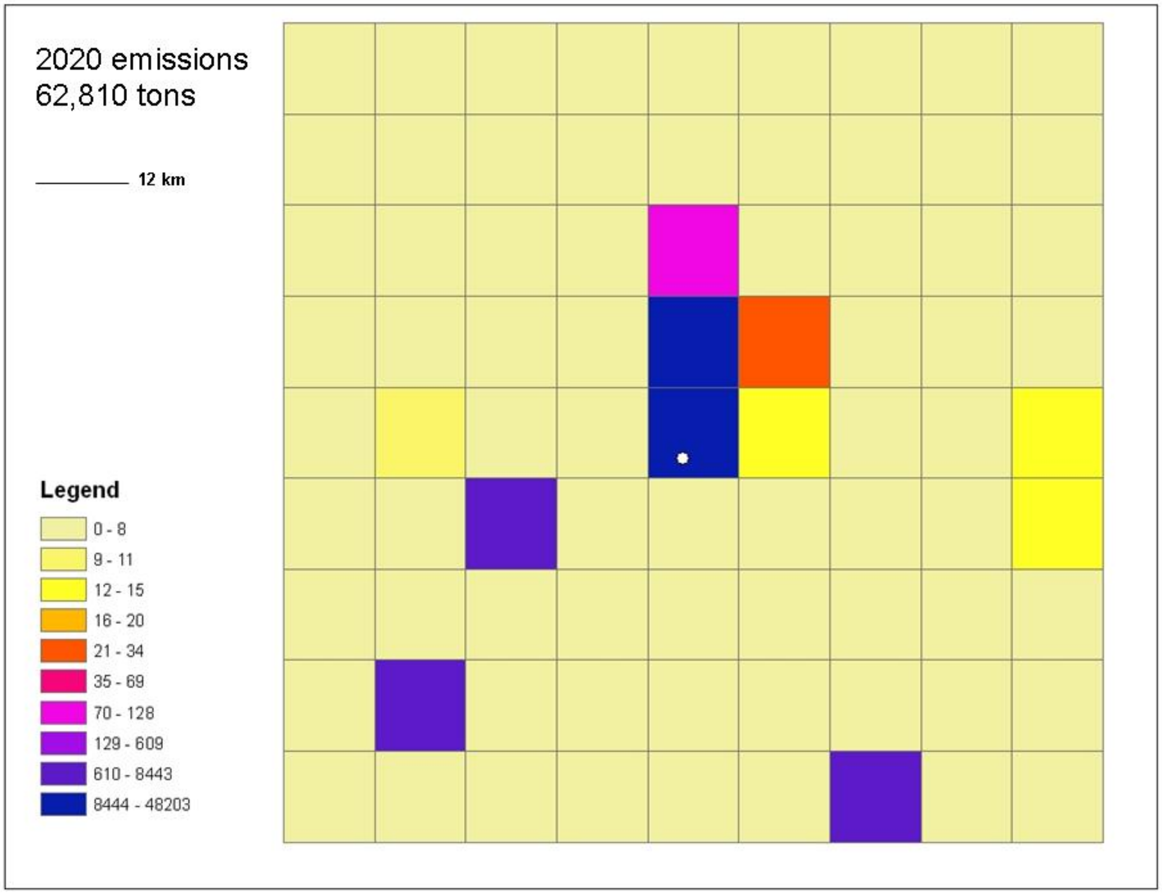
Figure 3.9. 2006 12 km grid cell SO_2 total emissions for Tazewell County monitor. The white dot represents the monitor location.



In 2020, the total matrix emissions were 62,810 tons with 48,203 in the monitor's home grid cell (Figure 3.10). As in 2006, the monitor's grid cell contains about 75% of the emissions and is the highest emitting grid cell for EGU point and non-EGU point, 33,610 and 12,458 tons respectively. The grid cell was also the highest emitting cell for other emissions, 2,135 tons.

The overall decrease in emissions was due to a decrease in EGU emissions between 2006 and 2020 with the monitor's grid cell being the dominant emission source. The decrease in emissions resulted in an emissions ratio of 0.67, which caused a concentration decrease from 222.3 to 149.6 ppb. This resulted in Tazewell County dropping from the third highest county in 2005-2007 to seventh highest in 2020.

Figure 3.10. 2020 12 km grid cell SO_2 total emissions for Tazewell County monitor. The white dot represents the monitor location.



3.3.2.2 Gila County

Gridded emissions for Gila County, AZ for 2006 and 2020 are shown in Figures 3.11 and 3.12 respectively. Emissions increased from 18,767 to 19,458 tons from 2006 to 2020. In 2006, the grid cell of the monitor contained 18,446 tons of SO_2 (98% of matrix total). The emissions were mostly non-EGU point sources, 18,438 tons (smelter activities), with seven tons from other sources. There were no EGU sources in the grid cell matrix for the monitor for either year. In 2020 the monitor's home grid cell contained 19,213 tons of SO_2 (98% of matrix total). The increase in emissions was due to an increase in other emissions (not EGU or non-EGU point) as the non-EGU emissions, for the grid cell and the matrix as a whole were relatively unchanged. The monitor's grid cell was the largest change in emissions. The increase in emissions resulted in an emissions ratio of 1.03 and an increase in design value concentrations from 286 to 296.5 ppb. Gila County remained the second highest county from 2005-2007 to 2020.

Figure 3.11. 2006 12 km grid cell SO_2 total emissions for Gila County monitor. The white dot represents the monitor location.

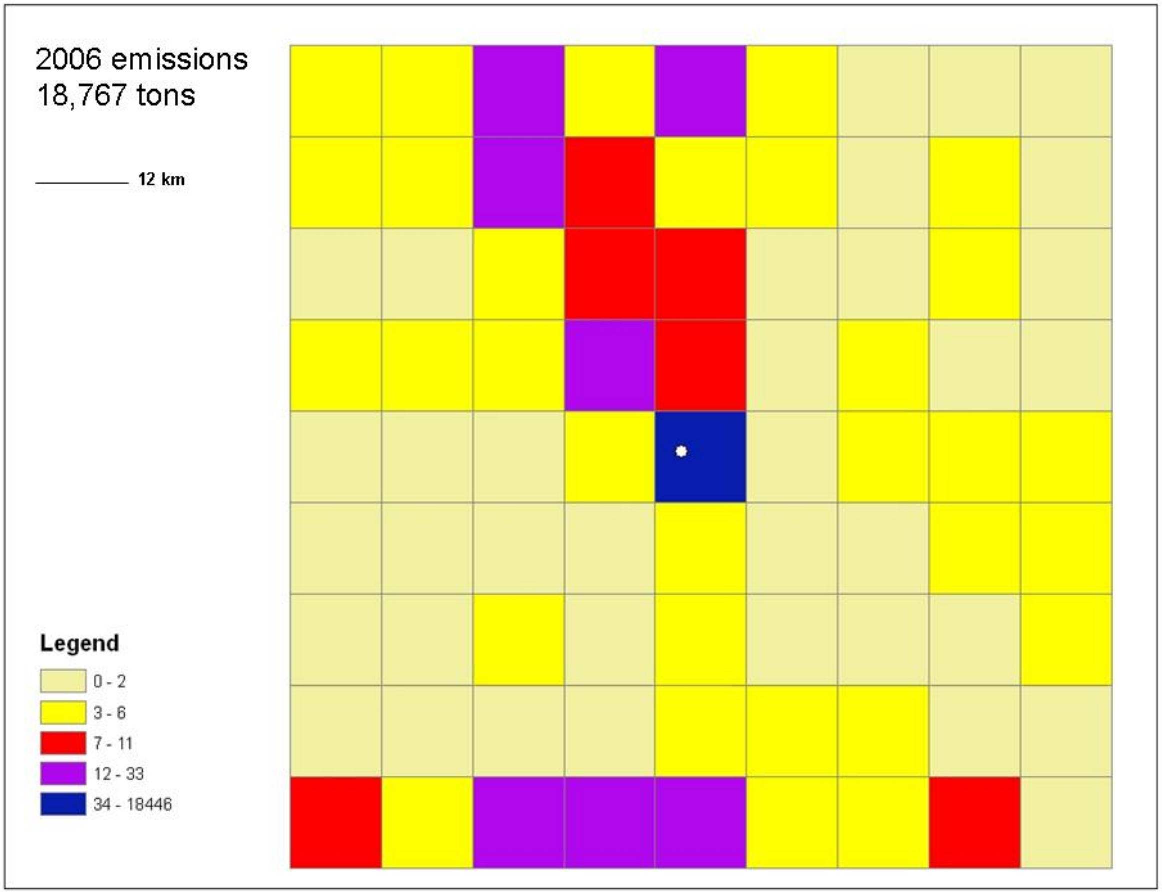
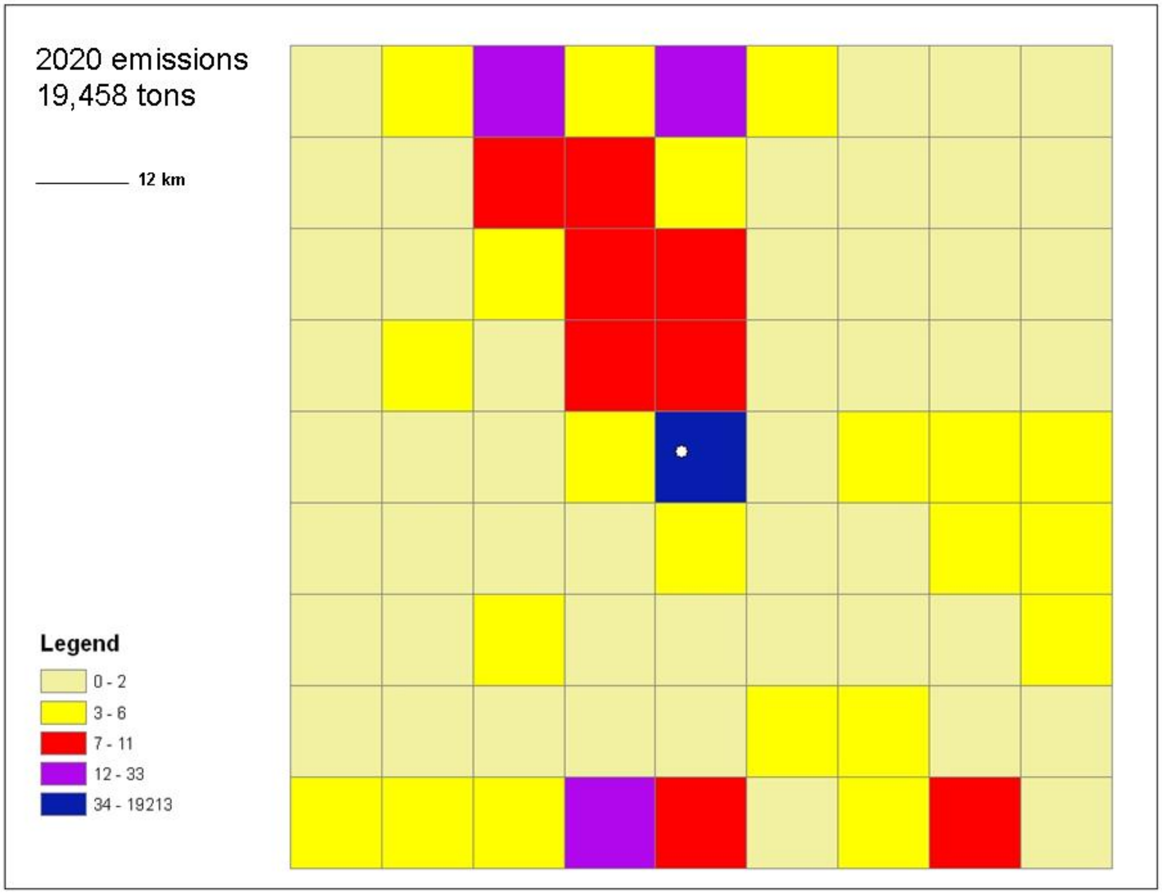


Figure 3.12. 2020 12 km grid cell SO_2 total emissions for Gila County monitor. The white dot represents the monitor location.



3.6 Summary

In summary, 2020 baseline NO_2 design value concentrations were projected from 2005-2007 observed design values using CMAQ emissions output from the 2006 and the 2020_070 scenario simulations performed for the ozone NAAQS RIA (U.S. EPA, 2008b). Results of the projections showed that, in 2020, nonattainment occurred for all four alternative standards (50, 75, 100, and 150 ppb). However, the number of counties exceeding the standards dropped from the 2005-2007 period.

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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 proposed 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 proposal would set a new short-term SO_2 standard based on the average of the 99th percentile of 1-hour daily maximum concentrations from three consecutive years. The proposal would set the level of this new standard within the range of 50 to 100 parts per billion (ppb). The proposal also requests comment on a standard level as high as 150 ppb. OMB Circular A-4 requires the RIA to contain, in addition to analysis of the impacts of the proposed NAAQS, analysis of a level more stringent and a level less stringent than the proposed NAAQS. As a lower bound, however, we chose an alternative primary standard of 50 parts per billion (ppb). This level captures the largest number of geographic areas that may be affected by a new SO_2 standard. Our analysis of this hypothetical scenario is meant to approximate the most comprehensive set of control strategies that areas across the country might employ to attain. (Note that we chose 50 ppb as an analytic lower bound well before decisions were made about either the proposed range, or the range for requesting public comment.)

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 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

[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.

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 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 $PM_{2.5}$. 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.

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 488 monitors in the current network. Chapter 3 explains that the current network is focused on longer terms indicators that that included in this proposal.

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 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.

4.1 Developing the Identified Control Strategy Analysis

The 2020 baseline air quality estimates revealed that 57 monitors in 34 counties had projected design values exceeding 50 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 50 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[2] 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 SO_2 controls 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 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 (section 3.2.1). The results of analyzing the control strategy indicate that there were 26 areas projected not to attain 50 ppb in 2020 using all identified control measures. To complete the analysis, EPA then extrapolated the additional

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

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 is the control strategy used in the Final Ozone NAAQS RIA that was completed in March 2008. The baseline strategy was developed to simulate attainment for the Ozone NAAQS in 2020. This strategy also accounted for extensive reductions in SO_2 emissions from EGUs as implemented in the Clean Air Interstate Rule (CAIR). While the US District Court for District of Columbia has remanded the CAIR, it still is in full effect. No additional controls for SO_2 are implemented in the baseline.

Consistent with the baseline, the Integrated Planning Model (IPM) version 3.0 was used to develop the background for the control strategy applied for the alternative standard of 50 ppb. Historically, EPA has used the IPM model to assess the cost and effectiveness of additional EGU controls. Due to time and resource limitations, EPA decided to only perform a single IPM run focused on the tightest alternative standard of 50 ppb. We used this IPM run as the means of identifying the units which needed to be controlled to assist an area to meet the various standard alternatives. The end result of this approach mimics an approach which may 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 applied to uncontrolled coal-fired units of size 100 MW and larger within the 50 km radius of violating monitors. Each unit has given the option of retrofitting with a Wet Flue Gas Desulfurization (FGD) scrubber with 95 percent SO_2 reduction efficiency or retire. This control measure is applicable to coal-fired EGUs with unit capacities above 100 MW. No controls were applied to EGUs under 100 MW unit capacity because EPA currently has insufficient data to estimate the impact of SO_2 controls on such small sources.

Detailed background information on both the EGU control strategy used in the Final Ozone NAAQS RIA, CAIR and IPM is included in the Final Ozone NAAQS RIA (see sections 3a.3.1 and 3a.3.2 of the RIA at http://www.epa.gov/ttn/ecas/ria.html). More information on the SO_2 measures can be found in the documentation for the IPM.[3]

[3] http://www.epa.gov/airmarkt/progsregs/epa-ipm/index.html

4.1.2 Controls Applied for the NonEGU Point and Area Sectors

NonEGU point and Area control measures were identified using AirControlNET 4.2[4,5] as well as the Control Strategy Tool[6] (CoST). AirControlNET has been used for developing control strategies as part of the PM NAAQS, Ozone NAAQS, and Lead NAAQS RIAs. 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 90% control of SO_2 for non-EGU point sources and 95 percent 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.[7]

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[4] See http://www.epa.gov/ttnecas1/AirControlNET.htm for a description of how AirControlNET operates and what data are included in this tool.

[5] While AirControlNET has not undergone a formal peer review, this software tool has undergone substantial review within EPA's OAR and OAQPS, and by technical staff in EPA's Regional offices. Much of the control measure data has been included in a control measure database that will be distributed to EPA Regional offices for use by States as they prepare their ozone, regional haze, and PM2.5 SIPs over the next 10 months. See http://www.epa.gov/particles/measures/pm_control_measures_tables_ver1.pdf for more details on this control measures database. In addition, the control measure data within AirControlNET has been used by various States and Regional Planning Organizations (RPOs) such as the Lake Michigan Air District Commission (LADCO), the Ozone Transport Commission (OTC), and the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) as part of their technical analyses associated with SIP development over the last 3 years. All of their technical reports are available on their web sites.

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

[7] 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.

