Final Ozone NAAQS Regulatory Impact Analysis

EPA-452/R-08-003
March 2008

Final Ozone NAAQS Regulatory Impact Analysis

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
Air Benefit and Cost Group (C439-02)
Research Triangle Park, North Carolina

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Overview

EPA has performed an illustrative analysis of the potential costs and human health and visibility benefits of nationally attaining a new ozone standard of 0.075 ppm. Per Executive Order 12866 and the guidelines of OMB Circular A-4, this Regulatory Impact Analysis (RIA) also presents analyses of three alternative standards, a less stringent 0.079 ppm and two more stringent options (0.065 and 0.070 ppm). 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 full attainment of the existing ozone and particulate matter (PM) National Ambient Air Quality Standards (NAAQS). The baseline also includes the Clean Air Interstate Rule and mobile source programs, which will help many areas move toward attainment of the current ozone standard.

This RIA is focused on development and analyses of illustrative control strategies to meet these alternative standards in 2020. This analysis does not prejudge the attainment dates that will ultimately be assigned to individual areas under the Clean Air Act, which contains a variety of potential dates and flexibility for extensions. For purposes of this analysis, though, we assume attainment by 2020 for all areas except for two areas (San Joaquin Valley and South Coast air basins) in California. The state has submitted to EPA plans for implementing the current ozone standard which propose that these two areas of California meet that standard by 2024. We have assumed for analytical purposes that the San Joaquin Valley and South Coast air basin would attain a new standard in 2030. The actual attainment year for all areas will be determined through the State Implementation Plan process. A separate analysis for the San Joaquin Valley and South Coast air basins in California is provided in Appendix 7b.

EPA designed a two-stage approach to estimating costs and benefits, because we recognized that some areas with significant ozone problems would need emission controls beyond those currently available to meet either the 1997 ozone standards, or alternative, more stringent standards. However, as documented in Chapter 5, there are numerous examples of how technological innovation has led to the development of new and improved ways of reducing air pollution, often at lower cost than estimated at the time a new NAAQS is established. The individual chapters of the RIA present more detail regarding estimated costs and benefits based on both partial attainment (manageable with current technologies) and full attainment (which in some locations will require new or innovative approaches and technology).

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

The prohibition against the consideration of cost in the setting of the primary air quality standards, however, does not mean that costs, benefits or other economic considerations are unimportant or should be ignored. The Agency believes that consideration of costs and benefits is an essential decision making tool for the efficient implementation of these standards. The impacts of cost, benefits, and efficiency are considered by the States when they make decisions regarding what timelines, strategies, and policies make the most sense.

Because States are ultimately responsible for implementing strategies to meet revised standards, this RIA provides insights and analysis of a limited number of illustrative control strategies that states might adopt to meet any revised standard. These illustrative strategies are subject to a number of important assumptions, uncertainties and limitations, which we document in the relevant portions of the analysis.

ES.1 Approach to the Analysis

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

The air quality modeling results for the *regulatory baseline* (explained in Chapter 3) provide the starting point for developing illustrative control strategies to attain the alternative standards that are the focus of this RIA. The baseline shows that by 2020, while ozone air quality would be significantly better than today under current requirements, several eastern and western states would need to develop and adopt additional controls to attain the new standard. After existing control technologies have been applied, additional unspecified emission reductions are applied to establish attainment. The cost of these unknown controls was extrapolated and is included in the total cost numbers.

In selecting controls, we focused more on ozone cost-effectiveness (measured as $/ppb) than on the NOx or VOC cost-effectiveness (measured as $/ton). Most of the overall reductions in NOx achieved our illustrative control strategy were from non-EGU point sources. The NOx based illustrative control strategies we analyzed are also expected to reduce ambient $PM_{2.5}$ levels in many locations. The total benefits estimates described here include the co-benefits of reductions in fine particulate levels (PM) associated with year-round application of NOx control strategies beyond those in the regulatory baseline. In moving further down the list of cost-effective known and available controls, we deplete our database of available choices of known controls, and are left with background emissions and remaining anthropogenic emissions for which we do not have enough knowledge to determine how, and at what cost, reductions can be achieved in the future when attainment would be required.

Estimated reductions in premature mortality from reductions in ambient ozone and PM dominate the benefits estimates. For this reason, our assessment provides a range of estimates for both PM and ozone premature mortality. Although we note that there are uncertainties that are not fully captured by this range of estimates, and that additional research is needed to more fully establish underlying mechanisms by which such effects occur, such ranges are illustrative of the extent of uncertainly associated with some different modeling assumptions.

ES.2 Results of Benefit-Cost Analysis

The following is a presentation of the benefits and costs of attaining various Ozone National Ambient Air Quality Standards in the year 2020. These estimates only include areas assumed to meet the current standard by 2020. As mentioned earlier, they do not include the costs or benefits of attaining the alternate standards in San Joaquin Valley and South Coast air basins. Due to the differences in attainment year and other assumptions underlying the 2020 analysis presented here, and the 2030 analysis in Appendix 7b, it is not appropriate to add the results together to get a national "full attainment" scenario.

In Tables ES.1 through ES.4, the individual row estimates reflect the different studies available to describe the ozone premature mortality relationship. Ranges within the total benefits column reflect variability in the studies upon which the estimates associated with premature mortality were derived. For the 0.075ppm alternative, $PM_{2.5}$ co-benefits account for between 42 and 99 percent of total benefits depending upon the study used. Details about these studies are in Chapter 6.

Ranges in the total costs column reflect different assumptions about the extrapolation of costs as discussed in Chapter 5. The low end of the range of net benefits is constructed by subtracting the highest cost from the lowest benefit, while the high end of the range is constructed by subtracting the lowest cost from the highest benefit. The presentation of the net benefit estimates represents the widest possible range from this analysis. These tables do not include visibility benefits, which are estimated at $160 million/yr.

Table ES.1: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.075 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	2.6 – 17	2.4 – 16	7.6 – 8.8	–6.3 – 9.5	–6.4 – 7.9
Meta-analysis	Bell et al. 2005	3.8 – 18	3.6 – 17	7.6 – 8.8	–5.0 – 11	–5.2 – 9.1
	Ito et al. 2005	4.4 – 19	4.3 – 17	7.6 – 8.8	–4.4 – 11	–4.5 – 9.8
	Levy et al. 2005	4.5 – 19	4.4 – 17	7.6 – 8.8	–4.3 – 11	–4.5 – 9.9
Assumption that association is not causal****		2.0 – 17	1.8 – 15	7.6 – 8.8	–6.8 – 9	–7.0 – 7.4

Table ES.2: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.079 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	1.4 – 11	1.3 – 9.9	2.4 – 2.9	–1.5 – 8.5	–1.6 – 7.5
Meta-analysis	Bell et al. 2005	1.9 – 11	1.8 – 10	2.4 – 2.9	–1.1 – 8.9	–1.2 – 7.9
	Ito et al. 2005	2.1 – 12	2.0 – 11	2.4 – 2.9	–0.83 – 9.2	–0.9 – 8.1
	Levy et al. 2005	2.1 – 12	2.0 – 11	2.4 – 2.9	–0.80 – 9.2	–0.9 – 8.2
Assumption that association is not causal****		1.2 – 11	1.1 – 9.7	2.4 – 2.9	–1.7 – 8.3	–1.8 – 7.3

Table ES.3: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.070 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	5.4 – 29	5.1 – 27	19 – 25	–20 – 10	–20 – 7.6
Meta-analysis	Bell et al. 2005	9.7 – 34	9.5 – 31	19 – 25	–15 – 15	–16 – 12
	Ito et al. 2005	12 – 36	12 – 33	19 – 25	–13 – 17	–13 – 14
	Levy et al. 2005	12 – 36	12 – 33	19 – 25	–13 – 17	–13 – 14
Assumption that association is not causal****		3.5 – 27	3.2 – 25	19 – 25	–22 – 8	–22 – 5.7

Table ES.4: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.065 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	9.0 – 46	8.6 – 42	32 – 44	–35 – 14	–35 – 9.7
Meta-analysis	Bell et al. 2005	17 – 54	16 – 50	32 – 44	–27 – 22	–28 – 18
	Ito et al. 2005	21 – 58	21 – 54	32 – 44	–23 – 26	–23 – 22
	Levy et al. 2005	21 – 58	21 – 54	32 – 44	–23 – 26	–23 – 22
Assumption that association is not causal****		5.5 – 42	5.1 – 38	32 – 44	–39 – 10	–39 – 6.2

*All estimates rounded to two significant figures. As such, they may not sum across columns. These estimates do not include visibility benefits. Only includes areas required to meet the current standard by 2020, does not include San Joaquin and South Coast areas in California. Appendix 7b shows the costs and benefits of attaining alternate standards in San Joaquin and South Coast California.

**Includes ozone benefits, and PM 2.5 co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. Tables exclude unquantified and nonmonetized benefits.

***Range reflects lower and upper bound cost estimates. Data for calculating costs at a 3% discount rate was not available for all sectors, and therefore total annualized costs at 3% are not presented here. Additionally, these estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

****Total includes ozone morbidity benefits and total PM co-benefits only.

Table ES.5 presents the total number of estimated ozone and $PM_{2.5}$-related premature mortalities and morbidities avoided nationwide in 2020.

Table ES.5: Summary of Total Number of Annual Ozone and $PM_{2.5}$-Related Premature Mortalities and Premature Morbidity Avoided: 2020 National Benefits*

Combined Estimate of Mortality Standard Alternative and Model or Assumption		Combined Range of Ozone Benefits and $PM_{2.5}$ Co-Benefits**			
		0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
NMMAPS	Bell (2004)	140 – 1,300	260 – 2,000	560 – 3,500	940 – 5,500
Meta-Analysis	Bell (2005)	200 – 1,300	420 – 2,200	560 – 4,100	2,000 – 6,500
	Ito (2005)	230 – 1,300	500 – 2,300	1,100 – 4,300	2,500 – 7,000
	Levy (2005)	230 – 1,400	510 – 2,300	1,400 – 4,400	2,500 – 7,100
Assumption that association is not causal***		120 – 1,200	190 – 2,000	310 – 3,200	490 – 5,000
Combined Estimate of Morbidity					
Acute Myocardial Infarction		570	890	1,500	2,300
Upper Respiratory Symptoms		3,100	4,900	8,100	13,000
Lower Respiratory Symptoms		4,200	6,700	11,000	17,000
Chronic Bronchitis		240	380	630	970
Acute Bronchitis		640	1,000	1,700	2,600
Asthma Exacerbation		3,900	6,100	10,000	16,000
Work Loss Days		28,000	43,000	72,000	110,000
School Loss Days		72,000	200,000	640,000	1,100,000
Hospital and ER Visits		890	1,900	5,100	9,400
Minor Restricted Activity Days		340,000	750,000	2,100,000	3,500,000