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), petroleum refineries	90—FGD scrubbers or SDA	$800-$8,000—FGD $900 – 7,000—SDA
Increase percentage sulfur conversion to meet sulfuric acid NSPS (99.7% reduction)	Sulfur recovery plants	75 to 95	$4,000
Sulfur recovery and/or tail gas treatment	Sulfuric Acid Plants	95-98	$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), 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 three years ago. 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 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), mineral products (primarily aluminum plants and 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 controls.

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. [8]

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 50 ppb alternative standard in 2020 are 759,000 tons. About 550,000 tons of the reductions are from EGUs, and 209,000 are from non-EGU point sources. For the other alternative standards, the total emission reductions in 2020 are estimated to range from 160,000 tons to 439,000 tons. For all of these standards, this analysis shows that roughly 60 to 70 percent of these reductions are from EGUs. All of the remaining reductions obtained come from non-EGU point sources except for the 50 and 75 ppb standards where a very small portion (below 0.2 percent) of reductions comes from area sources.

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

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

	50 ppb	75 ppb	100 ppb	150 ppb
Total Emission Reductions from Identified Controls:[c]	760,000	439,000	343,000	162,000
EGUs	550,000	317,000	256,000	119,000
Non-EGUs	209,000	122,000	87,000	44,000
Area Sources	1,000	100	0	0

[a]All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b] All estimates provided reflect the application of the identified control strategy analysis, incremental to a 2020 baseline of compliance with the current PM2.5 standards, and the necessary emission reductions estimated for attainment as shown in Chapter 2 for the areas covered by this analysis.
[c]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, with the percent of non-EGU point source reductions from industrial boilers ranging from 52 (150 ppb) to 67 (50 ppb). Sulfuric acid plants are the source category with the next highest percent of reductions (14 percent at 50 ppb, 45 percent at 150 ppb).

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

	50 ppb	75 ppb	100 ppb	150 ppb
Total Non-EGU Emission Reductions from Identified Controls:[c]	209,000	122,000	87,000	44,000
Industrial Boilers	139,000	82,000	54,000	23,000
Sulfuric Acid Plants	29,000	24,000	21,000	20,000
Commercial/Institutional Boilers	24,000	13,000	12,000	0
Petroleum Refineries	26,000	10,000	1,000	1,000
Mineral Products	7,000	5,000	200	100

[a]All estimates rounded to two significant figures. As such, totals may not sum down columns.
[b] All estimates provided reflect the application of the identified control strategy analysis, incremental to a 2020 baseline of compliance with the current PM2.5 standards, and the necessary emission reductions estimated for attainment as shown in Chapter 2 for the areas covered by this analysis.
[c]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 alternative standard of 50 ppb and also for the other three alternative standards.

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

State	County	Emission Reductions (annual tons/year)			
		50 ppb	75 ppb	100 ppb	150 ppb
Arizona	Gila Co	8,100	8,100	8,100	8,100
Delaware	New Castle Co	8,500			
Georgia	Chatham Co	18,000	18,000	18,000	
Idaho	Bannock Co	620			
Illinois	Cook Co	97,000	84,000	84,000	
Illinois	Madison Co	27,000	22,000		
Illinois	St Clair Co	47,000			
Illinois	Sangamon Co	590			
Illinois	Tazewell Co	28,000	28,000	23,000	
Illinois	Wabash Co	6,500			
Illinois	Will Co	56,000			
Indiana	Floyd Co	8,600			
Indiana	Fountain Co	4,000			
Indiana	Jasper Co	24,000			
Indiana	Lake Co	79,000	65,000		
Indiana	Morgan Co	6,100			
Indiana	Porter Co	54,000			
Indiana	Warrick Co	13,000			
Indiana	Wayne Co	4,600	4,600	4,600	
Iowa	Linn Co	4,200	4,200		
Iowa	Muscatine Co	5,400	5,400	5,400	
Kansas	Wyandotte Co	24,000			
Kentucky	Jefferson Co	8,600	5,500		
Kentucky	Livingston Co	48,000			
Louisiana	East Baton Rouge Par	36,000			
Missouri	Greene Co	450	450		
Missouri	Jackson Co	11,000	11,000	11,000	
Missouri	Jefferson Co	87,000	87,000	87,000	87,000
Missouri	St Louis	95,000			
Montana	Yellowstone Co	1,200			
Nebraska	Douglas Co	3,400			
New Mexico	San Juan Co	1,700			
New York	Chautauqua Co	5,700			
New York	Erie Co	2,900	2,900		
New York	Madison Co	160			
New York	Monroe Co	230			
North Carolina	New Hanover Co	9,700			
Ohio	Clark Co	2,200			
Ohio	Cuyahoga Co	29,000			
Ohio	Hamilton Co	21,000			
Ohio	Lake Co	26,000	26,000	26,000	
Ohio	Summit Co	19,000	19,000	19,000	8,800
Oklahoma	Muskogee Co	20,000			
Pennsylvania	Blair Co	790			
Pennsylvania	Northampton Co	8,900	5,200		

State	County	Emission Reductions (annual tons/year)			
		50 ppb	75 ppb	100 ppb	150 ppb
Pennsylvania	Warren Co	5,700	5,700	5,700	5,700
South Carolina	Lexington Co	9,900	8,100		
Tennessee	Blount Co	6,400			
Tennessee	Bradley Co	7,800	1,700		
Tennessee	Montgomery Co	1,100	1,100	1,100	
Tennessee	Shelby Co	9,200			
Tennessee	Sullivan Co	70,000	64,000	49,000	49,000
Texas	Harris Co	36,000			
Texas	Jefferson Co	11,000	3,300		
West Virginia	Hancock Co	13,000			
Wisconsin	Brown Co	14,000			
Wisconsin	Oneida Co	7,500	7,500	5,800	3,900

[a] All estimates rounded to two significant figures.

* Indicates a county that does not reach attainment of the alternative standard using identified controls.

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 57 counties under the alternative standards.

According to the data presented in Table 4.5, thirty-one of the 57 monitor areas are expected to reach attainment with the alternative standard of 50 ppb following implementation of the identified control strategy. For 26 areas, identified controls are not sufficient to reach attainment with the alternative standard of 50 ppb. However, there are fewer areas that do not reach attainment with the other standards as shown in Table 4.6. There are twelve areas out of attainment with the 75 ppb alternative standard, 8 areas out of attainment with the 100 ppb alternative standard, and only 2 out of attainment with the 150 ppb alternative standard.

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	Design Value After Application of Identified Controls			
		50 ppb	75 ppb	100 ppb	150 ppb
Arizona	Gila Co	172.7*	172.7*	172.7*	172.7*
Delaware	New Castle Co	50.4			
Georgia	Chatham Co	83.8*	83.8*	84.9*	
Idaho	Bannock Co	44.8			
Illinois	Cook Co	30.0	39.3	39.3	
Illinois	Madison Co	66.7*	72.8		
Illinois	St Clair Co	34.4			
Illinois	Sangamon Co	69.9*			
Illinois	Tazewell Co	81.8*	81.8*	95.1*	
Illinois	Wabash Co	48.3			
Illinois	Will Co	29.2			
Indiana	Floyd Co	61.2*			
Indiana	Fountain Co	49.5			
Indiana	Jasper Co	46.2			
Indiana	Lake Co	50.2	58.0		
Indiana	Morgan Co	50.3			
Indiana	Porter Co	39.9			
Indiana	Warrick Co	50.0			
Indiana	Wayne Co	115.8*	115.8*	115.8*	
Iowa	Linn Co	74.7*	74.7		
Iowa	Muscatine Co	108.6*	108.6*	108.6*	
Kansas	Wyandotte Co	37.7			
Kentucky	Jefferson Co	67.4*	71.1		
Kentucky	Livingston Co	25.1			
Louisiana	East Baton Rouge Par	44.7			
Missouri	Greene Co	79.0*	79.0*		
Missouri	Jackson Co	116.5*	116.5*	116.5*	
Missouri	Jefferson Co	146.0*	146.0*	146.0*	146.4
Missouri	St Louis	21.8			
Montana	Yellowstone Co	56.1*			
Nebraska	Douglas Co	60.6*			
New Mexico	San Juan Co	65.6*			
New York	Chautauqua Co	43.4			
New York	Erie Co	79.5*	79.5*		
New York	Madison Co	51.8*			
New York	Monroe Co	50.3			
North Carolina	New Hanover Co	50.5*			
Ohio	Clark Co	59.9*			
Ohio	Cuyahoga Co	27.4			
Ohio	Hamilton Co	43.2			
Ohio	Lake Co	57.6*	57.6	57.6	
Ohio	Summit Co	114.7*	114.7*	114.7*	145.1
Oklahoma	Muskogee Co	28.4			
Pennsylvania	Blair Co	50.3			
Pennsylvania	Northampton Co	66.5*	75.4		

State	County	Design Value After Application of Identified Controls			
		50 ppb	75 ppb	100 ppb	150 ppb
Pennsylvania	Warren Co	166.4*	166.4*	166.4*	166.4*
South Carolina	Lexington Co	49.9	55.3		
Tennessee	Blount Co	56.0*			
Tennessee	Bradley Co	44.8	75.0		
Tennessee	Montgomery Co	138.2*	138.2*	138.2*	
Tennessee	Shelby Co	47.0			
Tennessee	Sullivan Co	44.8	54.5	81.6	81.6
Texas	Harris Co	36.3			
Texas	Jefferson Co	44.4	68.8		
West Virginia	Hancock Co	47.1			
Wisconsin	Brown Co	48.7			
Wisconsin	Oneida Co	49.7	49.7	78.8	113.1

* Indicates a county that does not reach attainment of the alternative standard using identified controls.

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	150 ppb
Number of Areas Needing Emission Reductions Beyond Identified Controls	26	12	8	2

[a] There are 57 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 a 50 ppb alternative 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	150 ppb
Total Emission Reductions from Identified and Unidentified Controls	1,061,000	566,000	404,000	165,000
Total Emission Reductions from Unidentified Controls	301,000	127,000	61,000	2,600
Unidentified Reductions from EGUs	217,000	91,000	46,000	1,900
Unidentified Reductions from non-EGUs	84,000	36,000	15,000	700
Unidentified Reductions from Area Sources	75	30	0	0

[a] All estimates rounded to two significant figures.

Table 4.8 Emission Reductions Needed Beyond Identified Controls in 2020

State	County	Emission Reductions Needed Beyond Identified Controls (annual tons/year)			
		50 ppb	75 ppb	100 ppb	150 ppb
Arizona	Gila Co	8,000	6,400	4,800	1,500
Georgia	Chatham Co	12,000	3,000		
Illinois	Madison Co	14,000			
Illinois	Sangamon Co	6,700			
Illinois	Tazewell Co	13,000	2,700		
Indiana	Floyd Co	12,000			
Indiana	Wayne Co	18,000	11,000	4,300	
Iowa	Linn Co	6,100			
Iowa	Muscatine Co	19,000	11,000	2,700	
Kentucky	Jefferson Co	14,000			
Missouri	Greene Co	4,000	500		
Missouri	Jackson Co	33,000	21,000	8,200	
Missouri	Jefferson Co	49,000	36,000	23,000	
Montana	Yellowstone Co	1,400			
Nebraska	Douglas Co	6,100			
New Mexico	San Juan Co	6,300			
New York	Erie Co	7,800	1,100		
New York	Madison Co	1,100			
North Carolina	New Hanover Co	53			
Ohio	Clark Co	4,700			
Ohio	Lake Co	4,100			
Ohio	Summit Co	22,000	13,000	4,900	
Pennsylvania	Northampton Co	6,600			
Pennsylvania	Warren Co	8,400	6,600	4,800	1,200
Tennessee	Blount Co	3,100			
Tennessee	Montgomery Co	20,000	14,000	8,600	

[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 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.

- *Current PM2.5 Controls in Baseline*: Our 2020 analysis year baseline assumes that States will put in place the necessary control strategies to attain the current $PM_{2.5}$ standards. As States develop their plans for attaining these standards, their SO_2 control strategies may differ significantly from our analysis.

- *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.

- *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

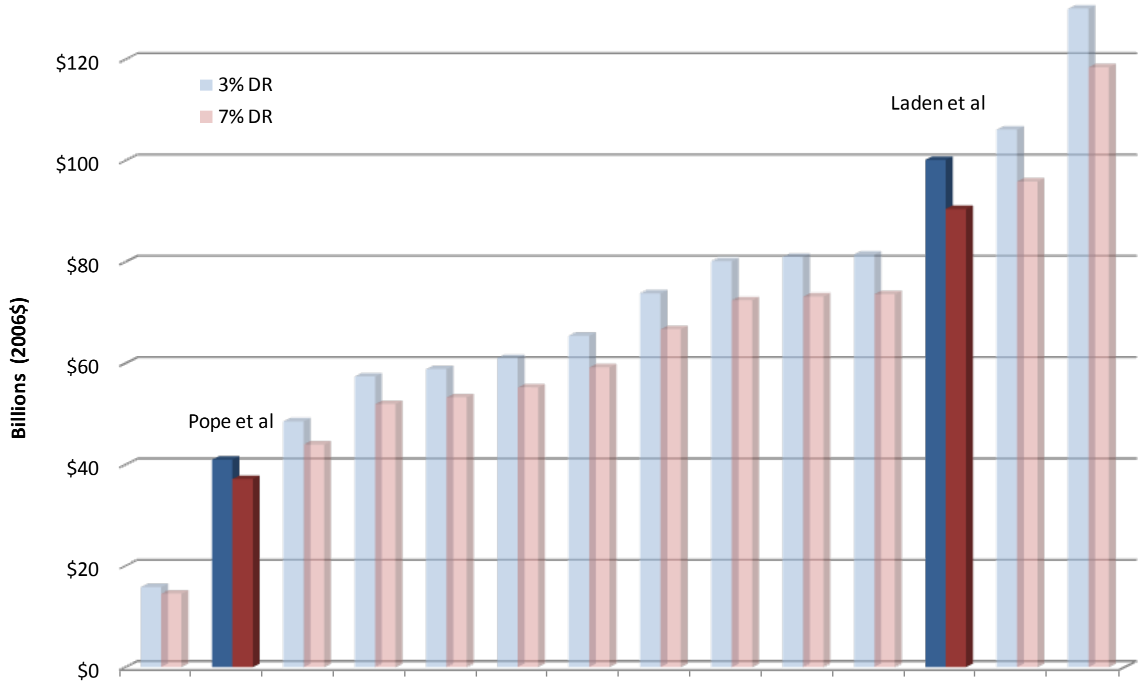
Synopsis

EPA estimated the monetized human health benefits of reducing cases of morbidity 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 an SO_2 standard at 50 ppb (99th percentile, daily 1-hour maximum), the total monetized benefits would be $41 to $100 billion at a 3% discount rate and $37 to $90 billion at a 7% discount rate. For an SO_2 standard at 75 ppb, the total monetized benefits would be $22 to $53 billion at a 3% discount rate and $20 to $48 billion at a 7% discount rate. For an SO_2 standard at 100 ppb, the total monetized benefits would be $16 to $38 billion at a 3% discount rate and $14 to $35 billion at a 7% discount rate. For an SO_2 standard at 150 ppb, the total monetized benefits would be $6.4 to $16 billion at a 3% discount rate and $5.8 to $14 billion at a 7% discount rate.

These estimates reflect EPA's most current interpretation of the scientific literature and include three key changes: (1) a no-threshold model for PM2.5 that calculates incremental benefits down to the lowest modeled air quality levels; (2) a different Value of Statistical Life (VSL); (3) two technical updates to the population dataset and aggregation method.[1] 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 SOx emission controls. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided in Figures 5.1 and 5.2 for the proposal standard range of 50 ppb to 100 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.

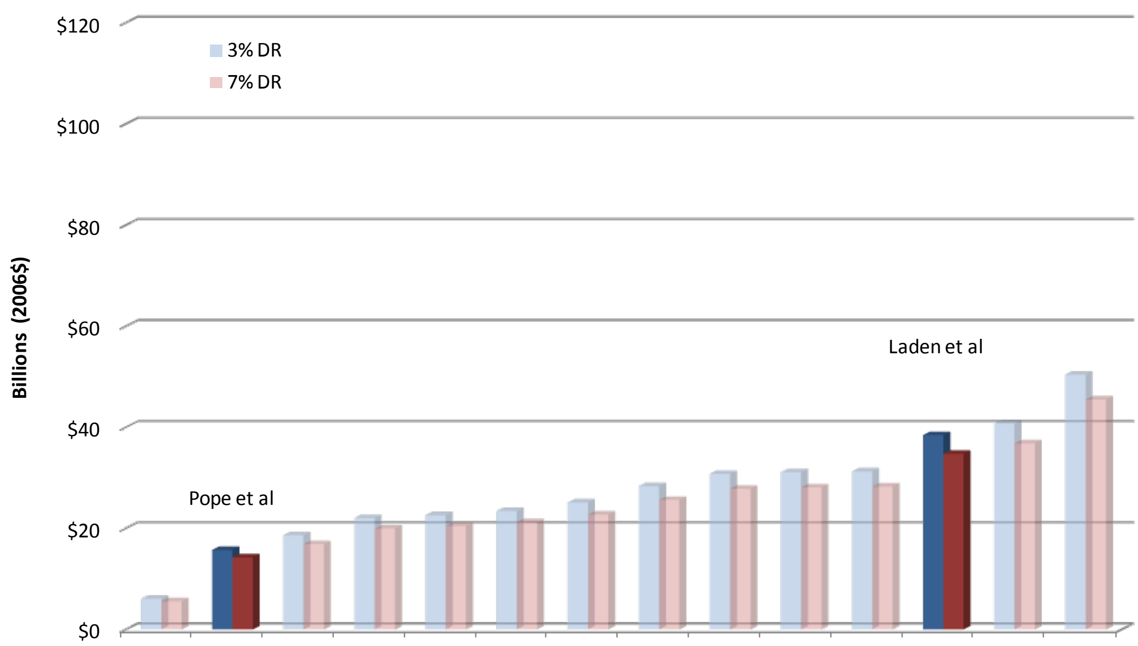
[1] Using the previous methodology (i.e., a threshold model at 10 $\mu g/m^3$ without two technical updates), the total monetized benefits would be $27 to $58 billion (2006$, 3 percent discount rate) for the 50 ppb standard alternative, $14 to $31 billion for the 75 ppb standard alternative, $10 to $22 billion for the 100 ppb standard alternative, and $4.2 to $9.0 billion for the 150 ppb standard alternative in 2020.