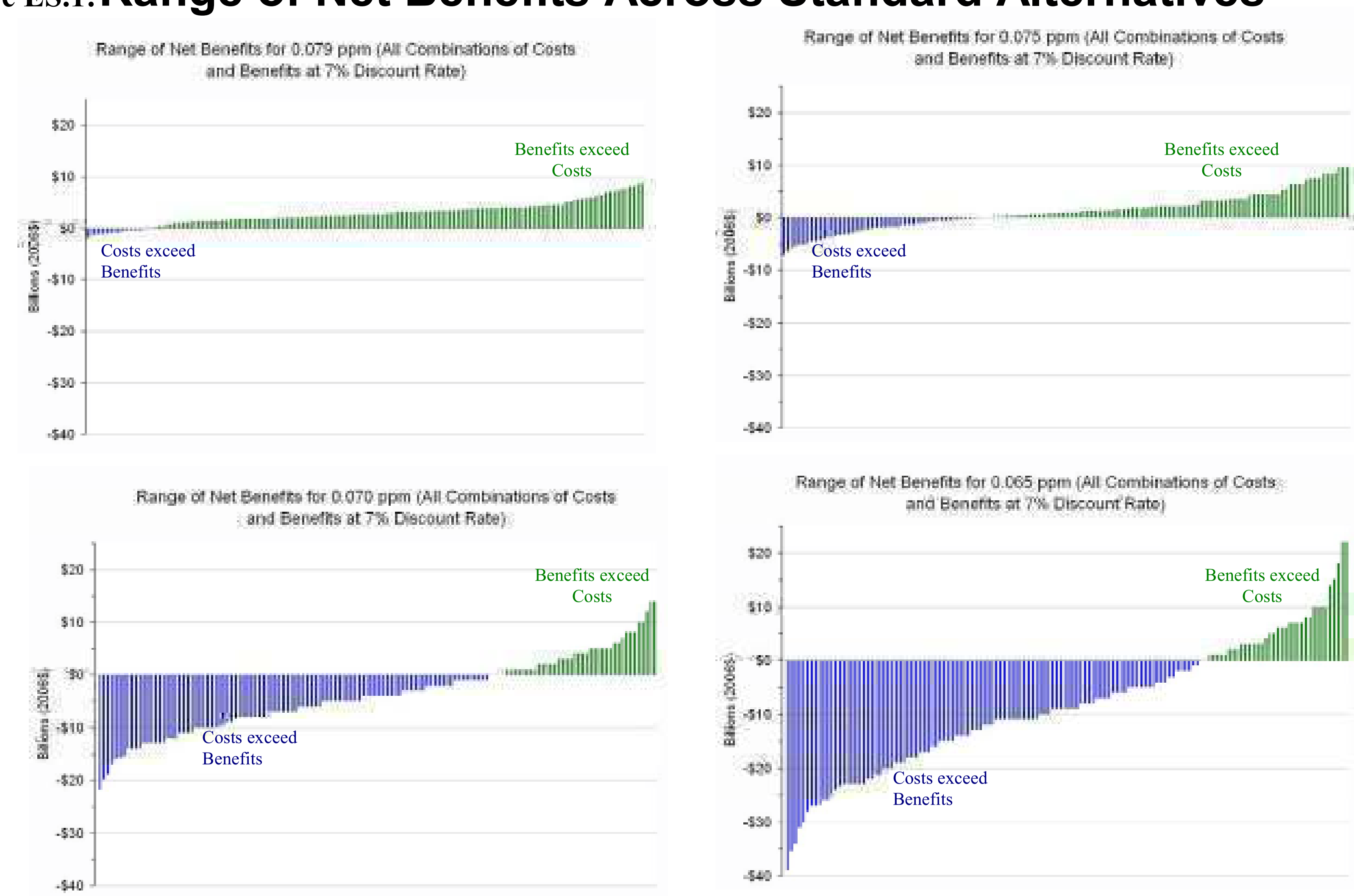
*Only includes areas required to meet the current standard by 2020, does not include San Joaquin Valley and South Coast air basins in California. Appendix 7b shows the costs and benefits of attaining alternate standards in San Joaquin and South Coast California.

**Includes ozone benefits, and PM 2.5 co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation described in Chapter 6.

***Estimated reduction in premature mortality due to $PM_{2.5}$ reductions only

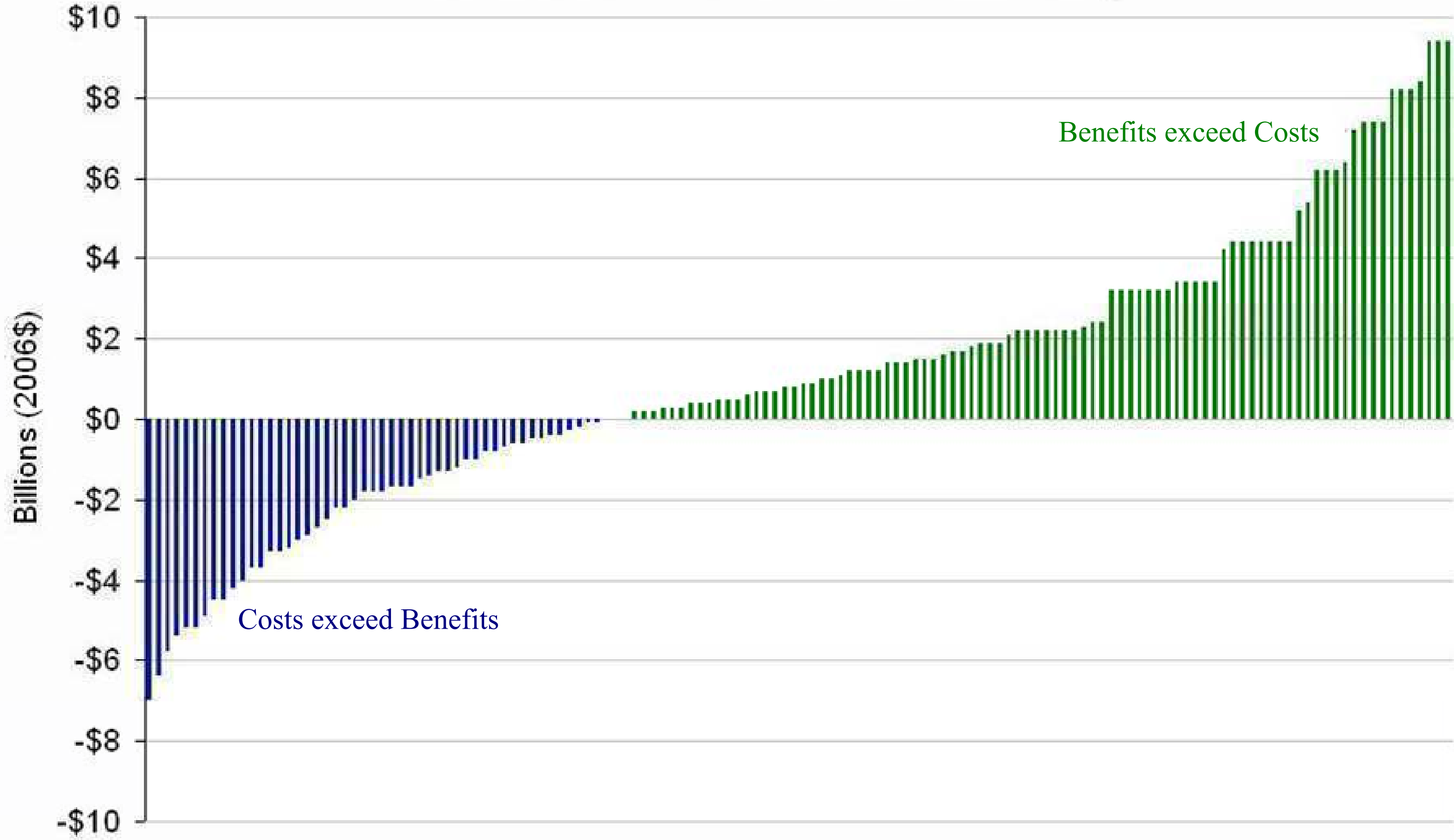
The following set of graphs is included to provide the reader with a richer presentation of the range of costs and benefits of the alternative standards. The graphs supplement the tables by displaying all possible combinations of net benefits, utilizing the five different ozone functions, the fourteen different PM functions, and the two cost methods. Each of the 140 bars in each graph represents an independent and equally probably point estimate of net benefits under a certain combination of cost and benefit estimation methods. Thus it is not possible to infer the likelihood of any single net benefit estimate. The blue bars indicate combinations where the net benefits are negative, whereas the green bars indicate combinations where net benefits are positive. Figure ES.1 shows all of these combinations for all standards analyzed. Figure ES.2 shows a close-up of the range of net benefits for the selected standard of 0.075 ppm.

Figure ES.1: Range of Net Benefits Across Standard Alternatives*



* This graph shows all 140 combinations of the 5 different ozone mortality functions and assumptions, the 14 different PM mortality functions, and the 2 cost methods. All combinations are treated as independent and equally probable.

Figure ES.2: Range of Net Benefits for 0.075 ppm (All Combinations of Costs and Benefits at 7% Discount Rate) *



* This graph shows all 140 combinations of the 5 different ozone mortality functions and assumptions, the 14 different PM mortality functions, and the 2 cost methods. All combinations are treated as independent and equally probable.

For the selected standard of 0.075 ppm, the median value of all of the independent point estimates is $0.8 billion, and the majority (64%) of the combinations indicate positive net benefits for this standard.

ES.3 Caveats and Conclusions

Of critical importance to understanding these estimates of future costs and benefits is that they are not intended to be forecasts of the actual costs and benefits of implementing revised standards. There are many challenges in estimating the costs and benefits of attaining a tighter ozone standard, which are fully discussed in Chapters 5, 6, and 7. Analytically, the characterization of mortality benefits and the estimation of the costs to the nation of fully attaining a tighter standard will be subject to further review by EPA science advisory boards.

There are significant uncertainties in both cost and benefit estimates. Below we summarize some of the more significant sources of uncertainty.

- Benefits estimates are influenced by our ability to accurately model relationships between ozone and PM and their associated health effects (e.g., premature mortality).

- Benefits estimates are also heavily dependent upon the choice of the statistical model chosen for each health benefit.

- EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality within the context of quantifying benefits. We expect to receive this advice in the spring of 2008

- As shown in figure ES.1 above, there is a considerable range of costs and benefits associated with attainment of a tighter ozone standard, especially in the range of PM 2.5 benefits. EPA has plans to ask its Science Advisory Board for advice about how to best characterize the PM mortality benefits in future analyses.

- PM co-benefits are derived primarily from reductions in nitrates (associated with NOx controls). As such, these estimates are strongly influenced by the assumption that all PM components are equally toxic. Co-benefit estimates are also influenced by the extent to which a particular area chooses to use NOx controls rather than VOC controls.

- EPA employed a monitor rollback approach to estimate the benefits of attaining an alternative standard of 0.079 ppm nationwide. This approach likely understates the benefits that would occur due to implementation of actual controls because controls implemented to reduce ozone concentrations at the highest monitor would likely result in some reductions in ozone concentrations at attaining monitors down-wind (i.e., the controls would lead to concentrations below the standard in down-wind locations).

- There are several nonquantified benefits (e.g., effects of reduced ozone on forest health and agricultural crop production) and disbenefits (e.g., decreases in tropospheric ozone lead to reduced screening of UV-B rays and reduced nitrogen fertilization of forests and cropland) discussed in this analysis in Chapter 6.

- Changes in air quality as a result of controls are not expected to be uniform over the country. In our hypothetical control scenario some increases in ozone levels occur in areas already in attainment, though not enough to push the areas into nonattainment

- As explained in Chapter 5, there are several uncertainties in our cost estimates. For example, the states are likely to use different approaches for reducing NOx and VOCs in their state implementation plans to reach a tighter standard. In addition, since our modeling of known controls does not get all areas into attainment, we needed to make assumptions about the costs of control technologies that might be developed in the future and used to meet the tighter alternative. For the 21 counties (in four geographic areas) that are not expected to attain 0.075 ppm[1] in 2020[2], assumed costs of unspecified controls represent a substantial fraction, of the costs estimated in this analysis ranging from 50% to 89% of total costs depending on the standard being analyzed.

- As discussed in Chapter 5, recent advice from EPA's Science Advisory Board has questioned the appropriateness of an approach similar to one of those used here for estimating extrapolated costs. For balance, EPA also applied a methodology recommended by the Science Advisory Board in an effort to best approximate the costs of control technologies that might be developed in the future.

- Both extrapolated costs and benefits have additional uncertainty relative to modeled costs and benefits. The extrapolated costs and benefits will only be realized to the extent that unknown extrapolated controls are economically feasible and are implemented. Technological advances over time will tend to increase the economic feasibility of reducing emissions, and will tend to reduce the costs of reducing emissions. Our estimates of costs of attainment in 2020 assume a particular trajectory of aggressive technological change. This trajectory leads to a particular level of emissions reductions and costs which we have estimated based on two different approaches, the fixed cost and hybrid approaches. An alternative storyline might hypothesize a much less optimistic technological change path, such that emissions reductions technologies for industrial sources would be more expensive or would be unavailable, so that emissions reductions from many smaller sources might be required for 2020 attainment, at a potentially greater cost per ton. Under this alternative storyline, two outcomes are hypothetically possible: Under one scenario, total costs associated with full attainment might be substantially higher. Under the second scenario, states may choose to take advantage of flexibility in the Clean Air Act to

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[1] Areas that do not meet 0.075 ppm are Chicago, Houston, the Northeastern Corridor, and Sacramento. For more information see chapter 4 section 4.1.1.

[2] This list of areas does not include the San Joaquin and South Coast air basins who are not expected to attain the current 0.08 ppm standard until 2024.

adopt plan with later attainment dates to allow for additional technologies to be developed and for existing programs like EPA's Onroad Diesel, Nonroad Diesel, and Locomotive and Marine rules to be fully implemented. If states were to submit plans with attainment dates beyond our 2020 analysis year, benefits would clearly be lower than we have estimated under our analytical storyline. However, in this case, state decision makers seeking to maximize economic efficiency would not impose costs, including potential opportunity costs of not meeting their attainment date, when they exceed the expected health benefits that states would realize from meeting their modeled 2020 attainment date. In this case, upper bound costs are difficult to estimate because we do not have an estimate of the point where marginal costs are equal to marginal benefits plus the costs of nonattainment. Clearly, the second stage analysis is a highly speculative exercise, because it is based on estimating emission reductions and air quality improvements without any information about the specific controls that would be available to do so.