Figure 5.1: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Attaining 50 ppb in 2020*



$PM_{2.5}$ mortality benefits estimates derived from 2 epidemiology functions and 12 expert functions

Figure 5.2: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Attaining 100 ppb in 2020*



$PM_{2.5}$ mortality benefits estimates derived from 2 epidemiology functions and 12 expert functions

*These graphs shows the estimated total monetized benefits in 2020 for the proposed standard range of 50 ppb and 100 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 at 75 ppb and 150 ppb 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 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 all relevant rules up to the recently revised NAAQS for ozone in March 2008 (U.S. EPA, 2008a).

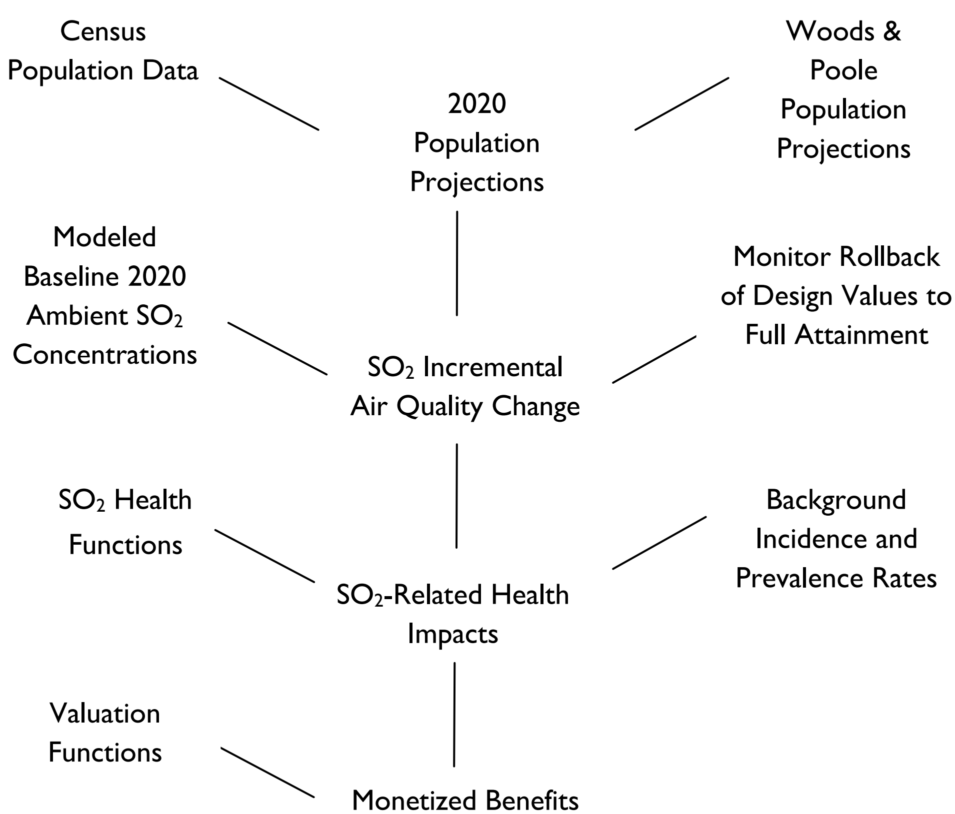
We compare benefits across four alternative SO_2 NAAQS levels: 50 ppb, 75 ppb, 100 ppb, and 150 ppb (99^{th} percentile). Consistent with EPA's approach for RIA benefits assessments, we estimate the health effects associated with an incremental difference in ambient concentrations between a baseline 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 5.10. Because some areas require substantial emission reductions from unknown sources to attain the various standards, the results are very sensitive to assuming full attainment. All of the other results tables in this chapter assume full attainment with the various alternative standards.

5.3 Overview of analytical framework for benefits analysis

5.3.1 Benefits Model

For the primary benefits analysis, we use the Environmental Benefits Mapping and Analysis Program (BenMAP) (Abt Associates, 2008) to estimate the health benefits occurring as a result of implementing alternative SO_2 NAAQS levels. Although EPA has used BenMAP extensively to estimate the health benefits of reducing exposure to $PM_{2.5}$ and ozone in previous RIAs, this is the first RIA in which EPA has used BenMAP to estimate the health benefits directly attributable to reducing exposure to SO_2. Figure 5.3 below shows the major components of, and data inputs to, the BenMAP model.

Figure 5.3: Diagram of Inputs to BenMAP model for SO_2 Analysis



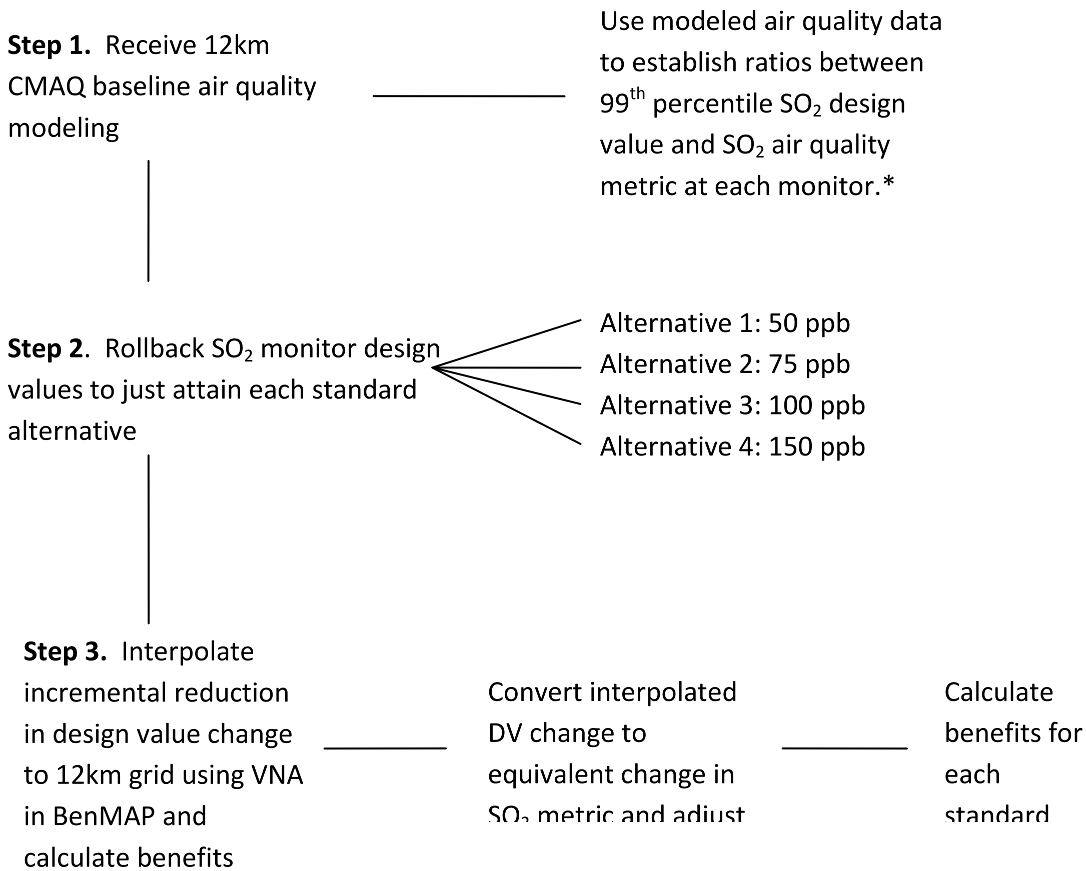
5.3.2 Air Quality Estimates

As Figure 5.3 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 2008 Ozone RIA as our baseline.[2]

The CMAQ air quality model provides projects both design values at SO_2 monitors and air quality concentrations at 12km by 12km 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 5.4 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).[3]

[2] See Chapter 3 for more detail regarding the air quality data used in this analysis.
[3] A sensitivity analysis of alternate VNA interpolation methods for the NO_2 NAAQS proposal RIA showed that the results were not sensitive to the interpolation method (U.S. EPA, 2009b).

Figure 5.4: Diagram of Rollback Method



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

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 50km 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 5.12.

[4] Please see Chapter 3 for more information regarding the technical basis for the 30 km assumption.

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 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 proposed NO_2 NAAQS (U.S. EPA, 2006a; U.S. EPA, 2008a; U.S. EPA, 2009b).

We selected the health endpoints to be consistent with the conclusions of the SO_2 ISA. 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 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

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[5] The O'Conner 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.

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.

[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).

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 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'Conner 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 is uncertain and that we initially assumed that it was log-linear, but have subsequently determined that it is logistic. This will be fixed in the RIA for the final SO_2 NAAQS.

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	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				0.057 (0.0567) [d]		
			One or more symptoms				0.207 (0.0567) [d]		
			Slow play				0.157 (0.0567) [d]		
			Nighttime asthma				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 5.12.

5.5 Valuation of Avoided Health Effects from SO_2 Exposure

The selection of valuation functions very similar to the NO_2 proposed NAAQS RIA (U.S. EPA, 2009b) 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 SO_2 Reduction Results

EPA estimated the monetized human health benefits of reducing cases of morbidity among populations exposed to SO_2 in 2020 for each of the alternative standard levels in 2006$. For an SO_2 standard at 50 ppb, the monetized benefits from reduced SO_2 exposure would be $12 million. For an SO_2 standard at 75 ppb, the monetized benefits from reduced SO_2 exposure would be $4.5 million. For an SO_2 standard at 100 ppb, the monetized benefits from reduced SO_2 exposure would be $1.9 million. For an SO_2 standard at 150 ppb, the monetized benefits from reduced SO_2 exposure would be $0.58 million. Figure 5.5 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 5.5: Breakdown of Monetized SO_2 Health Benefits by Endpoint

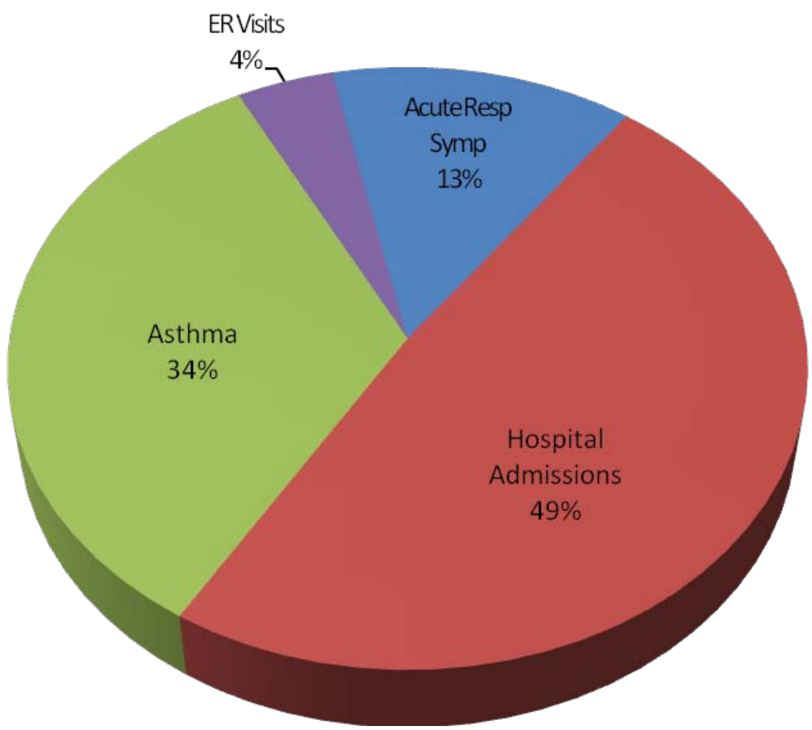

Table 5.5: SO_2 Health Benefits of Attaining Alternate Standard Levels in 2020 in 2006$ (95th percentile confidence interval)

		Incidence			Valuation	
50 ppb	Acute Respiratory Symptoms	53,000	(-29,000 -- 130,000)		$1,600,000	(-$1,000,000 -- $5,900,000)
	Hospital Admissions, Respiratory	240	(-15 -- 500)		$5,800,000	($170,000 -- $11,000,000)
	Asthma Exacerbation	74,000	(11,000 -- 180,000)		$4,000,000	($610,000 -- $12,000,000)
	Emergency Room Visits, Respiratory	1,400	(-340 -- 3,900)		$510,000	(-$77,000 -- $1,400,000)
				Total	**$12,000,000**	**(-$300,000 -- $31,000,000)**
75 ppb	Acute Respiratory Symptoms	20,000	(-11,000 -- 50,000)		$590,000	(-$370,000 -- $2,200,000)
	Hospital Admissions, Respiratory	97	(-6 -- 200)		$2,300,000	($69,000 -- $4,500,000)
	Asthma Exacerbation	28,000	(4,100 -- 69,000)		$1,500,000	($230,000 -- $4,500,000)
	Emergency Room Visits, Respiratory	530	(-130 -- 1,500)		$200,000	(-$30,000 -- $540,000)
				Total	**$4,600,000**	**(-$110,000 -- $12,000,000)**
100 ppb	Acute Respiratory Symptoms	8,200	(-4,500 -- 21,000)		$1,600,000	(-$160,000 -- $910,000)
	Hospital Admissions, Respiratory	42	(-3 -- 86)		$5,800,000	($30,000 -- $1,900,000)
	Asthma Exacerbation	12,000	(1,700 -- 29,000)		$4,000,000	($94,000 -- $1,900,000)
	Emergency Room Visits, Respiratory	220	(-55 -- 620)		$510,000	(-$12,000 -- $230,000)
				Total	**$1,900,000**	**(-$44,000 -- $5,000,000)**
150 ppb	Acute Respiratory Symptoms	2,400	(-1,300 -- 6,100)		$72,000	(-$46,000 -- $270,000)
	Hospital Admissions, Respiratory	13	(-1 -- 26)		$300,000	($9,100 -- $590,000)
	Asthma Exacerbation	3,500	(480 -- 8,400)		$180,000	($28,000 -- $550,000)
	Emergency Room Visits, Respiratory	68	(-17 -- 190)		$25,000	(-$3,900 -- $69,000)
				Total	**$580,000**	**(-$13,000 -- $1,500,000)**

*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	$12	N/A
	25km radius	$9.3	-21%
	100km radius	$15	26%
	Unconstrained	$22	89%
Location of Hospital Admission Studies	w/US-based studies only	$12	N/A
	w/Canada-based studies only	$62	424%
Asthma Pooling Method	Pool all endpoints together	$12	N/A
	One or more symptoms only	$12	-0.2%

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.[7,8]

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, 2008a) and NO_2 NAAQS RIA (U.S. EPA, 2009b). 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	

[7] In addition to reducing SO_2 emissions, the control strategy also reduces direct $PM_{2.5}$ emissions. Please see Table 5.7 for the total estimate of emission reductions used to calculate $PM_{2.5}$ co-benefits.

[8] Pollution controls installed to comply with this proposed 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 proposed standard might also help states attain a more stringent PM NAAQS if one is promulgated in 2011.

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.

- 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 (post-2006) 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 (post 2006) RIAs.
- Twelve estimates are based on the C-R functions from EPA's expert elicitation study[9,10] 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).[11] 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

[9] 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.
[10] Roman et al., 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.
[11] These two studies specify multi-pollutant models that control for SO_2, among other co-pollutants.

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 5.9). In 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 methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD) accompanying the recent final ozone NAAQS RIA (USEPA 2008a).[12] 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 mobile 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.[13] 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 draft Integrated Science Assessment (2008e; 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

[12] The Technical Support Document (U.S. EPA, 2008b), entitled: Calculating Benefit Per-Ton Estimates, can be found in EPA Docket EPA-HQ-OAR-2007-0225-0284.