- This analysis shows the costs and benefits of a standard of 0.075 ppm and other alternate standards of 0.079, 0.070, and 0.065. The costs and benefits are incremental to a baseline that assumes some additional technology changes in the onroad technology sector. If these changes do not occur, then cost for all standards would increase by $1.8 billion and benefits for all standards would increase by $360 million to $3.1 billion using 2006$ and a 3% discount rate, and $330 million to $2.8 billion when using a 7% discount rate.[3] Details about costs and benefits using an alternate baseline can be found in Appendix 7a.

[3] These estimates are highly uncertain and are purely illustrative estimates of the potential costs and benefits of these mobile control strategies. We present them only as screening-level estimates to provide a bounding estimate of the costs and benefits of including these emissions controls in the ozone NAAQS control case for all standards. As such, it would be inappropriate to apply these benefit per-ton estimates to other policy contexts, including other regulatory impact analyses. Furthermore, the benefits only reflect a partial accounting of the total benefits associated with emission reductions related to the mobile controls included in this sensitivity analysis.

Chapter 1: Introduction and Background

Synopsis

This document estimates the incremental costs and monetized human health and welfare benefits of attaining a revised primary ozone 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 ozone NAAQS. In some cases, EPA weighed the available empirical data 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 ozone NAAQS, and to meet the requirements of Executive Order 12866 and OMB Circular A-4 (described below in Section 1.2.2).

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." Ozone 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. 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. Economic factors cannot be considered.

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 ozone 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.[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. OMB circular A-4 also requires both a cost-benefit, and a cost-effectiveness analysis for rules where health is the primary effect. Within this RIA we provide a cost benefit analysis. We also provide a cost-effectiveness analysis which will be jointly presented in Appendix 6b.

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 one may be issued is to address market failure. The major types of market failure include: externality, market power, and inadequate or asymmetric information. Correcting market failures is one reason for regulation, but it is not the only reason. Other possible justifications include 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

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

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 firms 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 ozone 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 ozone 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.

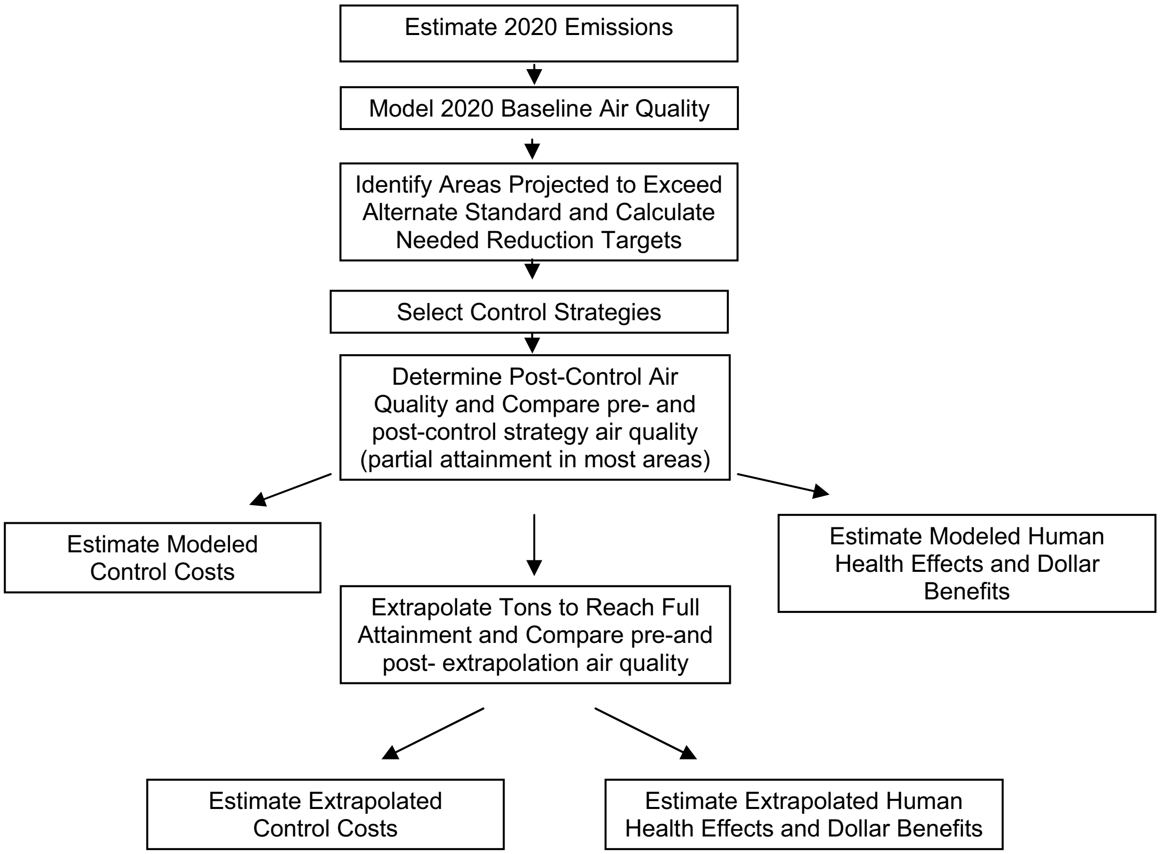
The illustrative goals of this RIA are somewhat different from other EPA analyses of national rules, or the implementation plans states develop, and the distinctions are worth brief mention. This RIA does not assess the regulatory impact of an EPA-prescribed national or regional rule such as the Clean Air Interstate Rule, nor does it attempt to model the specific actions that any state would take to implement a revised ozone 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 ozone 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. An additional limitation is that this analysis is carried out for the year 2020, before some areas are required to reach the current ozone standard. Section 1.3.1 below explains why EPA selected the analysis year of 2020. 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 ozone 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 framework of 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 allows EPA to build the ozone RIA analysis on the previously completed PM NAAQS RIA analysis which also used 2020 as its analysis year. Many areas will reach attainment of the current ozone standard or any alternative ozone standard by 2020. For purposes of this analysis, we assume attainment by 2020 for all areas except for two areas in California with unique circumstances described in Appendix 7b. 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, which contains a variety of potential dates and flexibility to move to later dates (up to 20 years), provided that the date is as expeditious as practicable.

The methodology first estimates what baseline ozone levels might look like in 2020 with existing Clean Air Act programs, including application of controls to meet the current ozone standard and the newly revised PM NAAQS standard and then models how ozone levels would be predicted to change following the application of additional controls to reach a tighter standard. This allows for an analysis of the incremental change between the current standard and an alternative standard. This timeline is also consistent with expected attainment in 2020 of the revised

Particulate Matter (PM) NAAQS covered in the PM NAAQS RIA issued in September 2006. As explained in Chapter 2, since one of the principal precursors for ozone, NOx, is also a precursor for PM, it is important that we account for the impact on ozone concentrations of NOx controls used in the hypothetical control scenario used 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

A hypothetical control strategy was developed for an alternative 8-hr ozone standard of 0.070 ppm, in order to illustrate one national scenario for how such a tighter standard might be met. First, EPA modeled the predicted 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 portions of the country that were predicted to be in non-attainment with 0.070 ppm in 2020. However, given the limitations of current technology and the amount of improvement in air quality needed to reach a standard of 0.070 ppm in some areas, it was also expected that modeling these known controls would not reduce ozone concentrations sufficiently to allow all areas to reach the more stringent standard. We performed air quality sensitivity modeling by reducing the remaining NOx and NOx + VOC emissions by 30, 60, and 90% beyond the percentage inventory reductions that were achieved by the modeled known control strategy. This enabled us to determine, for an extrapolation analysis, the approximate number of tons of additional reductions, beyond those achieved by known controls that would be required to meet the alternate standards.

1.3.3 Evaluating Costs and Benefits

Applying a two step methodology for estimating emission reductions needed to reach full attainment enabled EPA to evaluate nationwide costs and benefits of attaining a tighter ozone standard, albeit with substantial additional uncertainty regarding the second step estimates. Costs and benefits are presented in this RIA in the same two steps that emissions reductions were estimated. First, the costs associated with applying known controls were quantified, and presented along with an estimate of their economic impact. Second, EPA estimated costs of the additional tons of extrapolated emission reductions estimated which were needed to reach full attainment. The analysis of the benefits of setting an alternative primary standard included both mortality and morbidity calculations matching the costs of applying known controls and then the benefits of reaching full attainment. The costs and monetized benefits were then compared to provide an estimate of net benefits nationwide. It is important to note that this analysis did not estimate any separate costs or benefits of attaining a secondary NAAQS standard due to resource and time constraints. Since the secondary is being set to be equivalent to the primary standard, few additional costs and benefits are expected.

To streamline this RIA, this document refers to several previously published documents, including two technical documents EPA produced to prepare for the ozone NAAQS proposal. The first was a Criteria Document created by EPA's Office of Research and Development (published in 2006), which presented the latest available pertinent information on atmospheric science, air quality, exposure, dosimetry, health effect, and environmental effects of ozone. The second was a "Staff Paper" (published in 2007) that evaluated the policy implications of the key studies and scientific information contained in the Criteria Document, as well as presented a risk assessment for various standard levels. The Staff Paper also includes staff conclusions and recommendations to the Administrator regarding potential revisions to the standards. In addition to the Criteria Document and Staff Paper, this ozone RIA relies heavily on the 2006 RIA for particulate matter (PM). Many of the models and methodology used here are the same as in the PM NAAQS RIA. This RIA identifies methodologies used to generate data, but refers readers to the PM NAAQS RIA for many technical details. The focus of this RIA is to explain in detail how the approach or methodologies have changed from the PM NAAQS RIA analysis, and to present the results of the methodologies employed in this analysis, which compares attainment of tighter levels of the ozone standard to the baseline of the current standard.

1.4 Ozone Standard Alternatives Considered

EPA has performed an illustrative analysis of the potential costs and human health and visibility benefits of nationally attaining a new ozone standard of 0.075 ppm. Per Executive Order 12866 and the guidelines of OMB Circular A-4, this Regulatory Impact Analysis (RIA) also presents analyses of three alternative standards, a less stringent 0.079 ppm and two more stringent options (0.065 and 0.070 ppm). 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 full attainment of the existing ozone and particulate matter (PM) National Ambient Air Quality Standards (NAAQS). The baseline also includes the Clean Air Interstate Rule and mobile source programs, which will help many areas move toward attainment of the current ozone standard.

1.5 References

Henderson, R. 2006. October 24, 2006. Letter from CASAC Chairman Rogene Henderson to EPA Administrator Stephen Johnson, EPA-CASAC-07-001.

U.S. EPA. 1970. Clean Air Act. 40CFR50.

U.S. EPA. 2006. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF.

U.S. EPA. 2007. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. North Carolina. EPA-452/R-07-003

Chapter 2: Characterizing Ozone and Modeling Tools Used in This Analysis

Synopsis

This chapter describes the chemical and physical properties of ozone, general ozone air quality patterns, key health and environmental impacts associated with exposure to ozone, and key sources of ozone precursor emissions. In order to evaluate the health and environmental impacts of trying to reach a tighter ozone standard in the year 2020, it was necessary to use models to predict concentrations in the future. The tools and methodology used for the air quality modeling are described in this chapter. Subsequent chapters of this RIA rely heavily on the results of this modeling.

2.1 Ozone Chemistry

Ozone occurs both naturally in the stratosphere to provide a protective layer high above the earth, and at ground-level (troposphere) as the prime ingredient of smog. Tropospheric ozone, which is regulated by the NAAQS, is formed by both naturally occurring and anthropogenic sources. Ozone is not emitted directly into the air, but is created when its two primary components, volatile organic compounds (VOC) and oxides of nitrogen (NOx), combine in the presence of sunlight. VOC and NOx are often referred to as ozone precursors, which are, for the most part, emitted directly into the atmosphere.

Ambient ozone concentrations are directly affected by temperature, solar radiation, wind speed and other meteorological factors. Ultraviolet radiation from the sun plays a key role in initiating the processes leading to ozone formation. However, there is little empirical evidence directly linking day-to-day variations in observed surface ultraviolet radiation levels with variations in tropospheric ozone levels.

The rate of ozone production can be limited by either VOCs or NOx. In general, ozone formation using these two precursors is reliant upon the relative sources of hydroxide (OH) and NOx. When the rate of OH production is greater than the rate of production of NOx, indicating that NOx is in short supply, the rate of ozone production is NOx-limited. In this situation, ozone concentrations are most effectively reduced by lowering current and future NOx emissions, rather than lowering emissions of VOCs. When the rate of OH production is less than the rate of production of NOx, ozone production is VOC-limited. Here, ozone is most effectively reduced by lowering VOCs. Between the NOx- and VOC-limited extremes there is a transitional region where ozone is nearly equally sensitive to each species. However ozone is relatively insensitive to marginal changes in both NOx and VOC in this situation. In urban areas with a high population concentration, ozone is often VOC-limited. Ozone is generally NOx-limited in rural areas and downwind suburban areas. Additional information on ozone formation can be found in "Atmospheric Chemistry and Physics" (Seinfeld et. al., 1998).

Due to the complex photochemistry of ozone production, NOx emissions lead to both the formation and destruction of ozone, depending on the local quantities of NOx, VOC, and ozone catalysts such as the OH and HO2 radicals. In areas dominated by fresh emissions of NOx, ozone catalysts are removed via the production of nitric acid, which slows the ozone formation rate. Because NOx is generally depleted more rapidly than VOC, this effect is usually short-lived and the emitted NOx can lead to ozone formation later and further downwind. The terms “NOx disbenefits” or “ozone disbenefits” refer to the ozone increases that can result from NOx emission reductions in these localized areas.[1]

2.1.1 Temporal Scale

Ground-level ozone forms readily in the atmosphere, usually during hot weather. The effects of sunlight on ozone formation depend on its intensity and its spectral distribution. Ozone levels tend to be highest during the daytime, during the summer or warm season. Changing weather patterns contribute to day to day and interannual differences in ozone concentrations. Differences in climatic regime, amount and mixture of emissions, and the extent of transport contribute to variations in ozone from city to city.

2.1.2 Geographic Scale and Transport

In many urban areas, ozone nonattainment is not caused by emissions from the local area alone. Due to atmospheric transport, contributions of precursors from the surrounding region can also be important. Thus, in designing control strategies to reduce ozone concentrations in a local area, it is often necessary to account for regional transport within the U.S.

In some areas, such as California, global transport of ozone from beyond North America can contribute to nonattainment areas. In a very limited number of areas, including areas such as Buffalo, Detroit and El Paso, which are located near borders, emissions from Canada or Mexico may contribute to nonattainment. In these areas, our illustrative implementation strategies may have included more controls on domestic sources than would be required if cross-border transport did not occur. However, we have not conducted formal analysis, and as such cannot determine the contribution of non-U.S. sources to ozone design values. The transport of ozone is determined by meteorological and chemical processes which typically extend over spatial scales of several hundred kilometers. Additionally, convection is capable of transporting ozone and its precursors vertically through the troposphere, with resulting mixing of stratospheric ozone for periods of a month or more with tropospheric ozone.

The Technical Support Document (TSD) for the Clean Air Interstate Rule (CAIR) suggests that ozone transport constitutes a sizable portion of projected nonattainment in most eastern areas based on a 2010 analysis. A listing of Eastern states and the extent of transported ozone they receive in the CAIR analysis is located in the CAIR TSD.[2] We used this information to help guide the design of emissions control strategies in this analysis.

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[1] U.S. EPA. Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines. EPA420-R-04-007. May 2004.
[2] http://www.epa.gov/interstateairquality/pdfs/finaltech02.pdf, Table VI-2.

2.2 Sources of Ozone

The anthropogenic precursors of ozone originate from a wide variety of stationary and mobile sources. In urban areas, both biogenic (natural) and anthropogenic VOCs are important for ozone formation. Hundreds of VOCs are emitted by evaporation and combustion processes from a large number of anthropogenic sources. Current data show that solvent use and highway vehicles are the two main sources of VOCs, with roughly equal contributions to total emissions. Emissions of VOCs from highway vehicles account for roughly two-thirds of the transportation-related emissions.[3] By 2020, EPA emission projections show that VOC emissions from highway vehicles decrease significantly. Solvent use VOC decreases as well, but by 2020 solvent use VOC is projected to be a slightly more significant VOC contributor than mobile VOC. On the regional and global scales, emissions of VOCs from vegetation are much larger than those from anthropogenic sources.

Anthropogenic NOx emissions are associated with combustion processes. The two largest sources of NOx are electric power generation plants (EGUs) and motor vehicles. EGU NOx is approximately 40% less than onroad mobile NOx in 2001. Both decrease between 2001 and 2020, with onroad mobile NOx decreasing more, so that their emissions are similar in 2020. It is not possible to make an overall statement about their relative impacts on ozone in all local areas because EGUs are more sparse than mobile sources, particularly in the west and south (See Chapter 3 for a discussion of emission reductions projected in 2020 for the 8-hr ozone current standard baseline and the more stringent alternative control scenario). Natural NOx sources include stratospheric intrusions, lightning, soils, and wildfires. Lightning, fertilized soils, and wildfires are the major natural sources of NOx in the United States. Uncertainties in natural NOx inventories are much larger than for anthropogenic NOx emissions.

A complete list of emissions source categories, for both NOx and VOCs, is compiled in the final ozone Staff Paper (EPA, 2007a, pp. 2-3 to 2-6).

2.3 Modeling Ozone Levels in the Future

In order to evaluate the predicted air quality in 2020, it is necessary to use modeling to derive estimated air quality concentrations. The modeling analysis uses an emissions inventory and historical meteorological conditions to simulate pollutant concentrations. The predictions from the modeling are used to (a) project future ozone design values (a representation of the resultant air quality concentration in 2020 representing the 4th highest maximum 8-hr concentration) and (b) create spatial fields of ozone and $PM_{2.5}$ for characterizing human health impacts from reducing ozone precursors, which in the case of NOx will also affect the formation of $PM_{2.5}$. The air quality model used in this RIA is the Community Multi-Scale Air Quality (CMAQ) model[4]. The modeling for ozone and $PM_{2.5}$ was performed for a one year time period. All controls in the illustrative 0.070 scenario were applied similarly to all months. There were no controls applied

[3] U.S EPA. 2007. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. North Carolina. EPA-452/R-07-003.

[4] See CMAQ references listed at end of this chapter.

specifically for $PM_{2.5}$ co-benefits because the controls developed to reduce summer ozone were applied to all months (see Chapter 3).

2.3.1 CMAQ Model and Inputs

A national scale air quality modeling analysis was performed to estimate future year attainment/nonattainment of the current and alternative ozone standards. In addition, the model-based projections of ozone and $PM_{2.5}$ were used as inputs to the calculation of expected incremental benefits from the alternative ozone standards considered in this assessment. The 2002-based modeling platform (EPA, 2008) was used as the basis for air quality modeling of the future baseline emissions and illustrative control scenario. This modeling platform includes a number of updates and improvements to data and tools compared to the 2001-based platform that was used for the proposal modeling. For the final rule modeling we used the new 2002 National Emissions Inventory along with updated versions of the models used to project future emissions from electric generating units (EGUs) and onroad and nonroad vehicles. The proposal modeling was based on the 2001 National Emissions Inventory. The new platform also includes 2002 meteorology and more recent ambient design values which were used as the starting point for projecting future air quality. For proposal, we used meteorology for 2001 for modeling the East and 2002 for modeling the West. The updates[5] to CMAQ between proposal and final include (1) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH; (2) improved vertical convective mixing; (3) heterogeneous reaction involving nitrate formation; (4) an updated gas-phase chemistry mechanism, Carbon Bond 2005 (CB05); and (5) an aqueous chemistry mechanism that provides a comprehensive simulation of aerosol precursor oxidants.

The key non-emissions inputs to the CMAQ model include meteorological data, and initial and boundary concentrations. The CMAQ meteorological input files were derived from simulations of the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (Grell, Dudhia, and Stauffer, 1994). This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. The lateral boundary and initial species concentrations for the 36 km continental scale modeling domain, described below, were obtained from a three-dimensional global atmospheric chemistry model, the GEOSChem model (Yantosca, 2004). The global GEOSChem model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). We used GEOSChem results for 2002 to provide initial and boundary concentrations for our final rule air quality modeling. For proposal we used GEOSChem results for 2001.

EPA performed an extensive evaluation of CMAQ using the 2002 inputs for emissions, meteorology, and boundary conditions. Details of the model performance methodology and results are described in the 2002-Based Modeling Platform Report (EPA, 2008). As in the evaluation for previous model applications, the "acceptability" of model performance for the ozone RIA modeling was judged by comparing the results to those found in recent regional

[5] Additional documentation on the updates in CMAQ version 4.6 can be found at the following web site: http://www.cmascenter.org/.

ozone model applications for other EPA and non-EPA studies (see Appendix B of EPA, 2007b). Overall, the performance for the CMAQ application is generally within the range of these other applications.

Figure 2.1 shows the modeling domains that were used as a part of this analysis. The geographic specifications for these domains are provided in Table 2.1. All three modeling domains contain 14 vertical layers with a top at about 16,200 meters, or 100 mb. Two domains with 12 km horizontal resolution were used for modeling the 2002 base year, 2020 baseline and 2020 control strategy scenarios. These domains are labeled as the East and West 12 km domains in Figure 2.1. Simulations for the 36 km domain were only used to provide initial and boundary concentrations for the 12 km domains. As indicated above, the model produces spatial fields of gridded air quality concentrations on an hourly basis for the entire modeling domain. These gridded concentrations can be processed to produce a number of air quality metrics, including the 8-hr ozone design values, and can be used as inputs for the analysis of costs and benefits. The air quality modeling results are used in a relative sense to project concentrations for the future year scenarios using procedures consistent with EPA guidance (EPA, 2007b). For the final rule projections we used ambient design values for the period 2000 through 2004 as the starting point for projections. For the proposal, design values from 1999 through 2003 were used. The change between proposal and final in terms of the period of design values was made, in accordance with EPA guidance, in order to align the central year of design values with the base year of the emissions (i.e., 2001 for the proposed rule and 2002 for the final rule).

For this analysis, predictions from the East domain were used to provide data for all areas that are east of approximately 104 degrees longitude. Model predictions from the West domain we used for all areas west of this longitude.

Figure 2.1: Map of the CMAQ Modeling Domains Used for Ozone NAAQS RIA

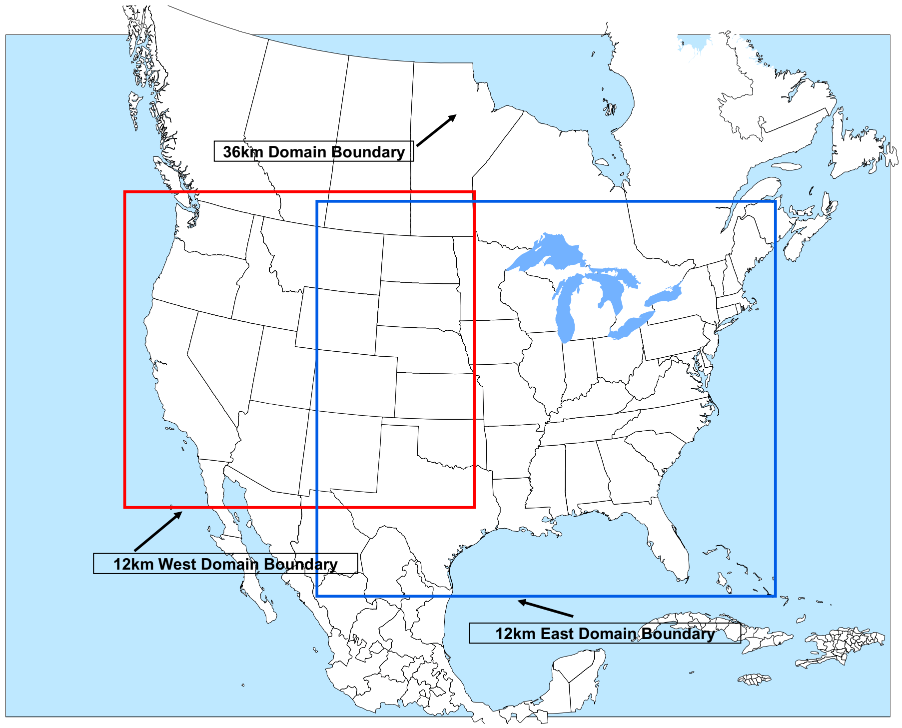

Table 2.1: Geographic Specifications of Modeling Domains

36 km Domain (148 x 112 Grid Cells)			12 km East Domain (279 x 240 Grid Cells)			12 km West Domain (213 x 192 Grid Cells)		
	Lon	lat		lon	lat		lon	lat
SW	−121.77	18.17	SW	−106.79	24.99	SW	−121.65	28.29
NE	−58.54	52.41	NE	−65.32	47.63	NE	−94.94	51.91

2.3.2 Emissions Inventory

The 2020 inventory, projected from the 2002 Version 3 emissions modeling platform (EPA, 2008), is the starting point for the baseline and control strategy for the Final Ozone NAAQS emissions inventory. The 2002 documentation describes the 2002 base year inventory as well as the projection methodology and controls applied to create year 2020 emissions. The 2020 inventory includes activity growth for some sectors, and controls including: the Clean Air Interstate Rule, the Clean Air Mercury Rule, the Clean Air Visibility Rule, the Clean Air Nonroad Diesel Rule, the Light-Duty Vehicle Tier 2 Rule, the Heavy Duty Diesel Rule, known plant closures, and consent decrees and settlements. Table 2.2 provides a comprehensive list of the rules/control strategies and projection assumptions in the 2020 inventory; full discussion of the 2020 inventory is provided in the 2002 Version 3 emissions modeling platform (EPA, 2008a). The data for the controls and projection strategies can be found in the Loco-Marine docket (EPA, 2008b).