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

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. Although this document does not represent final agency policy that has undergone the full agency scientific review process, it provides a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs. It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis.[14]

Because the benefits are sensitive to the assumption of a threshold, we also provide a sensitivity analysis using the previous methodology (i.e., a threshold model at 10 $\mu g/m^3$ without the two technical updates) as a historical reference. Table 5.12 shows the sensitivity of an assumed threshold on the monetized results, with and without an assumed threshold at 10 $\mu g/m^3$. Using the threshold model at 10 $\mu g/m^3$ without the two technical updates, we estimate the monetized benefits $27 to $58 billion (2006$, 3 percent discount rate) for the 50 ppb standard alternative, $14 to $31 billion for the 75 ppb standard alternative, $10 to $22 billion for the 100 ppb standard alternative, and $4.2 to $9.0 billion for the 150 ppb standard alternative.[15]

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 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 $5.5 million (2000$)[16] 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

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[14] In the Portland Cement RIA (U.S. EPA, 2009a), we solicited comment on the use of the no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP closed on September 4, 2009 (Docket ID No. EPA–HQ–OAR–2002–0051 available at http://www.regulations.gov). EPA is currently reviewing those comments.

[15] Using a 7% discount rate, these results would be approximately 9% lower.

[16] 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 $5.5 million value, the VSL is $7.7m.

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)[17] 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 $6.3 million (2000$).[18] The Agency is committed to using scientifically sound, appropriately reviewed evidence in valuing mortality risk reductions 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 5.6 illustrates the relative breakdown of the monetized $PM_{2.5}$ health benefits.

[17] In the (draft) update of the Economic Guidelines (U.S. EPA, 2008), 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.

[18] 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.

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

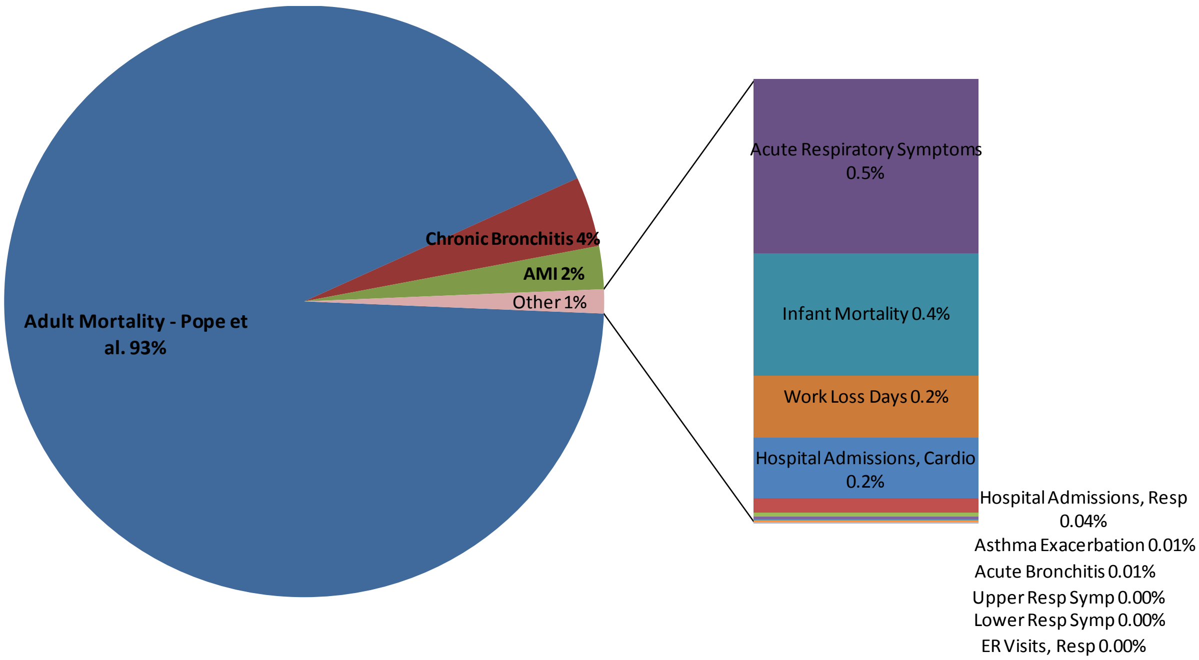
Health Endpoint	Central Estimate of Value Per Statistical Incidence (2020 income level)	Derivation of Distributions of Estimates
Premature Mortality (Value of a Statistical Life)	$8,900,000	EPA currently recommends a central VSL of $6.3m (2000$) based on a Weibull distribution fitted to 26 published 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, 1999).
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). Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings in (2006$): age of onset: at 3%, at 7% 25–44: $11,000, $10,000 45–54: $17,000, $15,000 55–65: $96,000, $86,000 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%)
<u>3% discount rate</u>		
Age 0–24	$80,000	
Age 25–44	$96,000	
Age 45–54	$100,000	
Age 55–65	$180,000	
Age 66 and over	$80,000	
<u>7% discount rate</u>		
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 5.6: 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. We provide the PM co-benefit results using both discount rates in Table 5.11 and the total monetized benefits (i.e., SO_2 and PM) 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.

The benefit-per-ton estimates are provided in Table 5.9 and the health incidences are provided in Table 5.10. Higher or lower estimates of benefits are possible using other assumptions; examples of this are provided for the proposed standard range of 50 ppb and 100 ppb in Figures 5.10 and 5.11. Table 5.11 shows the monetized results using the two epidemiology-based estimates as well as the 12 expert-based estimates. Figure 5.8 provides a graphical breakdown of the $PM_{2.5}$ co-benefits by sector. Figure 5.9 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
NO_2 EGU	$7,600	$19,000
NO_2 non-EGU	$5,000	$12,000
Direct $PM_{2.5}$:	$230,000	$570,000

*Estimates have been rounded to two significant figures. This table includes extrapolated tons, spread across the sectors in proportion to the emissions in the county. 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	150 ppb
Avoided Premature Mortality				
Pope	4,700	2,500	1,800	740
Laden	12,000	6,400	4,600	1,900
Woodruff (Infant Mortality)	18	10	7	3
Avoided Morbidity	3,200	1,700	1,200	490
Chronic Bronchitis	7,900	4,200	3,000	1,200
Acute Myocardial Infarction	1,200	640	460	190
Hospital Admissions, Respiratory	2,600	1,400	1,000	410
Hospital Admissions, Cardiovascular	4,600	2,500	1,800	720
Emergency Room Visits, Respiratory	7,400	3,900	2,800	1,200
Acute Bronchitis	590,000	310,000	230,000	92,000
Work Loss Days	81,000	43,000	31,000	13,000
Asthma Exacerbation	3,500,000	1,900,000	1,300,000	540,000
Acute Respiratory Symptoms	88,000	47,000	34,000	14,000
Lower Respiratory Symptoms	67,000	36,000	26,000	10,000
Upper Respiratory Symptoms	13,000	6,800	4,900	2,000

*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 $PM_{2.5}$.

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		150 ppb	
	3%	7%	3%	7%	3%	7%	3%	7%
Benefit-per-ton Coefficients Derived from Epidemiology Literature								
Pope et al.	$41,000	$37,000	$22,000	$20,000	$16,000	$14,000	$6,400	$5,800
Laden et al.	$100,000	$90,000	$53,000	$48,000	$38,000	$35,000	$16,000	$14,000
Benefit-per-ton Coefficients Derived from Expert Elicitation								
Expert A	$110,000	$96,000	$57,000	$51,000	$41,000	$37,000	$17,000	$15,000
Expert B	$81,000	$74,000	$43,000	$39,000	$31,000	$28,000	$13,000	$11,000
Expert C	$81,000	$73,000	$43,000	$39,000	$31,000	$28,000	$13,000	$11,000
Expert D	$57,000	$52,000	$31,000	$28,000	$22,000	$20,000	$9,000	$8,100
Expert E	$130,000	$120,000	$70,000	$63,000	$50,000	$45,000	$20,000	$18,000
Expert F	$74,000	$67,000	$39,000	$36,000	$28,000	$26,000	$12,000	$10,000
Expert G	$49,000	$44,000	$26,000	$23,000	$19,000	$17,000	$7,600	$6,900
Expert H	$61,000	$55,000	$33,000	$29,000	$23,000	$21,000	$9,500	$8,600
Expert I	$80,000	$72,000	$43,000	$39,000	$31,000	$28,000	$13,000	$11,000
Expert J	$65,000	$59,000	$35,000	$32,000	$25,000	$23,000	$10,000	$9,200
Expert K	$16,000	$15,000	$8,400	$7,700	$6,100	$5,600	$2,500	$2,300
Expert L	$59,000	$53,000	$31,000	$28,000	$23,000	$20,000	$9,200	$8,300

*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.

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 for an Alternative Standard SO_2 at 50 ppb

		Total $PM_{2.5}$ Benefits (billions of 2006$)	% Change from Default
Threshold Assumption (with Epidemiology Study)	No Threshold (Pope)	$38	N/A
	No Threshold (Laden)	$93	N/A
	Threshold (Pope)*	$25	-34%
	Threshold (Laden)*	$54	-42%
Discount Rate (with Epidemiology Study)	3% (Pope)	$38	N/A
	3% (Laden)	$93	N/A
	7% (Pope)	$35	-9%
	7% (Laden)	$84	-10%
Simulated Attainment (using Pope)	Full attainment	$38	N/A
	Partial Attainment	$29	-29%

* The threshold model is not directly comparable to the no-threshold model. The threshold 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 5.8: Monetized $PM_{2.5}$ Co-Benefits of Fully Attaining 50 ppb by $PM_{2.5}$ Precursor

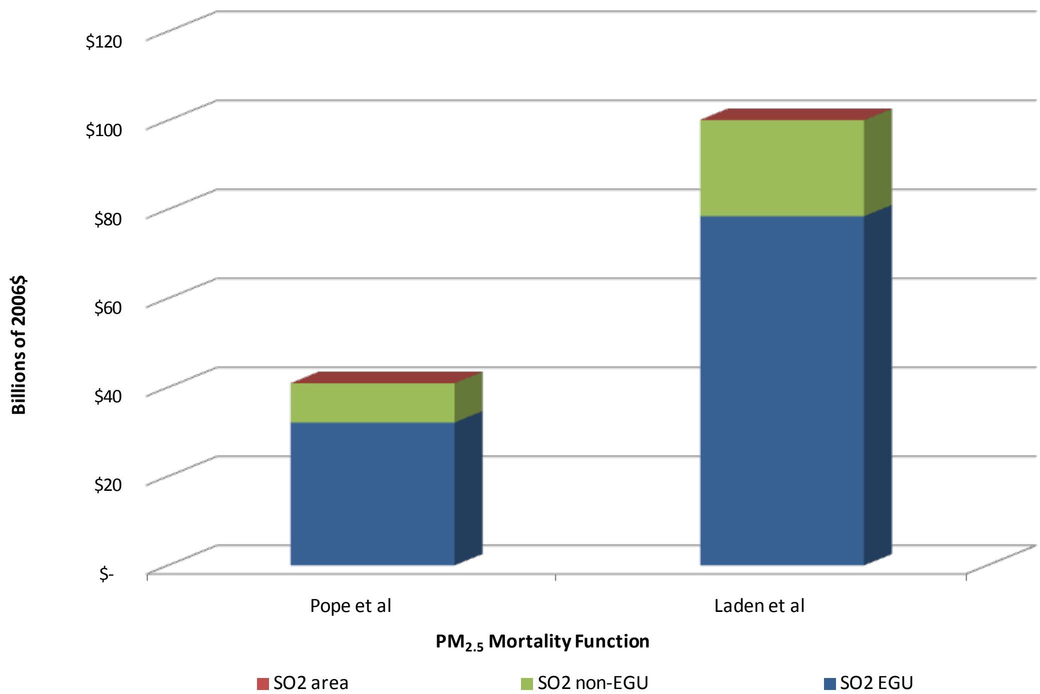
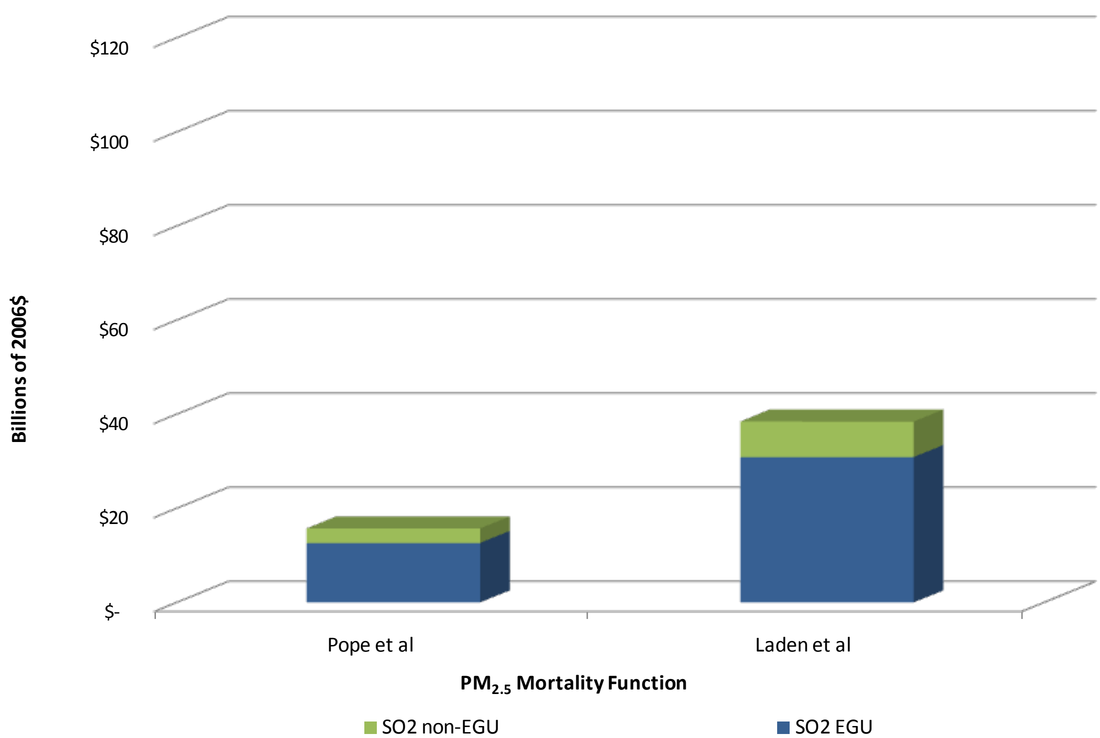


Figure 5.9: Monetized $PM_{2.5}$ Co-Benefits of Fully Attaining 100 ppb by $PM_{2.5}$ Precursor



* 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.

Figure 5.10: Monetized $PM_{2.5}$ Co-Benefits of Attaining 50 ppb*

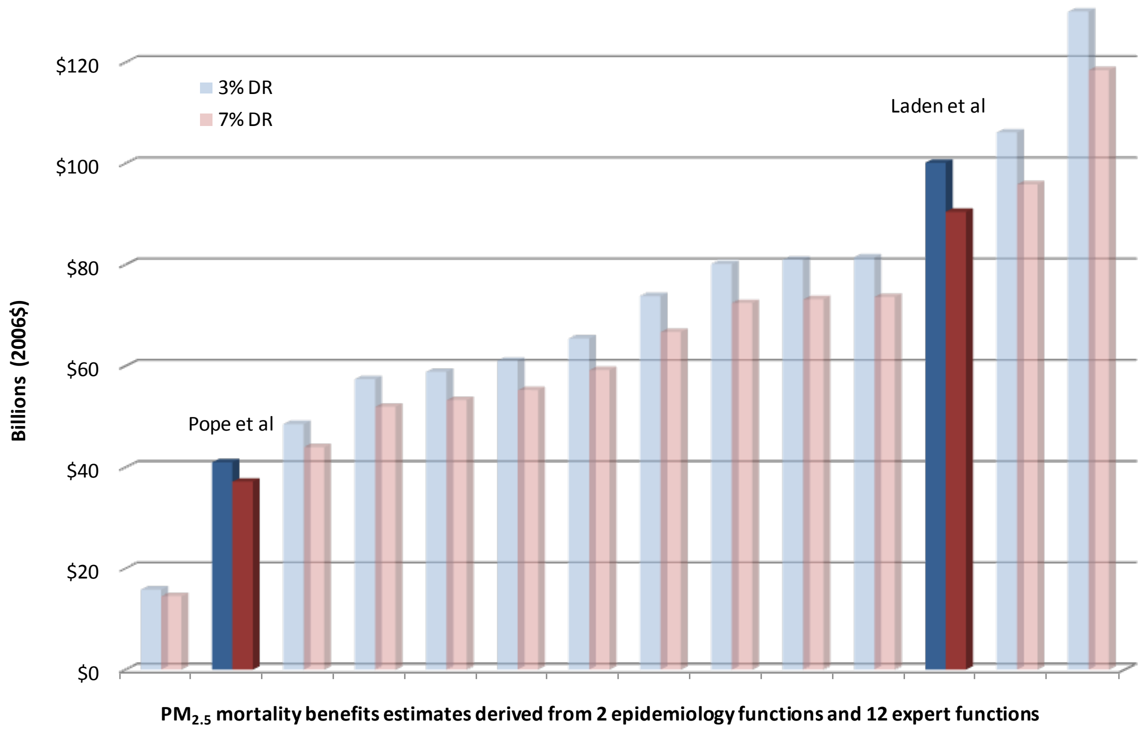
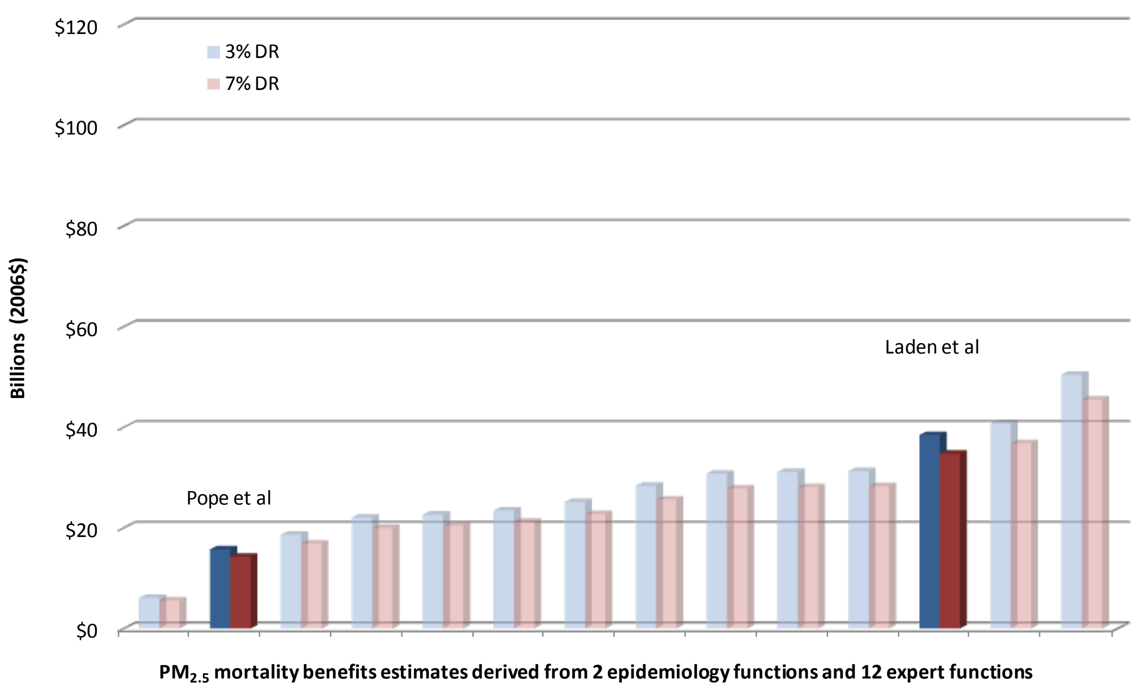


Figure 5.11: Monetized $PM_{2.5}$ Co-Benefits of Attaining 100 ppb*



* These graphs shows the estimated co- benefits in 2020 for the proposed standard range of 50 ppb and 100 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 at 75 ppb and 150 ppb would show a similar pattern.

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 an SO_2 standard at 50 ppb, the total monetized benefits would be $41 to $100 billion at a 3% discount rate and $37 to $90 billion at a 7% discount rate. For an SO_2 standard at 75 ppb, the total monetized benefits would be $22 to $53 billion at a 3% discount rate and $20 to $48 billion at a 7% discount rate. For an SO_2 standard at 100 ppb, the total monetized benefits would be $16 to $38 billion at a 3% discount rate and $14 to $35 billion at a 7% discount rate. For an SO_2 standard at 150 ppb, the total monetized benefits would be $6.4 to $16 billion at a 3% discount rate and $5.8 to $14 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.[19] 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. Figures 5.12 and 5.13 provides a graphical representation of all 14 total monetized benefits estimates, at both a 3 percent and 7 percent discount rate, for the proposed standard range of 50 ppb to 100 ppb, respectively. Figures for alternative standards at 75 ppb and 150 ppb would show a similar pattern.

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

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$)*

		SO_2	$PM_{2.5}$ (Pope et al)	$PM_{2.5}$ (Laden et al)	TOTAL (with Pope)	TOTAL (with Laden)
50 ppb	3% Full Attainment	$12	$41,000	$100,000	$41,000	$100,000
	7% Full Attainment	$12	$37,000	$90,000	$37,000	$90,000
	3% Partial Attainment	$12	$29,000	$76,000	$29,000	$76,000
	7% Partial Attainment	$12	$27,000	$69,000	$27,000	$69,000
75 ppb	3% Full Attainment	$4.6	$22,000	$53,000	$22,000	$53,000
	7% Full Attainment	$4.6	$20,000	$48,000	$20,000	$48,000
	3% Partial Attainment	$4.6	$17,000	$41,000	$17,000	$41,000
	7% Partial Attainment	$4.6	$15,000	$37,000	$15,000	$37,000
100 ppb	3% Full Attainment	$1.9	$16,000	$38,000	$16,000	$38,000
	7% Full Attainment	$1.9	$14,000	$35,000	$14,000	$35,000
	3% Partial Attainment	$1.9	$13,000	$33,000	$13,000	$33,000
	7% Partial Attainment	$1.9	$12,000	$29,000	$12,000	$29,000
150 ppb	3% Full Attainment	$0.6	$6,400	$16,000	$6,400	$16,000
	7% Full Attainment	$0.6	$5,800	$14,000	$5,800	$14,000
	3% Partial Attainment	$0.6	$6,300	$15,000	$6,300	$15,000
	7% Partial Attainment	$0.6	$5,700	$14,000	$5,700	$14,000

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

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	150 ppb
Avoided Premature Mortality				
Pope	4,700	2,500	1,800	740
Laden	12,000	6,400	4,600	1,900
Woodruff (Infant Mortality)	18	10	7	3
Avoided Morbidity				
Chronic Bronchitis	7,900	4,200	3,000	1,200
Acute Myocardial Infarction	1,200	640	460	190
Hospital Admissions, Respiratory	2,900	1,500	1,000	410
Hospital Admissions, Cardiovascular	4,600	2,500	1,800	720
Emergency Room Visits, Respiratory	590,000	310,000	230,000	92,000
Acute Bronchitis	81,000	43,000	31,000	13,000
Work Loss Days	3,500,000	1,900,000	1,300,000	540,000
Asthma Exacerbation	3,600,000	1,900,000	1,300,000	540,000
Acute Respiratory Symptoms	140,000	67,000	42,000	14,000
Lower Respiratory Symptoms	67,000	36,000	26,000	10,000
Upper Respiratory Symptoms	13,000	6,800	4,900	2,000

*All estimates are for the analysis year (2020) and are rounded to two significant figures.

Figure 5.12: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Attaining 50 ppb in 2020*

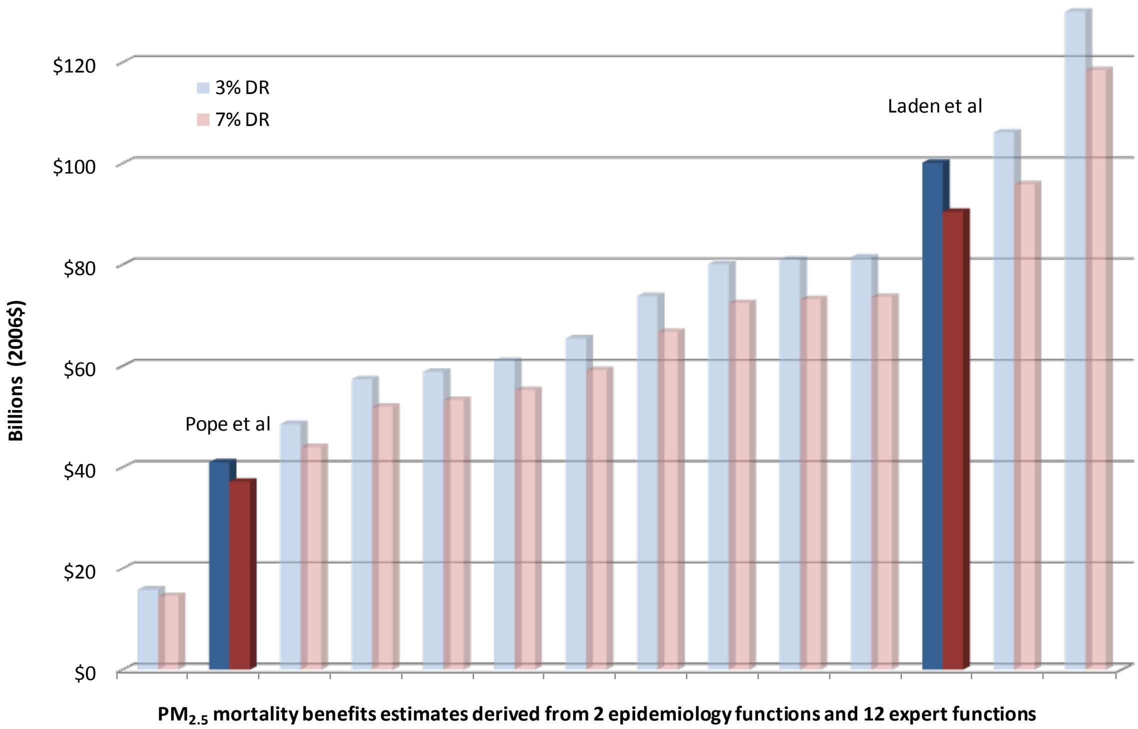
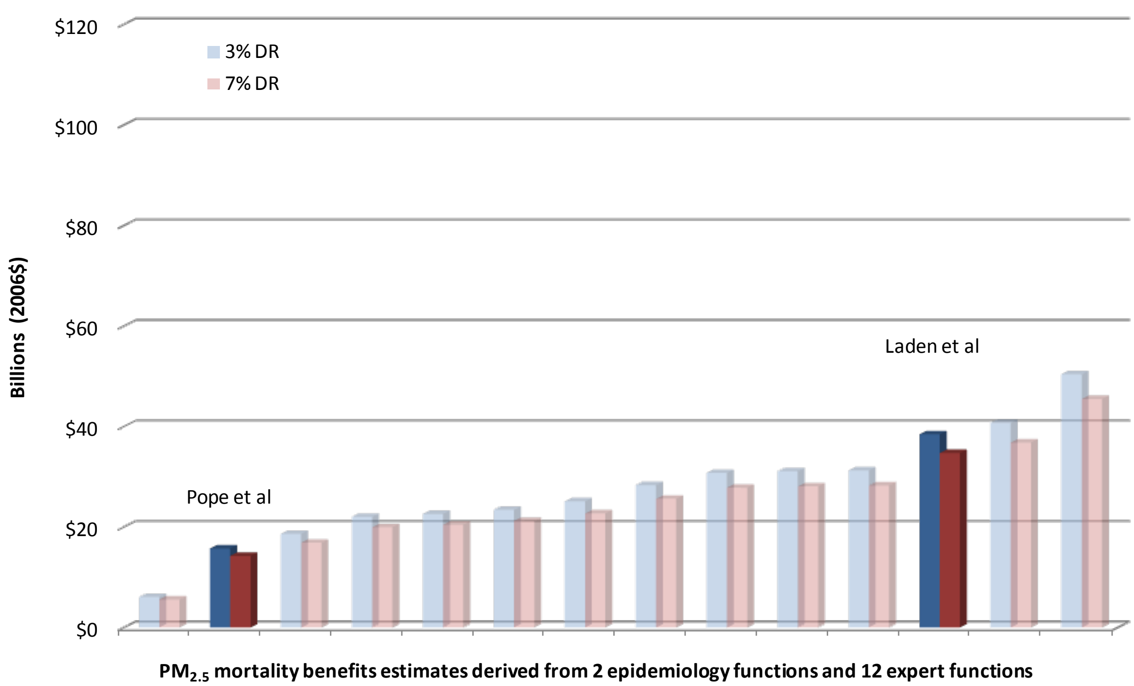


Figure 5.13: Total Monetized Benefits (SO_2 and $PM_{2.5}$) of Attaining 100 ppb in 2020*



* These graphs shows the estimated total monetized benefits in 2020 for the proposed standard range of 50 ppb and 100 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 at 75 ppb and 150 ppb would show a similar pattern.

5.9 Unquantified Welfare Benefits

This analysis is limited by the available data and resources. As such, we are not able to quantify several welfare benefit categories in this analysis because we are limited by the available data or resources. In this section, we provide a qualitative assessment of the two largest welfare benefit categories: ecosystem benefits of reducing sulfur deposition and visibility improvements.

5.9.1 Ecosystem Benefits of Reduced Sulfur Deposition

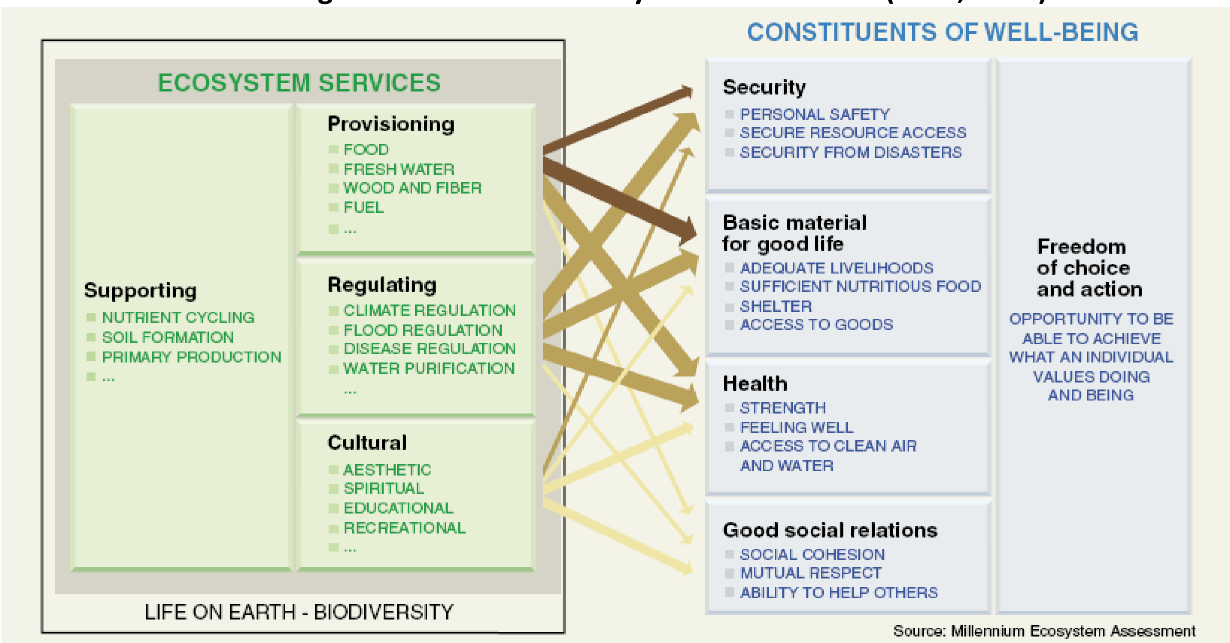
Ecosystem Services

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 5.14 provides the World Resources Institute'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:

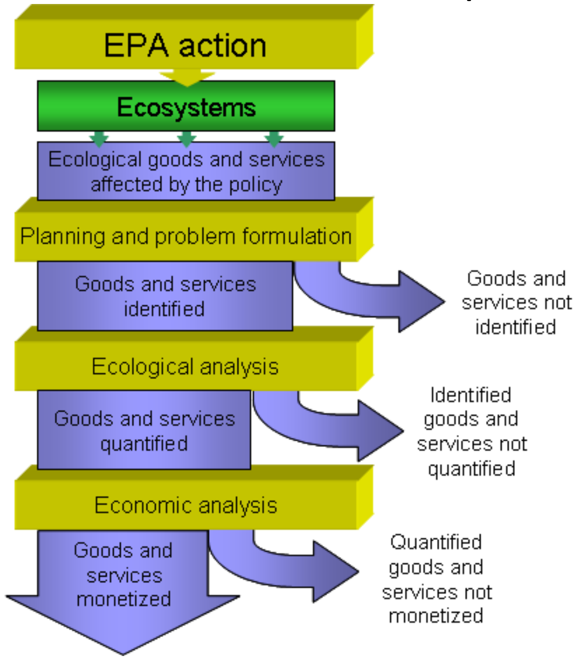
1. Provisioning: Products obtained from ecosystems, such as the production of food and water
2. Regulating: Benefits obtained from the regulation of ecosystem processes, such as the control of climate and disease
3. Cultural: Nonmaterial benefits that people obtain from ecosystems through spiritual enrichment, 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 5.14. 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 5.15.