Table 2.2: Control Strategies and Projection Assumptions in the 2020 Emissions Inventory

Control Strategies (Grouped by Affected Pollutants or Standard and Approach Used to Apply to the Inventory)	Pollutants Affected	Approach or Reference
Non-EGU Point Controls		
NOx SIP Call (Phase II): Cement Manufacturing Large Boiler/Turbine Units Large IC Engines	NOx	1
DOJ Settlements: plant SCC controls Alcoa, TX MOTIVA, DE	NOx, SO_2	2
Refinery Consent Decrees: plant/SCC controls	NOx, PM, SO_2	3
Closures, pre-2007: plant control of 100% Auto plants Pulp and Paper Municipal Waste Combustors Plants closed in preparation for 2005 inventory	all	4
Industrial Boiler/Process Heater plant/SCC controls for PM	PM	5
MACT rules, national, VOC: national applied by SCC, MACT Boat Manufacturing Polymers and Resins III (Phenolic Resins) Polymers and Resins IV (Phenolic Resins) Wood Building Products Surface Coating Generic MACT II: Spandex Production, Ethylene manufacture Large Appliances Miscellaneous Organic NESHAP (MON): Alkyd Resins, Chelating Agents, Explosives, Phthalate Plasicizers, Polyester Resins, Polymerized Vinylidene Chloride Manufacturing Nutritional Yeast Oil and Natural Gas Petroleum Refineries—Catalytic Cracking, Catalytic Reforming, & Sulfur Plant Units Pesticide Active Ingredient Production Publicly Owned Treatment Works Reinforced Plastics Rubber Tire Manufacturing Asphalt Processing & Roofing Combustion Sources at Kraft, Soda, and Sulfite Paper Mills Fabric Printing, Coating and Dyeing Iron & Steel Foundries Metal: Can, Coil Metal Furniture Miscellaneous Metal Parts & Products Municipal Solid Waste Landfills Paper and Other Web Plastic Parts Plywood and Composite Wood Products Wet Formed Fiberglass Production Wood Building Products Surface Coating Carbon Black Production Cellulose Products Manufacturing Cyanide Chemical Manufacturing	VOC	EPA, 2007f

(continued)

Table 2.2: Control Strategies and Projection Assumptions in the 2020 Emissions Inventory (continued)

Control Strategies (Grouped by Affected Pollutants or Standard and Approach Used to Apply to the Inventory)	Pollutants Affected	Approach or Reference
Friction Products Manufacturing Leather Finishing Operations Miscellaneous Coating Manufacturing Organic Liquids Distribution (Non-Gasoline) Refractory Products Manufacturing Sites Remediation		
Solid Waste Rules (Section 129d/111d) Hospital/Medical/Infectious Waste Incinerator Regulations	NOx, PM, SO_2	EPA, 2005
MACT rules, national, PM: Portland Cement Manufacturing Secondary Aluminum	PM	6
MACT rules, plant-level, VOC: Auto Plants	VOC	7
MACT rules, plant-level, PM & SO_2: Lime Manufacturing	PM, SO_2	8
MACT rules, plant-level, PM: Taconite Ore	PM	9
Stationary Non-point (Area) Assumptions		
Municipal Waste Landfills: projection factor of 0.25 applied	VOC	EPA, 2007f
Livestock Emissions Growth	NH_3, PM	10
Residential Wood Combustion Growth reflects increase in use of lower polluting wood stoves, and decrease in use of higher polluting stoves	all	11
Gasoline Stage II growth and control (also impacts non-EGU point sources in a couple of states)	VOC	12
Portable Fuel Container growth and control	VOC	13
EGU Point Controls		
CAIR/CAMR/CAVR IPM Model 3.0	NOx, SO_2, PM	14
Onroad Mobile and Nonroad Mobile Growth and Controls		
Onroad and Nonroad Growth: Onroad growth is based on VMT growth from Annual Energy Outlook (AEO) 2006 estimates of growth by vehicle type. Nonroad growth is based on activity increases from NONROAD model default growth estimates	all	
National Onroad Rules: Tier 2 Rule 2007 Onroad Heavy-Duty Rule Final Mobile Source Air Toxics Rule (MSAT2) Renewable Fuel Standard	all	
Local Onroad Programs: National Low Emission Vehicle Program (NLEV) Ozone Transport Commission (OTC) LEV Program	VOC	15

(continued)

Table 2.2: Control Strategies and Projection Assumptions in the 2020 Emissions Inventory (continued)

Control Strategies (Grouped by Affected Pollutants or Standard and Approach Used to Apply to the Inventory)	Pollutants Affected	Approach or Reference
National Nonroad Controls: Clean Air Nonroad Diesel Final Rule—Tier 4 Control of Emissions from Nonroad Large-Spark Ignition Engines and Recreational Engines (Marine and Land Based): "Pentathalon Rule"	all	16
Aircraft, Locomotives, and Commercial Marine Assumptions		
Aircraft: Itinerant (ITN) operations at airports	all	17
Locomotives: Energy Information Administration (EIA) fuel consumption projections for freight rail Clean Air Nonroad Diesel Final Rule—Tier 4 Locomotive Final Rulemaking, December 17, 1997	all	EPA, 2007e, 18
Commercial Marine: EIA fuel consumption projections for diesel-fueled vessels Freight-tonnage growth estimates fro residual-fueled vessels Clean Air Nonroad Diesel Final Rule—Tier 4 Emissions Standards for Commercial Marine Diesel Engines, December 29, 1999 Tier 1 Marine Diesel Engines, February 28, 2003	all	18, (EPA, 2007e)

APPROACHES:

1. Used *Emission Budget Inventories* report (EPA, 1999) for list of SCCs for application of controls, and for percent reductions (except IC Engines). Used Federal Register on Response to Court decisions (Federal Register, 2004) for IC Engine percent reductions and geographic applicability
2. For ALCOA consent decree, used http:// cfpub.epa.gov/compliance/cases/index.cfm; for MOTIVA: used information sent by State of Delaware
3. Used data provided by Brenda Shine, EPA, OAQPS
4. Closures obtained from EPA sector leads; most verified using the world wide web.
5. Used data list of plants provided by project lead from 2001-based platform; required mapping the 2001 plants to 2002 NEI plants due to plant id changes across inventory years
6. Same as used in CAIR, except added SCCs appeared to be covered by the rule: both reductions based on preamble to final rule. (Portland Cement used a weighted average across two processes)
7. Percent reductions recommended and plants to apply to reduction to were based on recommendations by rule lead engineer, and are consistent with the reference: EPA, 2007e
8. Percent reductions recommended are determined from the existing plant estimated baselines and estimated reductions as shown in the Federal Register Notice for the rule. SO2 % reduction will therefore be 6147/30,783 = 20% and PM10 and $PM_{2.5}$ reductions will both be 3786/13588 = 28%
9. Same approach used in CAIR: FR notice estimates reductions of "PM emissions by 10,538 tpy, a reduction of about 62%." Used same list of plants as were identified based on tonnage and SCC from CAIR.
10. Except for dairy cows and turkeys (no growth), based in animal population growth estimates from USDA and Food and Agriculture Policy and Research Institute.
11. Expected benefits of woodstoves change-out program: http://www.epa.gov/woodstoves/index.html
12. VOC emission ratios of year 2020 to year 2002 from the National Mobile Inventory Model (NMIM) results for onroad refueling including activity growth from VMT, Stage II control programs at gasoline stations, and phase in of newer vehicles with onboard Stage II vehicle controls.
13. VOC emission ratios of year 2020 to year 2002 from MSAT rule (EPA, 2007c, EPA, 2007d)
14. http://www.epa.gov/airmarkets/progsregs/epa-ipm/docs/summary2006.pdf
15. Only for states submitting these inputs: http://www.epa.gov/otaq/lev-nlev.htm
16. http://www.epa.gov/nonroad-diesel/2004fr.htm
17. Federal Aviation Administration (FAA) Terminal Area Forecast (TAF) System, February 2006: http://www.apo.data.faa.gov/main/taf.asp
18. http://www.epa.gov/nonroad-diesel/2004fr.htm

Differences between the 2020 emissions modeling platforms—particularly the inventories—used in the Ozone NAAQS Proposal and here in the Ozone NAAQS Final are discussed in the Appendix for Chapter 2.

The development of the 2020 baseline inventory and the modeled control scenarios are discussed in Chapter 3. The 2020 baseline inventory includes the same year 2020 Canada and year 1999 Mexico emissions as the Final PM NAAQS (EPA, 2006b).

2.4 References

Amar, P., R. Bornstein, H. Feldman, H. Jeffries, D. Steyn, R. Yamartino, and Y. Zhang. 2004. Final Report Summary: December 2003 Peer Review of the CMAQ Model. pp. 7.

Byun, D.W., and K.L. Schere. 2006. "Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System." *J. Applied Mechanics Reviews* 59(2):51-77.

Dennis, R.L., D.W. Byun, J.H. Novak, K.J. Galluppi, C.J. Coats, and M.A. Vouk. 1996. "The next generation of integrated air quality modeling: EPA's Models-3." *Atmospheric Environment* 30:1925-1938.

Grell, G., J. Dudhia, and D. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), *NCAR/TN-398+STR*., 138 pp, National Center for Atmospheric Research, Boulder CO.

Seinfeld, J.H. and S. N. Pandis, 1998: Atmospheric Chemistry and Physics. John Wiley & Sons, New York.

U.S. Environmental Protection Agency (EPA). 1999. "Science Algorithms of EPA Models-3 Community Multiscale Air Quality." (CMAQ Modeling System D.W. Byun and J.K.S. Ching, Eds. EPA/600/R-99/030, Office of Research and Development).

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

U.S. Environmental Protection Agency (EPA). 2006a. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF.

U.S. Environmental Protection Agency (EPA). 2006b. "Regulatory Impact Analysis for the Review of the Particulate Matter National Ambient Air Quality Standards (Chapter 2: Defining the $PM_{2.5}$ Air Quality Problem)." EPA-HQ-OAR-2006-0834-0048.3.

U.S. Environmental Protection Agency (EPA). 2007a. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. North Carolina. EPA-452/R-07-003.

U.S. Environmental Protection Agency (EPA). 2007b. "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze." EPA-454/B-07-002, http://www.epa.gov/scram001/guidance/guide/final-03-pm-rh-guidance.pdf.

U.S. Environmental Protection Agency (EPA). 2007c. *Regulatory Impact Analysis for Final Rule: Control of Hazardous Air Pollutants from Mobile Sources*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/420r07002.pdf.

U.S. Environmental Protection Agency (EPA). 2007d. *National Scale Modeling for the Final Mobile Source Air Toxics Rule*, Office of Air Quality Planning and Standards, Emissions Analysis and Monitoring Division, Research Triangle Park, NC 27711, EPA 454/R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/454r07002.pdf.

U.S. Environmental Protection Agency (EPA). 2007e. *Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder, Chapter 3: Emission Inventory*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105. EPA420-D-07-001, March 2007. Available at http://www.epa.gov/otaq/regs/nonroad/420d07001chp3.pdf.