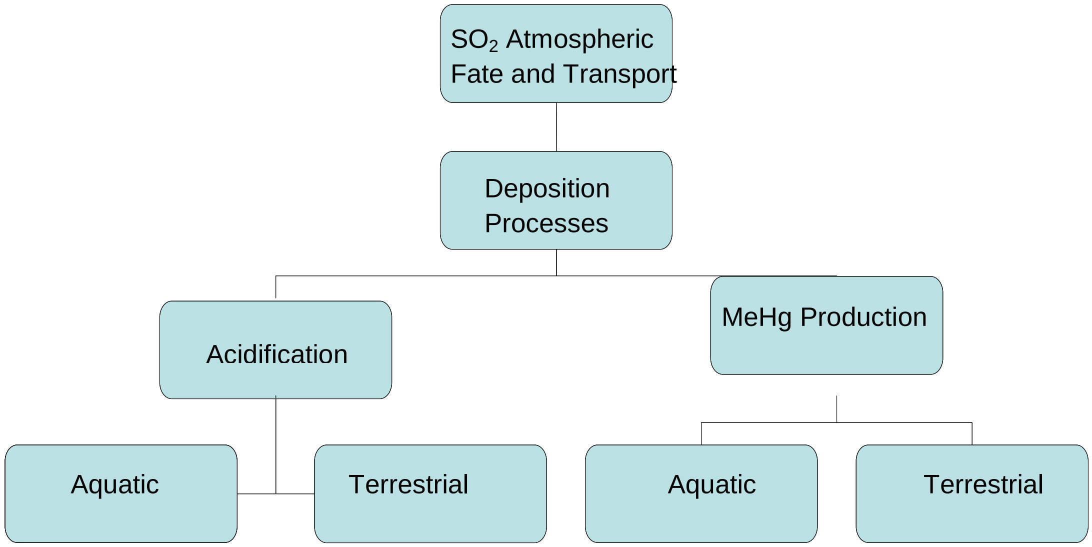
Figure 5.15: Schematic of the benefits assessment process (U.S. EPA, 2006c)



Science of Sulfur Deposition

Sulfur emissions occur over a wide area and depending on prevailing winds and other meteorological conditions, these emissions may be transported hundreds and even thousands of kilometers across North America. 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 of sulfur can occur in either a wet (i.e., rain, snow, sleet, hail, clouds, or fog) or dry form (i.e., gases, dust, and minute particulate matters). Together these emissions are deposited onto terrestrial and aquatic ecosystems across the U.S., contributing to the problems of acidification and methyl mercury production as represented in Figure 5-16.

Figure 5-16: 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. 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 causes acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. Major effects include a decline in sensitive tree species, such as red spruce (*Picea rubens*) and sugar maple (*Acer saccharum*); and a loss of biodiversity of fishes, zooplankton, and macro invertebrates. The sensitivity of terrestrial and aquatic ecosystems to acidification from sulfur deposition is predominantly governed by geological characteristics (bedrock, weathering rates, etc.). Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations. 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.

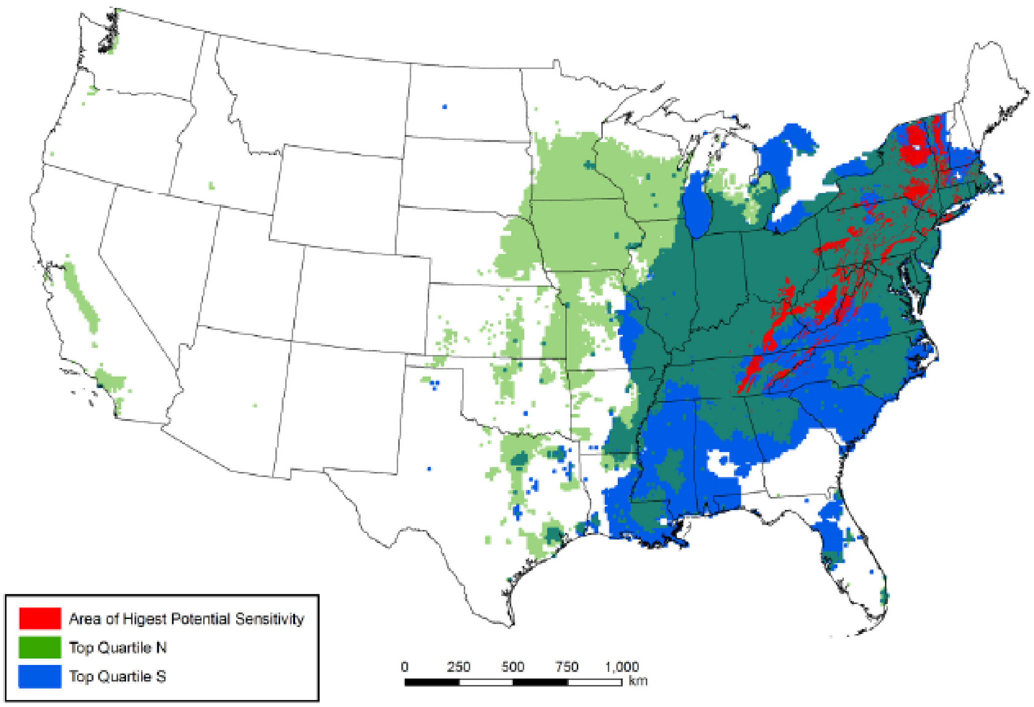
Geology (particularly surficial geology) the principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is (U.S. EPA, 2008f). Geologic formations having low base cation supply generally underlie the watersheds of acid-sensitive 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.

Terrestrial

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 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).

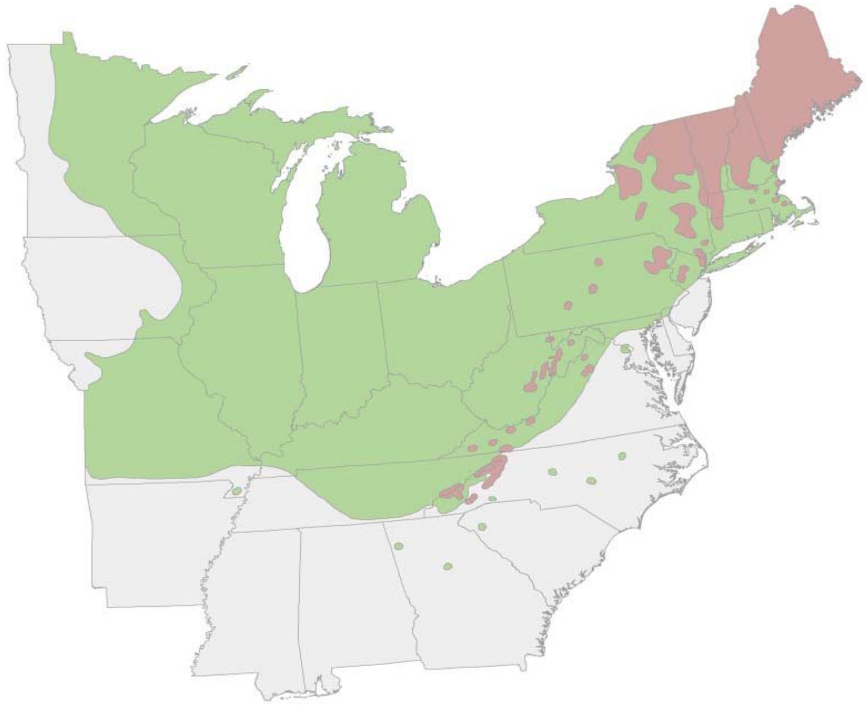
Certain ecosystems in the continental U.S. are potentially sensitive to terrestrial acidification, which is the greatest concern regarding sulfur deposition U.S. EPA (2008b). Figure 5-17 depicts the areas across the U.S. that are potentially sensitive to terrestrial acidification.

Figure 5-17: 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 5-18 shows the distribution of red spruce (brown) and sugar maple (green) in the eastern U.S.

Figure 5-18: Distribution of Red Spruce (pink) and Sugar Maple (green) in the Eastern U.S. (U.S. EPA, 2008f)



Ecosystem Services

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 (U.S. F.S., 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 (U.S. F.S., 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., 2008). 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 $25.25 (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 $52.36 for hunting and $34.46 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' willingness to pay (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 this study by the total number of households in the seven-state Appalachian region results in an aggregate annual value of $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 nitrogen and 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.

Aquatic Ecosystems

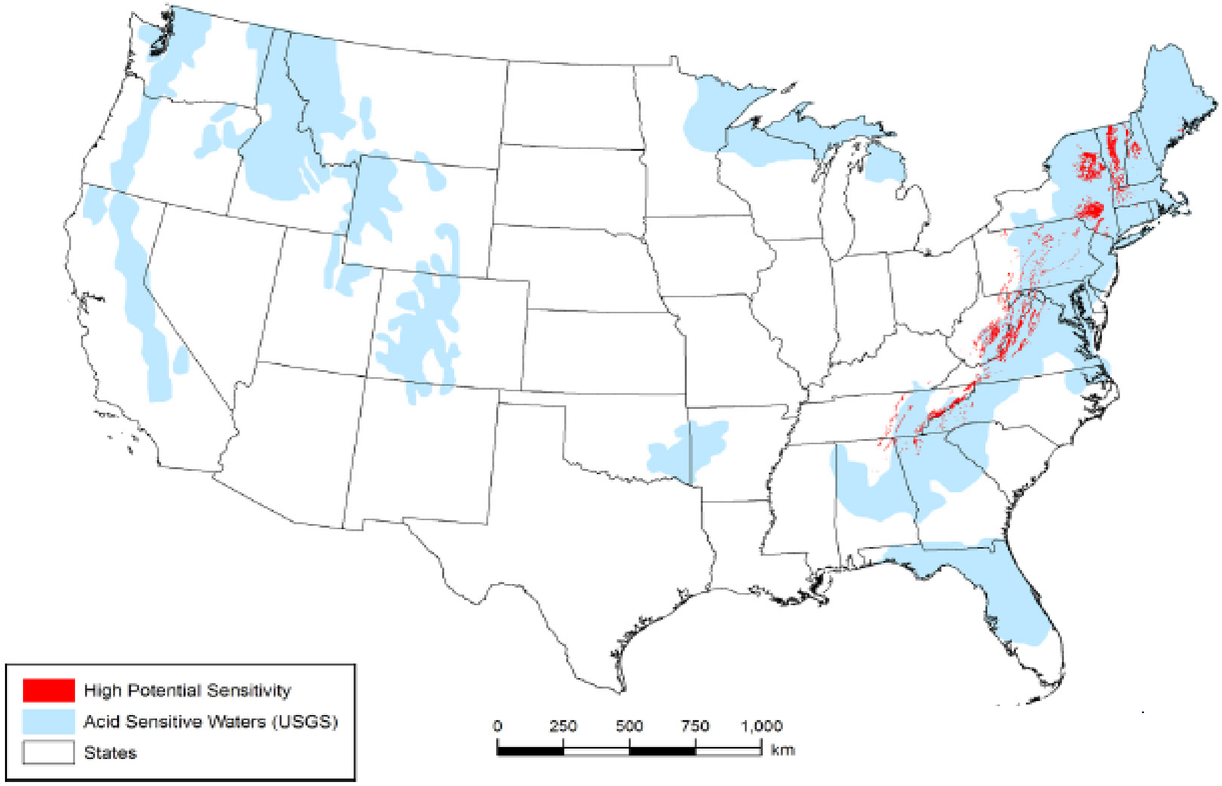
Aquatic effects of acidification have been well studied in the U.S. and elsewhere at various trophic levels. These studies indicate that aquatic biota have been affected by acidification at virtually all levels of the food web in acid sensitive aquatic ecosystems. Effects have been most clearly documented 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, 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. Several studies have shown that surface water with ANC values greater than 50 µeq/L tend to protect most fish (i.e., brook trout, others) and other aquatic organisms (see Table 5-15).

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 5-19 illustrates those areas of the U.S. where aquatic ecosystems are at risk from acidification.

Figure 5-19: Areas Potentially Sensitive to Aquatic Acidification (U.S. EPA, 2008b)



Ecosystem Services

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, although 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), 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 $35.91 for recreational fishing (in 2007 dollars); therefore, the implied total annual value of freshwater fishing in the northeastern United States was $5.06 billion in 2006. For recreation days, consumer surplus value is most commonly measured using recreation demand, travel cost models.

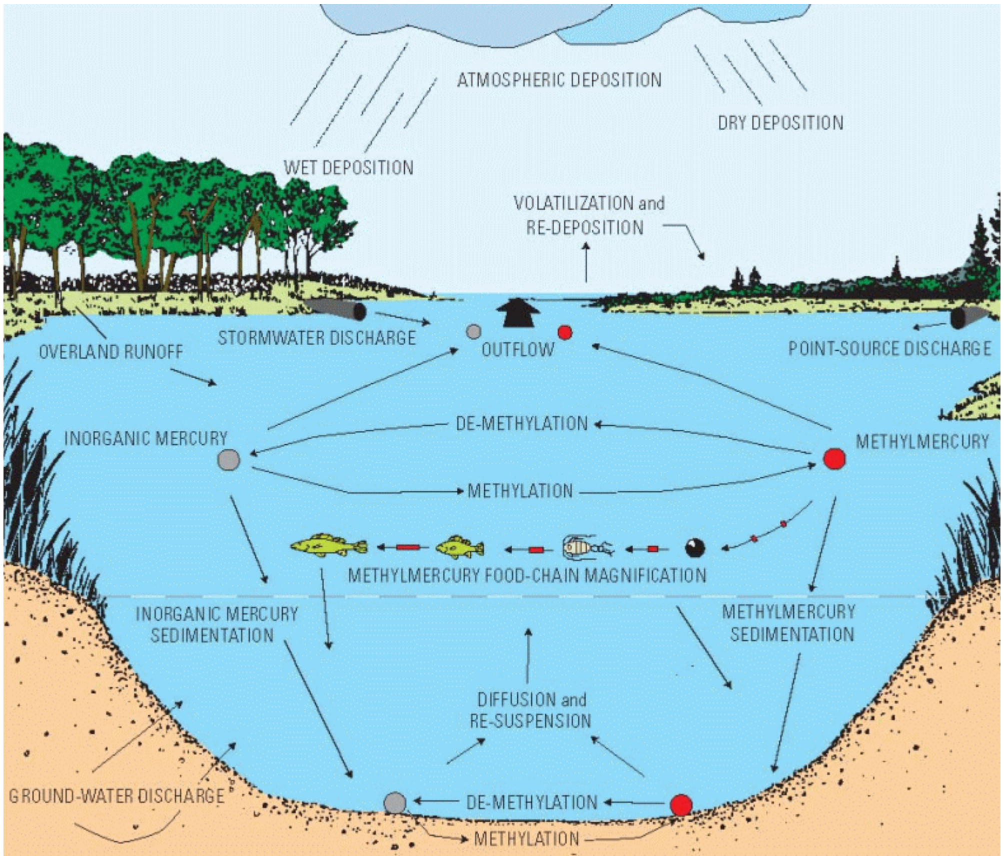
In addition, inland surface waters provide a number of regulating services associated with hydrological and climate regulation by providing environments that sustain aquatic food webs. These services are disrupted by the toxic effects of acidification on fish and other aquatic life. Although it is difficult 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.

Ecological Effects of Associated with Mercury Methylation

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. 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. Current evidence indicates that in watersheds where mercury is present, increased SO_x deposition very likely results in methylmercury accumulation in fish (Drevnick et al., 2007; Munthe et al, 2007). The ISA concluded that evidence is sufficient to infer a casual relationship between sulfur deposition and increased mercury methylation in wetlands and aquatic environments.

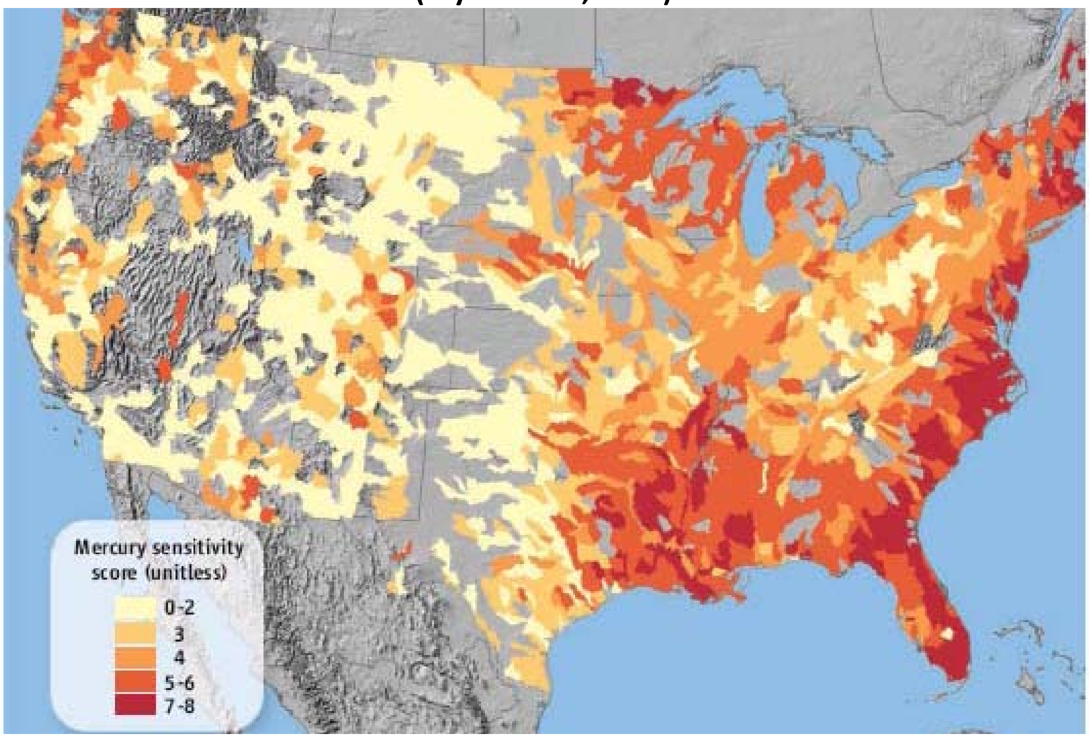
Establishing the quantitative relationship between sulfate and mercury methylation in natural settings is difficult because of the presence of multiple interacting factors in aquatic and terrestrial environments, including wetlands, aquatic environments where sulfate, sulfur-reducing bacteria (SRB), and mercury are present. The presence of sulfate, inorganic mercury, and sulfate reducing bacteria (SRB) are the primary requirements for bacterially mediated sulfate-reducing mercury conversion. 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 5-20 depicts the mercury cycle.