U.S. Environmental Protection Agency (EPA). 2007f. *Guidance for Estimating VOC and NOx Emission Changes from MACT Rules,* U.S. Environmental Protection Agency Office of Air Quality Planning and Standards, Air Quality Policy Division, Research Triangle Park, NC 27711, EPA-457/B-07-001, May 2007. Available at http://www.epa.gov/ttn/naaqs/ozone/o3imp8hr/documents/guidance/200705_epa457_b-07-001_emission_changes_mact_rules.pdf.

U.S. Environmental Projections Agency (EPA). 2008a. Air Quality Modeling Platform for the Ozone National Ambient Air Quality Standard Final Rule Regulatory Impact Assessment.

U.S. Environmental Projections Agency (EPA). 2008b. Technical Support Document: Preparation of Emissions Inventories For the 2002-based Platform, Version 3, Criteria Air Pollutants, USEPA, January, 2008.

Yantosca, B. 2004. GEOS-CHEMv7-01-02 User's Guide, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, October 15, 2004.

Appendix 2: Additional Emissions Modeling Platform Information

2a.1 Discussion of Similarities and Differences Between Emissions Modeling Platforms Used in Ozone NAAQS Proposal and Final

All emissions modeling in the Ozone NAAQS Proposal was based off the 2001 emissions modeling platform. Version 3 of the 2002 emissions modeling platform (EPA, 2008) is used for the Final Ozone NAAQS. In both platforms, emissions are first projected to a year 2020 Base case. The following discusses similarities and differences in the 2001 and 2002 emission platforms, as well as assumptions used to project emissions to the year 2020.

2a.1.1 Similarities in the 2001 and 2002 Emissions Modeling Platforms

The 2001 and 2002 emissions platforms share the same Canada, Mexico, and offshore oil production emissions. Both platforms also share the same wildfire and prescribed burning emissions. Most input ancillary files used in the emissions processor are also unchanged; specifically, almost all cross-reference factors used in speciation profile assignments and temporal and spatial allocations are the same. The land use data for biogenic emissions (BELD3) is the same. The projection approach for stationary non-EGU emissions is also unchanged; however, for a couple of source categories, activity growth was slightly modified to account for the change in starting year -2002, rather than 2001. This effect on year 2020 activity (growth) factors is very small. Plant closures, consent decrees and settlements, and most national programs for stationary non-EGUs are applied as consistently as possible in 2002 as in 2001, by which, we used a cross-reference file to match controls for plants in the 2001 to the 2002 inventories.

2a.1.2 Key Changes to the Emissions Modeling Platform

As discussed in Chapter 2, the Final Ozone NAAQS utilizes the 2020 inventory, projected from the 2002 Version 3 emissions modeling platform. The Proposal utilized the 2001-based, projected to year 2020, "PM NAAQS" platform (EPA, 2006). The most significant change in the emissions modeling platform is the improvements to emissions estimates over multiple inventory sectors. See the 2002, Version 3 documentation for detailed information on these improvements. The SMOKE input ancillary data was updated to account for new source categories appearing in different inventory sectors; examples include farms and airports in the point source inventory and the new inclusion of portable fuel container emissions resulting from the Mobile Source Air Toxics (MSAT2) Rule (EPA, 2007a and 2007b). Another significant change in the emissions modeling platforms is the use of a new chemical mechanism -CB05 (Yarwood, 2005) versus CB-IV in the proposal platform.

Emissions by geographic area and by model platform in the base and future years are shown in Figure 2a.1 and Figure 2a.2, for NOx and VOC, respectively. "Northeast" in all figures represents the full OTC (Ozone Transport Commission) member states: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, and the District of Columbia. Emissions summaries from the northern counties of Virginia, while part of the OTC, are included in the "rest of US" geographic area. The "Midwest" geographic area includes Illinois, Indiana, Ohio, Michigan, and Wisconsin.

Figure 2a.1: Total Anthropogenic NOx Emissions [tons/year] by Year and Platform

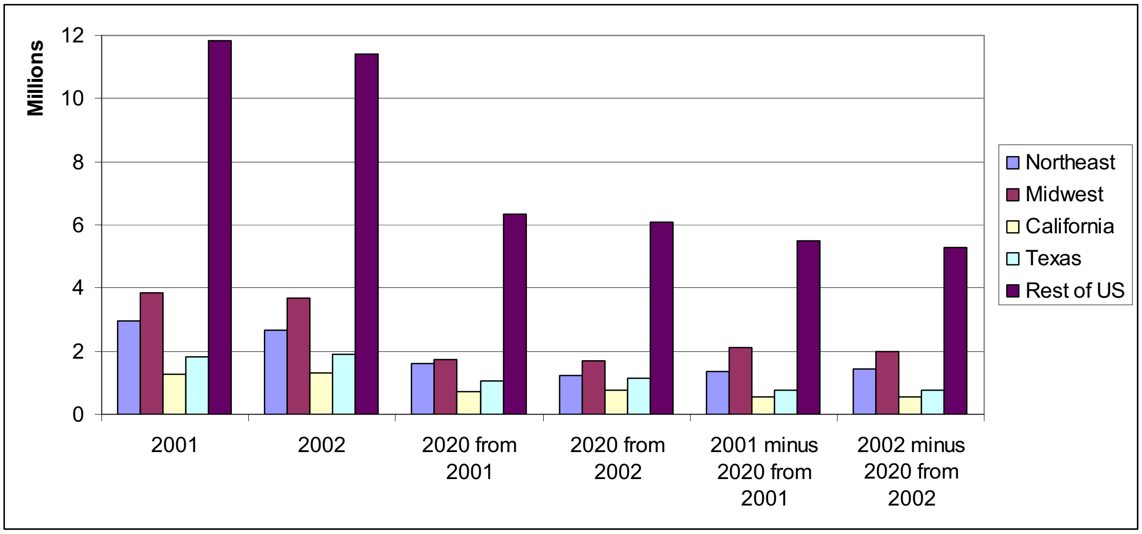

Figure 2a.2: Total Anthropogenic VOC Emissions [tons/year] by Year and Platform

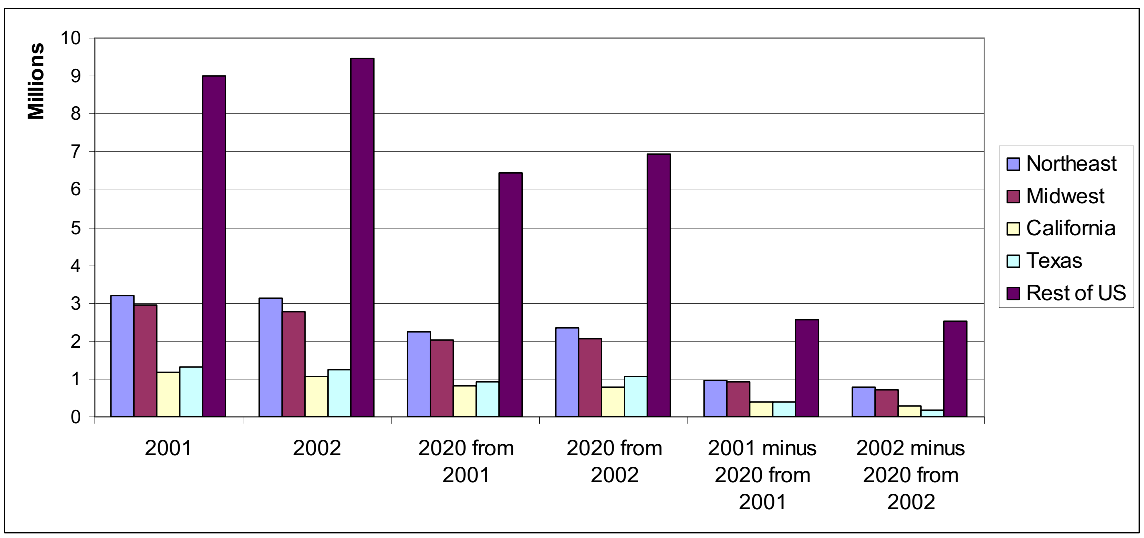

Figure 2a.1 and Figure 2a.2 demonstrate that total NOx and VOC emissions do not differ significantly by geographic area when comparing the inventories used in the proposal (2001) and final (2002). Small decreases in NOx and VOC are evident in the Northeast and Midwest, and small decreases in NOx are also seen in the rest of the US. In contrast, slight overall increases of NOx in Texas and VOC in the rest of the US can be seen.

Year 2020 emissions, projected from the 2001 and 2002 emission platforms show slightly less NOx in 2020 in the 2002-based platform in the Northeast, Midwest, and rest of the US. Perhaps most significant from an air quality modeling aspect is the relative change in emissions in 2020 when migrating from the 2001 to the 2002 emission platforms, represented by the last 2 sets of columns in Figure 2a.1 and Figure 2a.2. These show slightly less raw reductions in NOx and VOC for all regions with the exception of a very slight increase in NOx reductions in 2020-based-off-2002 in the Northeast and California. The net effect of these emission summaries is that large changes in air quality modeling ozone estimates are unlikely to be explained by significant changes in the overall emission changes by migrating from the 2001-based emissions platform in the proposal to the 2002-based emissions platform used in the final rulemaking.

Emissions inventory summaries broken down by sectors (e.g., EGU, non-EGU Point, Onroad Mobile, Nonroad Mobile…) also do not show any significant differences by geographic area for year 2020 between the 2001-based and 2002-based emission modeling platforms.

2a.2 References

U.S. Environmental Protection Agency (EPA). 2006. "Regulatory Impact Analysis for the Review of the Particulate Matter National Ambient Air Quality Standards (Chapter 2: Defining the PM 2.5 Air Quality Problem)." EPA-HQ-OAR-2006-0834-0048.3.

U.S. Environmental Protection Agency (EPA). 2007a. *Regulatory Impact Analysis for Final Rule: Control of Hazardous Air Pollutants from Mobile Sources*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/420r07002.pdf.

U.S. Environmental Protection Agency (EPA). 2007b. *National Scale Modeling for the Final Mobile Source Air Toxics Rule*, Office of Air Quality Planning and Standards, Emissions Analysis and Monitoring Division, Research Triangle Park, NC 27711, EPA 454/R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/454r07002.pdf.

U.S. Environmental Projections Agency (EPA). 2008. Air Quality Modeling Platform for the Ozone National Ambient Air Quality Standard Final Rule Regulatory Impact Assessment.

Yarwood, G., S. Rao, M. Yocke, and G. Whitten, 2005. Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the U.S. EPA, RT-0400675. Available at http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf.

Chapter 3: Modeled Control Strategy - Design and Analytical Results

Synopsis

In order to estimate the costs and benefits of alternate ozone standards, EPA has analyzed one possible hypothetical scenario to illustrate the control strategies that areas across the country might employ to attain an alternative more stringent primary standard of 0.070 ppm. We modeled the lower end of the range to capture a larger number of geographic areas that may be affected by a new ozone standard. Specifically, EPA has modeled the impact that additional emissions controls across numerous sectors would have on predicted ambient ozone concentrations, incremental to meeting the current $PM_{2.5}$ and ozone standards (baseline). 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 ozone standard should be implemented, and states will make all final decisions regarding implementation strategies once a final NAAQS has been set.

In order to model a hypothetical control strategy incremental to attainment of the current standard, EPA approached the analysis in stages. First, EPA identified controls to be included in the baseline. These included current state and federal programs (see) plus controls to attain the current ozone standard (Table 3.1) and $PM_{2.5}$ standards (see http://www.epa.gov/ttnecas1/ria.html for a complete list of controls). Then, EPA applied additional known controls within geographic areas designed to bring areas predicted to exceed 0.070 ppm in 2020 into attainment. This chapter presents the hypothetical modeled control strategy, the geographic areas where controls were applied, and the results of the modeling which predicted ozone concentrations in 2020 after application of the strategy. The strategy to attain a 0.070 ppm level was the only strategy modeled for air quality changes by EPA. EPA did not expect the modeled control strategy to result in attainment at 0.070 ppm everywhere, and the modeled control strategy did yield only partial attainment. Chapter 4 will explain how EPA used additional air quality modeling to estimate total annual tons/year of emissions reductions needed to achieve ozone concentrations for 0.075 ppm as well as the less stringent option of 0.079 ppm the and the more stringent options of 0.070 ppm and 0.065 ppm). Chapters 5 and 6 present the estimated costs and benefits of the modeled costs and benefits for partial attainment.

Because EPA's baseline indicated that some areas were not likely to be in attainment with the current standard by 2020 (0.08 ppm, effectively 0.084 ppm based on current rounding conventions)—(Figure 3.4) EPA expected that known controls would not be enough to bring those areas, and likely others, into attainment with 0.070 ppm in 2020. Modeling results showed that to be the case (see Figure 3.13).

Because it was impossible to meet either the current or any tighter ozone standard nationwide using only known controls, EPA conducted a second step in the analysis, and estimated the number of further tons of emission reductions needed to attain an alternate primary ozone standard (presented in Chapter 4). It is uncertain what controls States would put in place to attain a tighter standard, since additional control measures are not currently recognized as being commercially available. However, existing emissions inventories for the areas that were predicted to be in nonattainment after application of all known controls, do indicate that substantial amounts of ozone precursor emissions (i.e., tons of NOx or VOC) are available for control, pending future technology. Chapter 4 describes the methodology EPA used to estimate the amount of extrapolated tons necessary for control to reach attainment, and Chapters 5 and 6 present the extrapolation-based costs and benefits of achieving the reductions in ozone necessary to either fully or partially attain the standards in 2020, except for a few areas in California, which will be more fully explained in Chapter 4.

3.1 Establishing the Baseline

The regulatory impact analysis (RIA) is intended to evaluate the costs and benefits of reaching attainment with potential alternative ozone standards. In order to develop and evaluate a control strategy for attaining a more stringent (0.070 ppm) primary standard, it is important to first estimate ozone levels in 2020 given the current NAAQS standards and trends (more information is provided in Chapter 1). This scenario is known as the baseline. Establishing this baseline allows us to estimate the incremental costs and benefits of attaining any alternate primary standard.

This focus on the assessment of the incremental costs and benefits of attaining any alternative standard is an important difference from the focus of the risk assessment used in developing the standard. For purposes of the Staff Paper-risk assessment, risks are estimated associated with just meeting recent air quality and upon just meeting the current and alternative standards as well as incremental reductions in risks in going from the current standard to more stringent alternative standards. When considering risk estimates remaining upon attaining a given standard, EPA is only interested in the risks in excess of policy relevant background (PRB). PRB is defined in the ozone Criteria Document and Staff Paper as including (1) O3 in the U.S. from natural sources of emissions in the U.S., Canada, and Mexico, and (2) O3 in the U.S. from the transport of O3 or the transport of emissions from both natural and man-made sources, from outside of the U.S. and its neighboring countries (Staff Paper, p.2-54). Emissions of ozone precursors from natural sources (e.g., isoprenes emitted from trees) and from sources outside of the U.S. are uncertain, as are the specific impacts those emissions will have on ozone concentrations in areas exceeding alternative standards. Our models use available information on these emissions in generating future projections of baseline ozone concentrations, and our modeled reductions in U.S. emissions of NOx and VOC are based on these baseline levels that include the contribution of natural and non-U.S. emissions. To the extent that these emissions contribute a greater (lesser) proportion of ozone on high ozone days, more (less) reductions in emissions from U.S. sources might be required to reduce ozone levels below the analyzed alternative standards.

In contrast, the RIA only examines the incremental reduction, not the remaining risk, which results from changes in U.S. anthropogenic emissions. The air quality modeling used to establish the baseline for the RIA explicitly includes contributions from natural and anthropogenic emissions in Canada, Mexico, and other countries abroad, as well as the contributions to ozone levels from natural sources in the U.S. Since the RIA does not attempt to estimate the risk remaining upon meeting a given standard, and the alternative standards are clearly above the

Staff Paper estimates of PRB, we do not consider PRB a component of the RIA costs and benefits estimates.

In developing the baseline it was important to recognize that there are several areas that are not required to meet the current standard by 2020. The Clean Air Act allows areas with more significant air quality problems to take additional time to reach the current standard. Two areas in Southern California[1] are not planning to meet the current standard by 2020.

The baseline includes controls which EPA estimates need to be included to attain the current standard (0.08 ppm, effectively 0.084 ppm based on current rounding conventions) for 2020. Two steps were used to develop the baseline. First, the reductions expected in national ozone concentrations from national rules in effect or proposed today were considered, in addition to the controls applied as part of the $PM_{2.5}$ NAAQS RIA analysis. Second, since these reductions alone were not predicted to bring all areas into attainment with the tighter standard, EPA used a hypothetical control strategy to apply additional known controls. Additional control measures were used in five sectors to establish the baseline:[2] Non-Electricity Generating Unit Point Sources (NonEGUs), Non-Point Area Sources (Area), Onroad Mobile Sources and Nonroad Mobile Sources. A fifth sector was used in the subsequent control strategy for a tighter alternative standard: Electricity Generating Unit Point Sources (EGUs). Each of these sectors is defined below for clarity.

- NonEGU point sources are stationary sources that emit at least one criteria pollutant with emissions of 100 tons per year or higher. NonEGU point sources are found across a wide variety of industries, such as chemical manufacturing, cement manufacturing, petroleum refineries, and iron and steel mills.

- NonPoint Area Sources[3] (Area) 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.

- Onroad Mobile Sources are mobile sources that travel on roadways. These sources include automobiles, buses, trucks, and motorcycles traveling on roads and highways.

- Nonroad Mobile Sources[4] are any combustion engine that travels by other means than roadways. These sources include railroad locomotives; marine vessels; aircraft; off-road

[1]At the time of this analysis the South Coast and San Joaquin Valley air basins are expected to request a redesignation to extreme status for the current ozone standard.
[2] In establishing the baseline, EPA selected a set of cost-effective controls to simulate attainment of the current ozone and $PM_{2.5}$ standards. These control sets are hypothetical as states will ultimately determine controls as part of the SIP process.
[3] Areas Sources include the nonpoint emissions sector only.
[4] For the purposes of presentation nonroad mobile sources incorporates both the nonroad emissions sector and the aircraft, locomotive, and marine vessels emissions sector.

motorcycles; snowmobiles; pleasure craft; and farm, construction, industrial and lawn/garden equipment.

- Electricity Generating Unit Point Sources (EGUs) 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.

3.1.1 Control Measures Applied in the Baseline for Ozone Precursors

The purpose of identifying and modeling baseline controls for ozone precursors, NOx and VOC, is to reduce ambient ozone concentrations to meet the current ozone standard in this analysis. Control measures were applied in the baseline to reduce ozone concentrations in addition to the control set developed for the hypothetical national attainment strategy presented in the $PM_{2.5}$ NAAQS RIA (for more information, see http://www.epa.gov/ttn/ecas/ria.html).

The additional known controls included in the baseline to simulate attainment with current ozone NAAQS are listed in Table 3.1 and are described below. Details regarding the individual controls are provided in Appendix 3. Due to the extensive reductions from EGUs already implemented in CAIR/CAMR/CAVR, no additional EGU controls were included for the current ozone standard.

Controls included in the baseline for NonEGU point and Area sources came from a variety of geographic areas and scales. Almost all available controls in Chicago, Houston, and California were included in the baseline because these areas contain counties that were projected to be nonattainment of the current ozone NAAQS in 2020.

NOx controls from NonEGU point/Area sources were included in two ways. First, controls were included in counties with monitors that were projected to violate the current standard in 2020. Controls were then applied to all surrounding counties within the same state that were completely contained within 200 km[5] of the county containing the projected violating monitor (Figure 3.1). Second, controls were applied to large nonEGU point sources[6] outside the 200km buffer zones. The criteria for control was as follows: the plant level emissions exceeded 1,000 tons of NOx in 2020, the plant was in a county that touches the 200km buffer, and the plant was close to a nonattainment county that had difficulty attaining the baseline in the ozone NAAQS proposal RIA. VOC controls were applied to select counties where: VOC emissions were high (>5,000 tpy or >25tpy/sq. mi), the county design value was projected to be $\geq$ 0.08 ppm in the 2020 basecase, and the area had some historical evidence that VOC controls would appreciably lower ozone in the local region (Figure 3.2). This evidence came from internal EPA modeling or State-submitted modeling.

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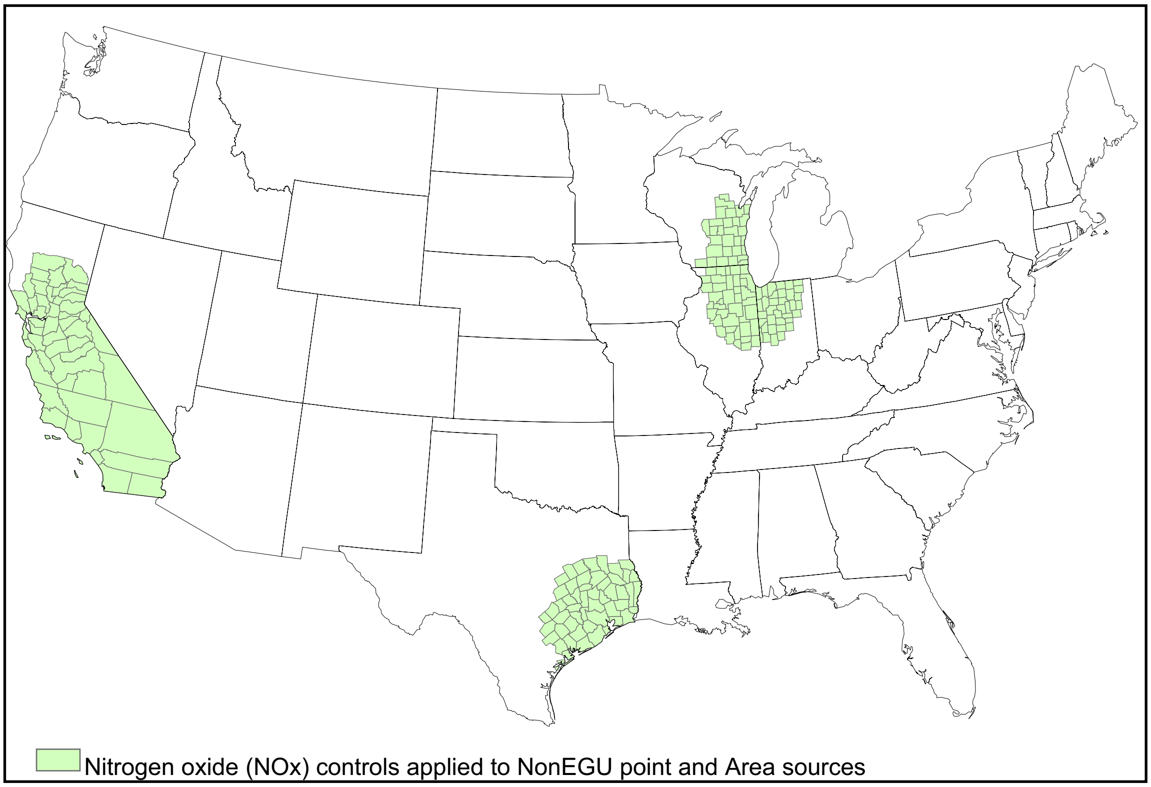
[5] It is a generic approximation used in this analysis for the sphere of possible emissions influence on air quality at the violating monitors. The actual area of emissions control is determined by states during attainment planning.
[6] Large point sources, due to the relative magnitude of emissions and high emissions stack heights, theoretically may impact air quality at a downwind violating monitor at distances beyond 200km.