Figure 5-20: The mercury cycle in an ecosystem (USGS, 2006)



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 or on U.S. Food and Drug Administration's action limits. 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. Figure 5.21 illustrates a map of mercury-sensitive watersheds based on sulfate concentrations, acid neutralizing capacity (ANC), levels of dissolved organic carbon and pH, mercury species concentrations, and soil types to gauge the methylation sensitivity (Myers et al., 2007).

Figure 5.21: Preliminary USGS map of mercury methylation–sensitive watersheds (Myers et al., 2007)



Decreases in sulfate deposition/emissions have already shown promising reductions in methylmercury (U.S. EPA, 2009e). 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).

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 methyl mercury in fish from sulfur deposition, it is likely, given the number of state advisories and the EPA/FDA guidelines (EPA/FDA, 2004) on consumption for pregnant women and young children, that this service is negatively affected.

Ecological Effects Associated with Gaseous Sulfur Dioxide

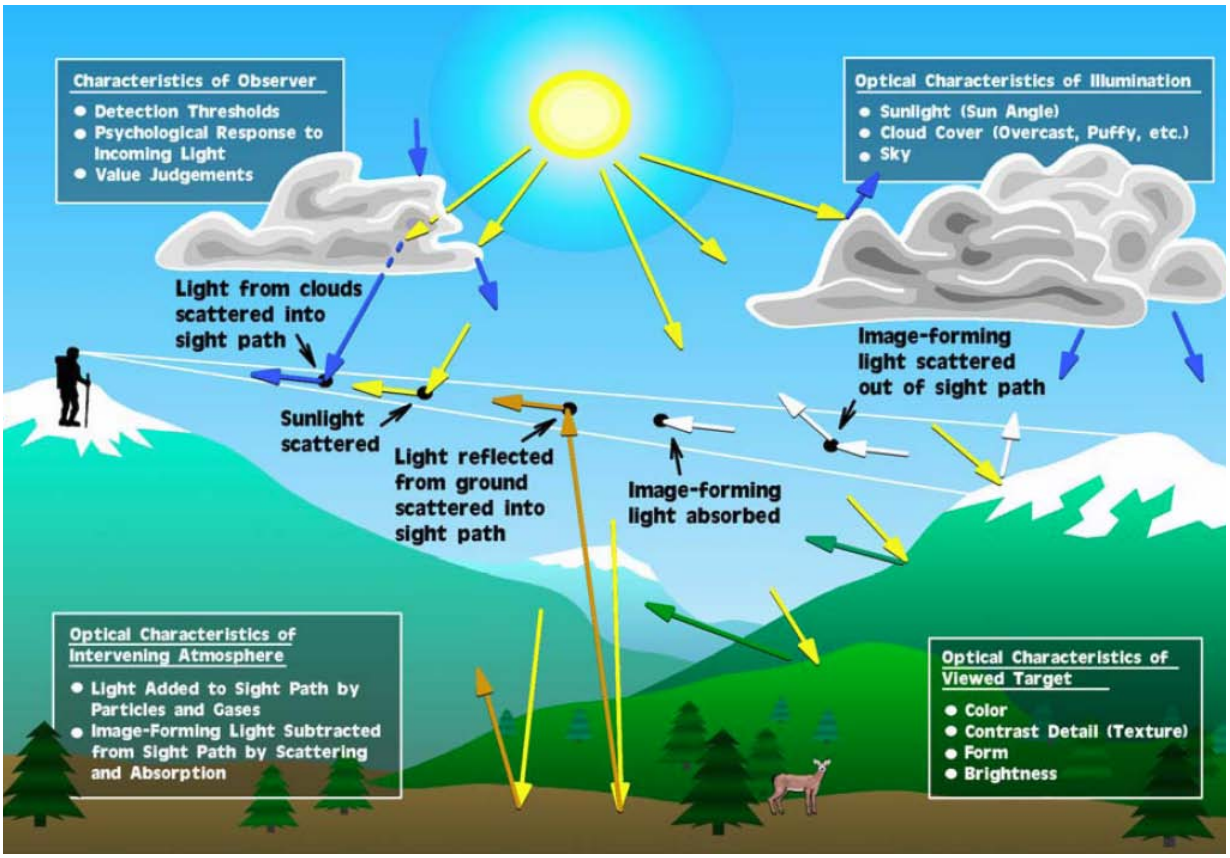
Uptake of gaseous sulfur dioxide in a plant canopy is a complex process involving adsorption to surfaces (leaves, stems, and soil) and absorption into leaves. SO_2 penetrates into leaves through to the stomata, although there is evidence for limited pathways via the cuticle. Pollutants must be transported 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 and nitrogen 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. 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. 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 5-22 for an illustration of the important factors affecting visibility.

Figure 5-22: 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 5-23) (U.S. EPA, 2009d).

Figure 5-23: 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. 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. In fact, particulate sulfate is the largest contributor to regional haze in the eastern U.S. (i.e., 40% or more annually and 75% during summer). In the western U.S., particulate sulfate contributes to 20-50% of regional haze (U.S. EPA, 2009d). 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, 1999).

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.

5.9.1 Monte Carlo analysis

Similar to other recent RIAs, we used Monte Carlo methods for estimating 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 5.5 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.

5.9.2 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 5.16 and 5.17, we repeat the results of this sensitivity analysis already presented in previous section for comparison purposes. 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 the most stringent alternative analyzed (50 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.

Table 5.16: 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	$12	N/A
	25km radius	$9.3	-21%
	100km radius	$15	26%
	Unconstrained	$22	89%
Location of Hospital Admission Studies	w/US-based studies only	$12	N/A
	w/Canada-based studies only	$62	424%
Asthma Pooling Method	Pool all endpoints together	$12	N/A
	One or more symptoms only	$12	-0.2%

Table 5.17: Sensitivity Analyses for $PM_{2.5}$ Health Co-Benefits for an Alternative Standard SO_2 at 50 ppb

		Total $PM_{2.5}$ Benefits (billions of 2006$)	% Change from Default
Threshold Assumption (with Epidemiology Study)	No Threshold (Pope)	$38	N/A
	No Threshold (Laden)	$93	N/A
	Threshold (Pope)*	$25	-34%
	Threshold (Laden)*	$54	-42%
Discount Rate (with Epidemiology Study)	3% (Pope)	$38	N/A
	3% (Laden)	$93	N/A
	7% (Pope)	$35	-9%
	7% (Laden)	$84	-10%
Simulated Attainment (using Pope)	Full attainment	$38	N/A
	Partial Attainment	$29	-29%

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

5.9.3 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 5.9). 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.

5.9.4 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 gradient of ambient SO_2 concentrations is difficult to estimate due to the sparsity of the monitoring network in some areas. The 12km 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'Conner et al. (2007). 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 (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).

5.11 Discussion

The results of this benefits analysis suggest that attaining any of the SO_2 alternative standards would produce substantial health benefits in the form of fewer respiratory hospitalizations, respiratory emergency department visits and cases of acute respiratory symptoms from reduced SO_2 exposure. In addition, attaining any of the SO_2 alternative 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.

This analysis is the first time that EPA has estimated the monetized human health benefits of reducing exposure to SO_2 to support a proposed 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. 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 $PM_{2.5}$ co-benefits represent over 99% of the total monetized benefits. This result is consistent with recent RIAs, where the $PM_{2.5}$ co-benefits represent a large proportion of total monetized benefits. This is primarily due to 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 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 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.

In section 5.7 of this RIA, we discuss the revised presentation using benefits based on Pope et al. and Laden et al. as anchor points instead of 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

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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 proposed 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 the proposed alternative standard, respectively, while Section 6.4 outlines the main limitations of the analysis. As mentioned previously, the analysis is presented here for four alternative standards: 50 ppb, 75, ppb, 100 ppb, and 150 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 alternative standards. The fourth subsection provides a brief discussion of the monitoring costs associated with the 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 488 monitors in the current network. It is important to note that the proposed 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.

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 SO2 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 proposed SO_2 NAAQS focuses SO_2 emission controls EGU sources first, then nonEGU sources, and then area sources.

6.1.1.1 EGU Sources: the Integrated Planning Model

The Integrated Planning Model (IPM) version 3.0 was used to develop the background for the control strategy applied for the alternative standard of 50 ppb. The model determines the least-cost means of meeting energy and peak demand requirements over a specified period, while complying with specified constraints, including air pollution regulations, transmission bottlenecks, fuel market restrictions, and plant-specific operational constraints. IPM is unique in its ability to provide an assessment that integrates power, environmental, and fuel markets. The model accounts for key operating or regulatory constraints (e.g., emission limits, transmission capabilities, renewable generation requirements, fuel market constraints) that are placed on the power, emissions, and fuel markets. IPM is particularly well-suited to consider complex treatment of emission regulations involving trading and banking of emission allowances, as well as traditional command-and-control emission policies.

Detailed background information on IPM is included in the Final O3 NAAQS RIA (see sections 3a.3.1 and 3a.3.2 of the RIA at **http://www.epa.gov/ttn/ecas/ria.html**).

6.1.1.2 NonEGU Point and Area Sources

After designing the hypothetical control strategy using the methodology discussed in Chapter 4, EPA used AirControlNET to estimate engineering control costs for nonEGU and Area sources. AirControlNET 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 AirControlNET 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 AirControlNET 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.

[1] For more information on this cost methodology and the role of AirControlNET, 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.

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 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% and 3%, where estimates are available. However, it is important to note that it is not possible to estimate cots for both 7% and 3% discount rates for controls applied to every emissions sector. Total annualized costs were calculated using a 3% discount rate for controls that had a capital component and where equipment life values were available. In this RIA, nonEGU point sources were the only sector with available data to perform a sensitivity analysis of our annualized control costs to the choice of interest rate. Sufficient information on annualized capital calculations was not available for area sources to provide a reliable 3% discount rate estimate.

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[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.

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

The interest rate used for the EGU control costs is 5.3%, and is an internal rate of return for retrofit control applications within the IPM model.[4]

Table 6.2 summarizes these costs in total and by sector nationwide. As indicated in the table, the estimated annualized costs of these controls under the 50 ppb alternative standard in 2020 are $2.3 billion per year (2006$). Applying a three percent discount rate where this can take place, this estimate becomes $2.0 billion per year. For the other 3 alternative standards examined, in 2020 the annualized costs range from $0.4 billion for $1.1 billion with a seven percent discount rate and $0.3 to $1.0 billion with a three percent discount rate. Consistent with Chapter 4's summary of the air quality impacts associated with identified controls, the cost estimates in Table 6.2 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 share of costs from EGU controls is 59% for the 50 ppb alternative standard; non-EGU point sources have a 41% share using the costs annualized at the seven percent discount rate. The share of identified control costs from EGU controls rises to 71% for the least stringent alternative standard (150 ppb).

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. to only 16 units for the 150 ppb standard and up to 114 units for the 50 ppb standard. Early retirements for 4 of the 114 units in the EGU analysis are predicted, but these units represent less than 1 percent of the affected EGU capacity. An important caveat to this presentation of the EGU costs is that the CAIR and CAMR rules which govern some aspects of the trading system for EGUs and are in the baseline for this RIA are being reconsidered by EPA. It is not certain how the reductions from these specific controls on these EGUs may be incorporated in future trading systems. It is likely that these control cost estimates are high given that they do not take into account the market advantages of being included in an emissions trading system. .[5]

Table 6.3 presents the identified control costs in 2020 by county for each alternative standard. These costs are shown for a 7 percent discount rate where it can be calculated.

[4] Refer to IPM documentation at http://www.epa.gov/airmarkt/progsregs/epa-ipm/docs/Section-7.pdf for more information.

[5] As a comparison to the costs shown in this table, we found that the cost of attaining the 50 ppb standard using the results of the IPM run, which presents the costs in terms of the impact to the generation system as a whole, was roughly 7% cheaper (or $1.26 billion in 2006 dollars) than the control cost identified here.

Table 6.2: Annual Control Costs of Identified Controls in 2020 in Total and by Sector (Thousands of 2006$) [a, b]

	50 ppb		75 ppb		100 ppb		150 ppb	
	3% Discount Rate[c]	7% Discount Rate	3% Discount Rate[c]	7% Discount Rate	3% Discount Rate[c]	7% Discount Rate	3% Discount Rate[c]	7% Discount Rate
Total Costs for Identified Controls:	2,020,000	2,290,000	1,020,000	1,140,000	840,000	900,000	340,000	370,000
EGUs	1,360,000	1,360,000	740,000	740,000	590,000	590,000	260,000	260,000
Non-EGUs	670,000	930,000	280,000	400,000	240,000	310,000	80,000	110,000
Area Sources	2,600	2,600	400	400	0	0	0	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 of compliance with the current PM2.5 standards.
[c] Total annualized costs were calculated using a 3% discount rate . For this identified control strategy, data for calculating annualized costs at a 3% discount was available for non-EGU point sources. Therefore, the total annualized cost value presented in this referenced cell is an aggregation of engineering costs at 3% and 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 6.3: Identified Controls – Total Annual Cost by County in 2020 (Thousands of 2006$)[a,b,c,d]

State	county	Identified Controls Total Annual Cost (Thousands 2006$)			
		50 ppb	75 ppb	100 ppb	150 ppb
Arizona	Gila Co	$8,000	$8,000	$8,000	$8,000
Delaware	New Castle Co	$71,000			
Georgia	Chatham Co	$32,000	$32,000	$2,400	
Idaho	Bannock Co	$600			
Illinois	Cook Co	$190,000	$190,000	$190,000	
Illinois	Madison Co	$20,000	-$600[e]		
Illinois	Sangamon Co	$14,000			
Illinois	Tazewell Co	$97,000	$97,000	$68,000	
Illinois	Wabash Co	$17,000			
Indiana	Fountain Co	$16,000			
Indiana	Lake Co	$81,000	$40,000		
Indiana	Morgan Co	$36,000			
Indiana	Warrick Co	$26,000			
Indiana	Wayne Co	$43,000	$43,000	$43,000	
Iowa	Linn Co	$11,000	$11,000		
Iowa	Muscatine Co	$24,000	$24,000	$24,000	
Kansas	Wyandotte Co	$21,000			
Kentucky	Jefferson Co	$91,000	$47,000		
Kentucky	Livingston Co	$170,000			

Louisiana	East Baton Rouge Parish	$32,000			
Missouri	Greene Co	$7,000	$7,000		
Missouri	Jackson Co	$39,000	$39,000	$39,000	
Missouri	Jefferson Co	$220,000	$220,000	$220,000	$210,000
Montana	Yellowstone Co	$23,000			
Nebraska	Douglas Co	$21,000			
New Mexico	San Juan Co	$7,000			
New York	Chautauqua Co	$22,000			
New York	Erie Co	$8,400	$8,400		
New York	Madison Co	$430			
New York	Monroe Co	$600			
North Carolina	New Hanover Co	$64,000			
Ohio	Clark Co	$780			
Ohio	Hamilton Co	$87,000			
Ohio	Lake Co	$81,000	$81,000	$81,000	
Ohio	Summit Co	$51,000	$51,000	$51,000	$9,700
Oklahoma	Muskogee Co	$39,000			
Pennsylvania	Blair Co	$1,400			
Pennsylvania	Northampton Co	$130,000	$16,000		
Pennsylvania	Warren Co	$32,000	$32,000	$32,000	$32,000
South Carolina	Lexington Co	$24,000	$22,000		
Tennessee	Blount Co	$57,000			
Tennessee	Bradley Co	$24,000	$3,100		
Tennessee	Montgomery Co	$39,000	$39,000	$39,000	
Tennessee	Shelby Co	$30,000			
Tennessee	Sullivan Co	$120,000	$110,000	$99,000	$99,000
Texas	Harris Co	$63,000			
Texas	Jefferson Co	$20,000	$5,300		
West Virginia	Hancock Co	$39,000			
Wisconsin	Brown Co	$34,000			
Wisconsin	Oneida Co	$18,000	$18,000	$14,000	$9,200
	Total Cost	**$2,300,000**	**$1,100,000**	**$900,000**	**$370,000**

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 of compliance with the current PM2.5 standards.

[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.

[e] This negative cost estimate reflects the sum of the non-EGU and area source cost and the cost estimate for an EGU predicted to retire in 2020 as a result of the control strategies applied to this county. The reduction in annual costs for the retired EGU exceeds the other control costs incurred in this county in 2020.

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.[6]

> *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*

[6] 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 two to twenty-six 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, and there is limited information on average or marginal costs for SO_2 controls applied to EGUs to sources outside of those to which this analysis applies (EGUs with unit capacities under 100 MW). 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 non-EGU 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 $5,200/ton (2006$).[7] Also, this estimate is considerably greater than the current and

[7] 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/.

futures prices for SO_2 emissions allowances traded for compliance with the CAIR program.[8] Finally, as 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).

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[8] 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.

This result is highly unlikely given the uncertainty surrounding the assumptions implicit in this estimate (e.g. projecting 11 years in to 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. EPA plans to provide an update on this approach as part of the final SO2 NAAQS RIA in June 2010 and hopefully utilize portions of it in the proposed PM2.5 NAAQS RIA to be released in November 2010.

Table 6.4 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 6.4: Extrapolated Costs Estimated for the Alternative Standards (Millions of 2006$) [a, b]

	50 ppb		**75 ppb**		**100 ppb**		**150 ppb**	
	3% Discount Rate[c]	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**
Total Extrapolated Costs:	4,520,000	4,520,000	1,910,000	1,910,000	920,000	920,000	39,000	39,000

[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 proposed 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 proposed monitoring requirements of this rule. Details of the burden estimate are contained in the information collection request (ICR) accompanying the proposed rule.[9] The ICR estimates annualized costs of a new monitoring network at approximately $_ million per year (2006 dollars).

6.1.5 Summary of Cost Estimates

Table 6.5 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. Table 6.6 presents the total costs for the identified controls, the extrapolated costs, and the total costs for the control strategies applied for all of the alternative standards. Using that estimate, we find that the total annualized costs for the 50 ppb alternative standard in 2020 are $6.8 billion (2006$) 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 $0.4 billion to $3.0 billion (2006$). The portion of these costs accounted for by identified controls ranges from 33 percent for the 50 ppb standard to 91 percent for the 150 ppb standard. Hence, the portion of these costs accounted for by extrapolated controls ranges from 67 percent for the 50 ppb standard to 9 percent for the 150 ppb standard.

Finally, Table 6.7 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 50 ppb, reductions from non-EGUs occur at $4,500/ton while the annual cost/ton for EGU sector is $2,500/ton. These estimates fall as the stringency of the alternative standard decreases, until the annual cost/ton for non-EGUs falls to $2,500/ton while the annual cost/ton for EGUs is $2,200/ton. All of these estimates are for reductions in 2020 in 2006 dollars and using a seven percent discount rate.

[9] ICR 2358.01, May 2009.

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

		50 ppb		75 ppb		100 ppb		150 ppb	
		3% Discount Rate[c]	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**
Identified Control Costs		$2,020	$2,290	1,020	1,140	840	900	340	370
Monitoring Costs		$not available yet[d]	$not available yet[d]						
Extrapolated Costs	Fixed Cost ($10,000/ton)	$3,010	$3,010	1,270	1,270	610	610	30	30
	[e]Fixed Cost ($15,000/ton)	$4,520	$4,520	1,900	1,900	920	920	40	40
	Fixed Cost ($20,000/ton)	$6,030	$6,030	2,540	2,540	1,230	1,230	50	50
Total Costs	Fixed Cost ($10,000/ton)	$5,040	$5,310	2,290	2,410	1,450	1,510	370	400
	[e]Fixed Cost ($15,000/ton)	**$6,540**	**$6,810**	**2,920**	**3,040**	**1,760**	**1,820**	**380**	**410**
	Fixed Cost ($20,000/ton)	$8,050	$8,320	3,560	3,680	2,070	2,130	390	420

[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 of compliance with the current PM2.5 standards.

[c] 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.

[d] These numbers do not represent a different discount rate for 3% and 7%.

[e] 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 6.6: Annual Control Costs of Controls in 2020 in Total (Identified + Extrapolated) and by Sector (Thousands of 2006$) [a, b]

	50 ppb		75 ppb		100 ppb		150 ppb	
	3% Discount Rate[c]	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**	**3% Discount Rate[c]**	**7% Discount Rate**
Grand Total Costs:	6,540,000	6,810,000	2,920,000	3,040,000	1,760,000	1,830,000	380,000	410,000
Total Extrapolated Costs: [d,e]	4,520,000	4,520,000	1,910,000	1,910,000	920,000	920,000	39,000	39,000
Total Costs for Identified Controls:	2,020,000	2,290,000	1,020,000	1,140,000	840,000	900,000	340,000	370,000
EGUs	1,360,000	1,360,000	740,000	740,000	590,000	590,000	260,000	260,000
Non-EGUs	670,000	930,000	280,000	400,000	240,000	310,000	80,000	110,000
Area Sources	2,600	2,600	400	400	0	0	0	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 of compliance with the current PM2.5 standards.
[c] 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.
[d] These numbers do not represent a different discount rate for 3% and 7%.
[e] 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 shown in this table.

Table 6.7: Annual Cost per Ton of Identified Controls applied for the Alternative Standards by Emissions Sector (2006$) [a, b]

	50 ppb		75 ppb		100 ppb		150 ppb	
Emissions Sector	3% Discount Rate[c]	7% Discount Rate	3% Discount Rate[c]	7% Discount Rate[c]	3% Discount Rate[c]	7% Discount Rate[c]	3% Discount Rate[c]	7% Discount Rate[c]
NonEGU	$3,200	$4,500	**$2,300**	**$3,300**	**$2,800**	**$3,600**	**$1,800**	**$2,500**
Area	$2,600	$2,600	**$2,600**	**$2,600**	**N/A**	**N/A**	**N/A**	**N/A**
EGU	$2,500	$2,500	**$2,300**	**$2,300**	**$2,300**	**$2,300**	**$2,200**	**$2,200**

[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 of compliance with the current PM2.5 standards.
[c] 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 this identified control strategy, data for calculating annualized

costs at a 3% discount was available for point sources. Therefore, the total annualized cost value presented in this referenced cell is an aggregation of engineering costs at 3% and 7% discount rate.

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[10] 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)[11] 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.

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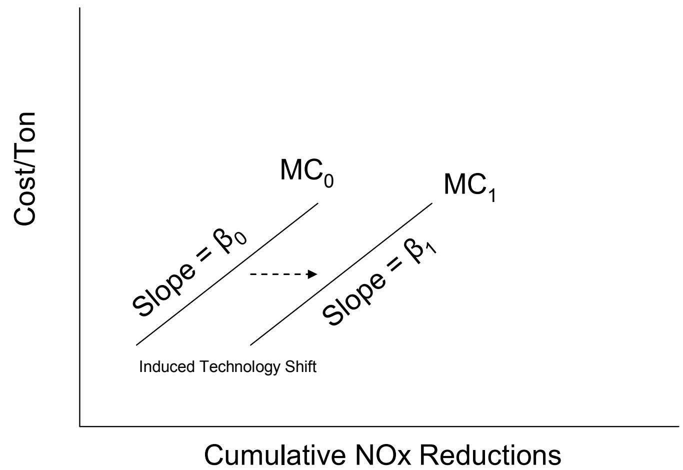
[10] Harrington et al. (2000) and previous studies cited by Harrington.
Harrington, W., R.D. Morgenstern, and P. Nelson. 2000. "On the Accuracy of Regulatory Cost Estimates." *Journal of Policy Analysis and Management* 19(2):297-322.
[11] Figure 6.1 shows a linear marginal abatement cost curve. It is 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.[12] 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 time is called Wright's Equation (Gumerman and Marnay, 2004)[13]. This equation, shown below, has been shown to be widely applicable in manufacturing:

Wright's Equation: $C_N = C_o * N^b$,

Where:

N = cumulative production

[12] 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.

[13] 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.

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.[14] 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.

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[15] conducted an analysis of the predicted and actual costs of 28 federal and state rules, including 21 issued by

[14] 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.

[15] 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.

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.

- *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.[16] 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

[16] 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.

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[17] 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.[18] An example focusing on fuel rules is provided in Table 6.8:

Table 6.8: 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

[17] 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.

[18] 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."

[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.[19]

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[20] 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.”

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[21]. 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.[22]

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[19] 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.

[20] 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.

[21] 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.

[22] 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.

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 6.9 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 50 ppb alternative standard, the most stringent alternative standard included in the analysis. Control costs are allocated to specific source categories by North American Industry Classification System (NAICS) code.

Table 6.9: Identified Costs/Revenue Ratios by Affected Industry for Alternative Standard 50 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
211	Oil and Gas Extraction	20	23	231,000	<0.01%
2211	Electric Power Generation, Transmission and Distribution	1,388	1,389	440,000	0.32%
311	Food Manufacturing	55	55	589,000	<0.01%
312	Beverage and Tobacco Product Manufacturing	1.3	1.3	128,000	<0.01%
313	Textile Mills	1.1	1.1	36,000	<0.01%
322	Paper Manufacturing	$143	$143	$170,000	< 0.01%
324	Petroleum and Coal Products Manufacturing	$245	$245	$590,000	< 0.01%
325	Chemical Manufacturing	$96	$96	$720,000	< 0.01%
326	Plastics and Rubber Products Manufacturing	60	60	211,000	<0.01%
327	Nonmetallic Mineral Product Manufacturing	266	306	128,000	<0.01%
331	Primary Metal Manufacturing	$144	$144	$250,000	< 0.01%
332	Fabricated metal product manufacturing	6.4	6.4	344,000	< 0.01%
335	Electrical equipment, appliance, and component manufacturing	5.0	5.0	129,000	< 0.01%
336	Transportation equipment manufacturing	2.9	2.9	737,000	< 0.01%
541	Professional, scientific, and technical services	3.9	3.9	1,345,000	< 0.01%
611	Educational services	137	137	47,000	0.29%
622	Hospitals	8.7	8.7	713,000	<0.01%
922[f]	Justice, Public Order and Safety Activities	2.5	2.5	-	-

928[f]	National Security and International Affairs	$14	$14	-	-

[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 of compliance with the current PM2.5 and Ozone standards.
[c] NAICS codes were unavailable for area source controls and the best workplaces for commuters control. These controls account for less than 1% 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 alternative SO_2 NAAQS of 50 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 6.9 suggests that at the electric power industry level, the annualized costs associated with the most stringent alternative standard analyzed (50 ppb) represent only about 0.3 percent of its revenues in 2020. In addition, for the other industries affected under the 50 ppb standard, no other industry has annualized costs of more than 0.3 percent of its revenues. As a result we can conclude that impacts to supply and electricity price are small. In addition, since these results reflect an analysis for the most stringent alternative standard, results for the other standards will show lower energy impacts. For example, the impact to the electric power industry (NAICS

2211) is an annual cost of less than 0.2 percent of revenues at the 75 ppb standard, and less than 0.1 percent of revenues for the 150 ppb standard.

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, 100 ppb, and 150 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 alternative standard of 50 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 proposed 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, 100 ppb, and 150 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. NonEGU and area source controls largely include measures from the AirControlNET control technology database. For these sources, we estimated costs based on the cost equations included in AirControlNET. The identified controls strategy for nonEGU Point and Area sources incorporated annualized engineering cost per ton caps. These caps were defined as the upper cost per ton for controls of nonEGU point and area sources. The caps used were originally developed for the Ozone NAAQS analysis, where NOx controls were also applied.

The EGU analysis included in this RIA utilizes the integrated planning model (IPM) v3.0 as part of the updated modeling platform.[1] IPM v3.0 includes input and model assumption updates in modeling the power sector and incorporates Federal and State rules and regulations adopted before September 2006 and various new source review (NSR) settlements. The SO_2 control technology options used in IPM v3.0 includes flue gas desulfurization (FGD), also known as "scrubbers". It is important to note that beyond these emission control options, IPM offers other compliance options for meeting emission limits. These include fuel switching, re-powering, and adjustments in the dispatching of electric generating units.

Finally, 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 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 an SO_2 standard at 50 ppb (99th percentile daily 1-hour maximum), the total monetized benefits would be $41 to $100 billion at a 3% discount rate and $37 to $90 billion at a 7% discount rate. For an SO_2 standard at 75 ppb, the total monetized benefits would be $22 to $53 billion at a 3% discount rate and $20 to $48 billion at a

[1] http://www.epa.gov/airmarkets/progsregs/epa-ipm/past-modeling.html.

7% discount rate. For an SO_2 standard at 100 ppb, the total monetized benefits would be $16 to $38 billion at a 3% discount rate and $14 to $35 billion at a 7% discount rate. For an SO_2 standard at 150 ppb, the total monetized benefits would be $6.4 to $16 billion at a 3% discount rate and $5.8 to $14 billion at a 7% discount rate.

These estimates reflect EPA's most current interpretation of the scientific literature and include three key changes from the 2008 ozone NAAQS RIA: (1) a no-threshold model for PM2.5 that calculates incremental benefits down to the lowest modeled air quality levels; (2) a different Value of Statistical Life (VSL); (3) two technical updates to the population dataset and aggregation method. 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 SOx emission controls. Higher or lower estimates of benefits are possible using other assumptions (see Figures 5.1-5.2). 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.

Table 7.1 presents total national primary estimates of costs and benefits for a 3% discount rate and a 7% discount rate. The total benefits estimates include SO_2-related benefits as well as $PM_{2.5}$ co-benefits. 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 *Extrapolated portion (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 separates the portion of benefits associated with reduced levels of SO2 from the additional reductions in health effects that come with the implementation of the control strategy – (i.e., the $PM_{2.5}$ co-benefits). For instance, for an alternative standard of 100 ppb,

$1.9 million in benefits are associated with reductions in SO2 while between 16,000 M and 39,000 M are associated with the $PM_{2.5}$ co-benefits.

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 Health Benefits	Monetized $PM_{2.5}$ Health Co-benefits	Costs	Monetized Net Benefits
Partial attainment (known controls)	50 ppb	31	3%	--[b]	$29,000 to $76,000	$2,000	$27,000 to $74,000
			7%	--[b]	$27,000 to $69,000	$2,300	$25,000 to $67,000
	75 ppb	12	3%	--[b]	$17,000 to $41,000	$1,000	$16,000 to $40,000
			7%	--[b]	$15,000 to $37,000	$1,100	$14,000 to $36,000
	100 ppb	6	3%	--[b]	$13,000 to $33,000	$840	$12,000 to $32,000
			7%	--[b]	$12,000 to $29,000	$900	$11,000 to $28,000
	150 ppb	4	3%	--[b]	$6,300 to $15,000	$340	$6,000 to $16,000
			7%	--[b]	$5,700 to $14,000	$370	$5,300 to $14,000
Extrapolated portion (unidentified controls)	50 ppb	26	3%	--[b]	$12,000 to $24,000	$4,500	$7,500 to $20,000
			7%	--[b]	$10,000 to $21,000	$4,500	$5,500 to $17,000
	75 ppb	12	3%	--[b]	$5,000 to $12,000	$1,900	$3,100 to $10,000
			7%	--[b]	$5,000 to $11,000	$1,900	$3,100 to $9,100
	100 ppb	8	3%	--[b]	$3,000 to $5,000	$920	$2,000 to $4,000
			7%	--[b]	$2,000 to $5,000	$920	$1,100 to $4,000
	150 ppb	2	3%	--[b]	$100 to $250	$39	$60 to $180
			7%	--[b]	$90 to $220	$39	$50 to $180
Full attainment	50 ppb	57	3%	$12	$41,000 to $100,000	$6,500	$34,000 to $94,000
			7%	$12	$37,000 to $90,000	$6,800	$30,000 to $83,000
	75 ppb	24	3%	$4.6	$22,000 to $53,000	$2,900	$19,000 to $50,000
			7%	$4.6	$20,000 to $48,000	$3,000	$17,000 to $45,000
	100 ppb	14	3%	$1.9	$16,000 to $38,000	$1,800[c]	$14,000 to $36,000
			7%	$1.9	$14,000 to $35,000	$1,800[c]	$12,000 to $33,000
	150 ppb	6	3%	$0.6	$6,400 to $16,000	$380	$6,000 to $16,000
			7%	$0.6	$5,800 to $14,000	$410	$5,400 to $14,000

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates. Benefits are shown as a range from Pope et al (2002) to Laden et al. (2006). Estimates reflect full attainment with the alternate standards, including emission reductions from known and unidentified controls. Monetized benefits do not include unquantified benefits, such as other health effects, reduced sulfur deposition, or improvements in visibility.

[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 potion of the SO_2 benefits are attributable to the known controls and a portion of the SO_2 benefits are attributable to the extrapolated controls. Because all SO_2-related benefits are short-term effects, the results are identical for all discount rates.

[c] Although the costs appear the same for full attainment of 100 ppb due to rounding, the unrounded costs are actually $67,000 higher at a 7% discount rate.

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.

- *Current PM2.5 Controls in Baseline*: Our 2020 analysis year baseline assumes that States will put in place the necessary control strategies to attain the current $PM_{2.5}$ standards. As States develop their plans for attaining these standards, their SO_2 control strategies may differ significantly from our analysis.

- *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 gradient of ambient SO_2 concentrations is difficult to estimate due to the sparsity of the monitoring network in some areas. The 12km 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'Conner et al. (2007). 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. Compared to the $PM_{2.5}$ co-benefits, the benefits from reduced SO_2 exposure appear small. This is primary due to 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 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.