Table 3.1: Controls for Current Ozone Standard by Sector Applied in the Baseline Determination for 2020

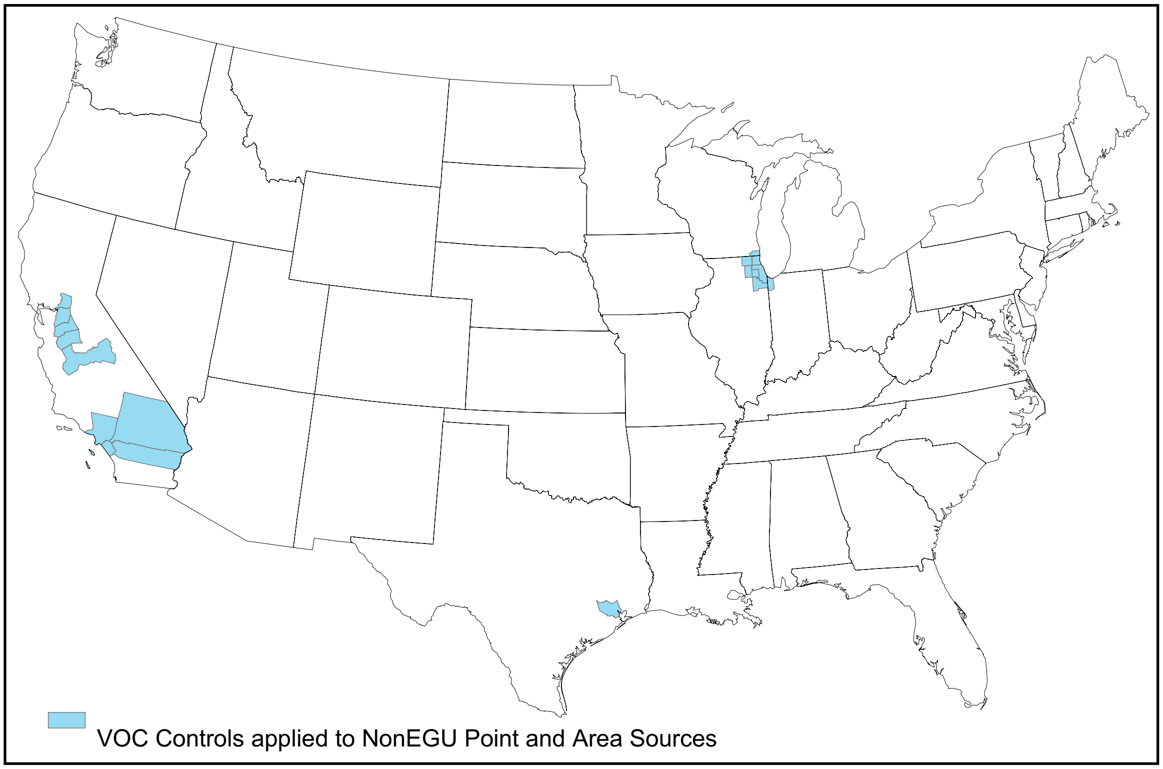
Sector	Control Measures	
	NOx	VOC
NonEGU Point	Biosolid Injection Technology LNB (Low NOx Burner) LNB + FGR (Flu Gas Recirculation) LNB + SCR (Selective Catalytic Reduction) NSCR (Non-selective Catalytic Reduction) OXY-Firing SCR SCR + Steam Injection SCR + Water Injection SNCR (Selective Non-catalytic Reduction) SNCR—Urea SNCR—Urea Based	Permanent Total Enclosure (PTE) Work Practices, Use of Low VOC Coatings (NonEGU Point Sources)
Area	RACT to 25 tpy (LNB) Switch to Low Sulfur Fuel Water Heater + LNB Space Heaters	CARB Long-Term Limits Catalytic Oxidizer Equipment and Maintenance Gas Collection (SCAQMD/BAAQMD) Incineration >100,000 lbs bread Low Pressure/Vacuum Relief Valve OTC Mobile Equipment Repair and Refinishing Rule OTC Solvent Cleaning Rule SCAQMD—Low VOC SCAQMD Limits SCAQMD Rule 1168 Work Practices, Use of Low VOC Coatings (Area Sources) Switch to Emulsified Asphalts
Onroad Mobile	Diesel Retrofits Reduce Gasoline Reid Vapor Pressure (RVP) to 7.0 (EPA, 2005a) Elimination of Long Duration Idling Continuous Inspection and Maintenance Commuter Programs Additional Technology Changes in the Onroad Transportation Sector	
Nonroad Mobile	Diesel Retrofits and Engine Rebuilds Reduce Gasoline Reid Vapor Pressure (RVP) to 7.0 (EPA, 2005a) Aircraft NOx International Standard	
EGU	None	None

Figure 3.1: Counties Where Controls for Nitrogen Oxides (NOx) Were Included for NonEGU Point and Area Sources, for the Current Ozone Standard in the Baseline



For the Onroad and Nonroad Mobile source sectors, some controls were applied nationwide for the current ozone standard in the baseline, while others were applied statewide in certain states or locally in a limited number of counties (see Figure 3.3). Counties were identified for locally applied Mobile source controls as follows: counties projected to have a monitor that exceeded the current standard were surrounded by a 200km buffer zone, and controls were included in the counties within this buffer that were within the same state as the exceeding monitor. Where some control measures overlapped for a given county, controls with the lowest costs were generally included first. Both onroad and nonroad diesel retrofits and idling elimination were included in California with an assumed 75% market penetration, and in baseline reduction areas outside of California with an assumed 25% market penetration. EPA determined that 25% would have a significant impact, but was feasible to achieve and was applied for reduction areas outside of California. EPA further determined that for southern California a 75% level of reduction could be achieved, which was the highest cost-effective penetration rate that EPA felt could be reasonably accomplished.

Figure 3.2: Counties Where Controls for Volatile Organic Chemicals (VOCs) Were Applied to NonEGU Point and Area Sources for the Current Ozone Standard in the Baseline

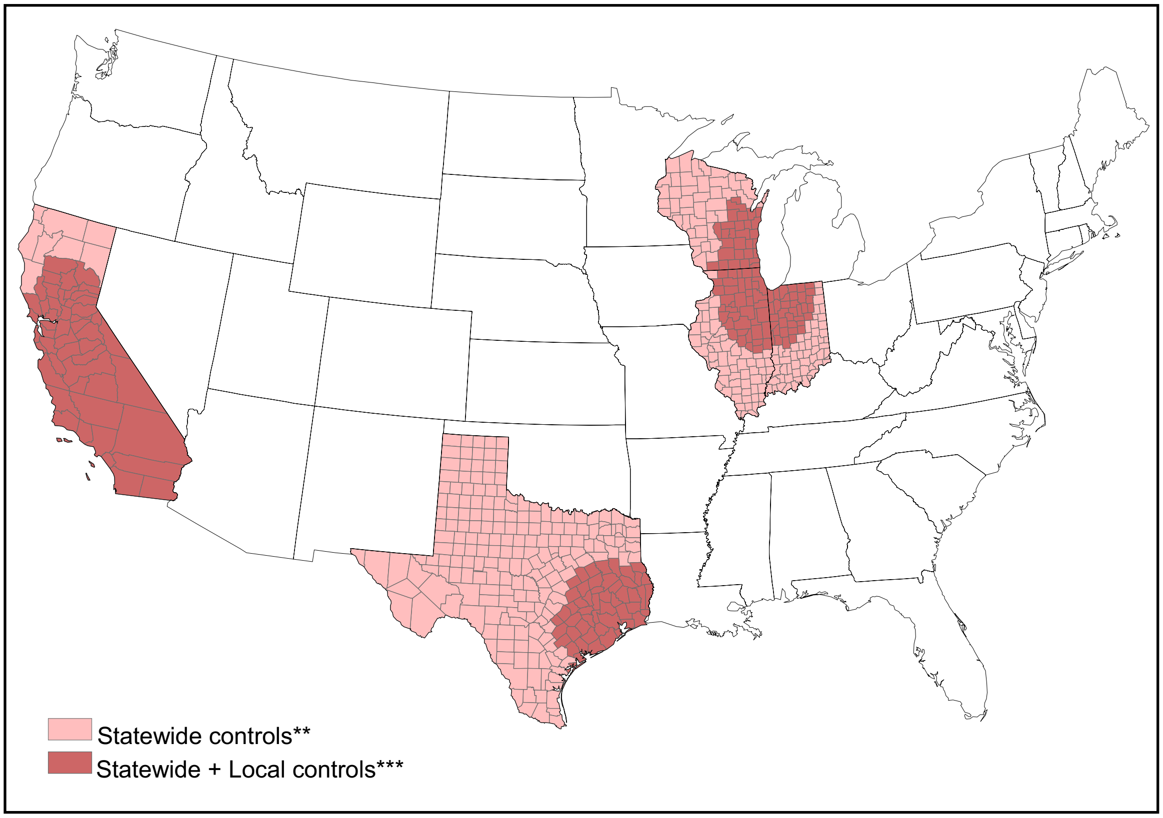


3.1.2 Ozone Levels for Baseline

Establishing the baseline required design values (predicted concentrations) of ozone across the country. Because the intention of this evaluation was to achieve attainment of the current ozone standard, controls were included to reduce ambient ozone concentrations to 0.08 ppm (effectively 0.084 ppm based on current rounding conventions). A map of the country is presented in Figure 3.4, which shows predicted concentrations for the 661 counties with ozone monitors. Projections of ozone design values were developed according to procedures outlined in EPA modeling guidance.[7,8]

[7] Available online at: http://www.epa.gov/scram001/guidance/guide/final-03-pm-rh-guidance.pdf
[8] As part of the procedure for projecting future ozone design values, the guidance recommends using a criterion that there be a minimum of 5 modeled days with predicted base year ozone at or above 0.070 ppm. This criterion was relaxed to a minimum of 1 day at or above 0.060 ppm for the 82 counties with fewer than 5 days with predicted 2002 concentrations at or above 0.070 ppm.

Figure 3.3: Areas Where NOx and VOC Controls Were Included for Mobile Onroad and Nonroad Sources in Addition to National Mobile Controls* for the Current Ozone Standard in the Baseline



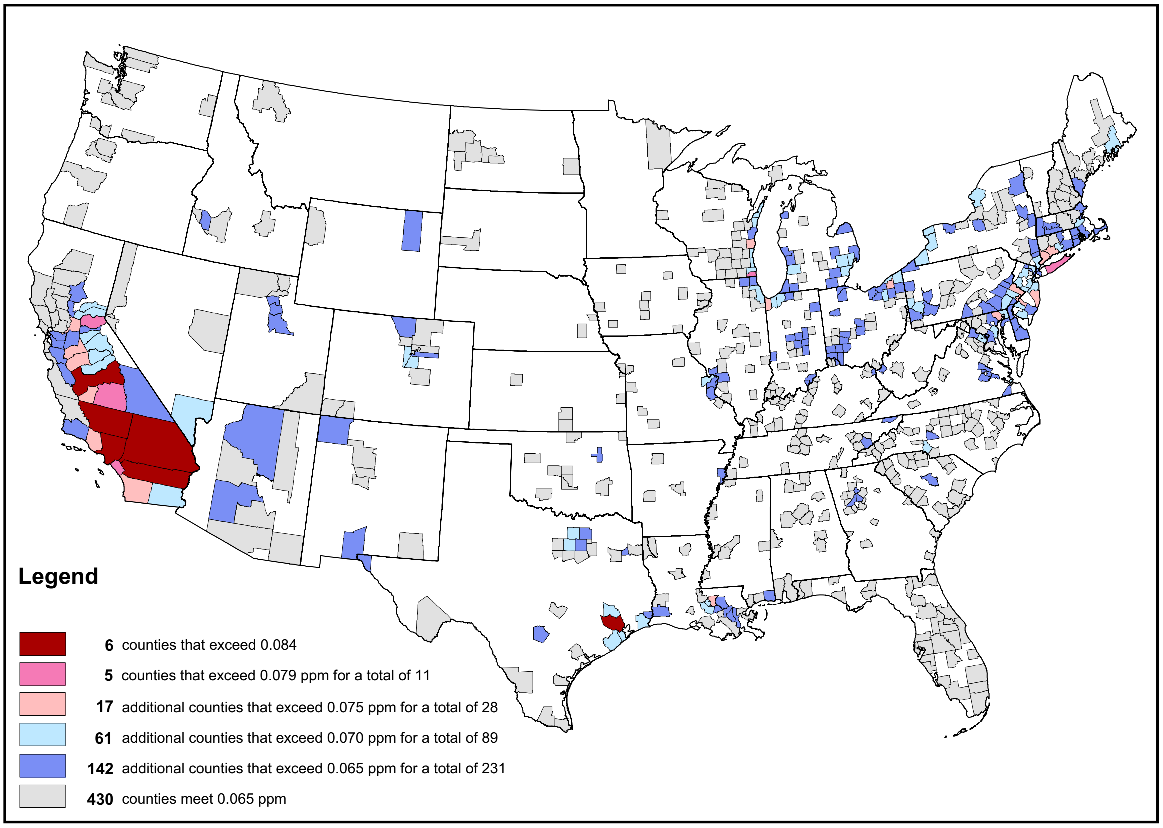
* International Aircraft NOx Standard, national control measures applied as part of the PM NAAQS RIA, and Additional Technology Changes in the Onroad Transportation Sector.

**Onroad retrofits, elimination of long duration idling, and lower Reid Vapor Pressure (RVP) gasoline.

***Nonroad retrofits, continuous inspection and maintenance, and commuter programs.

The baseline shows that 6 counties would not meet the current ozone standard in 2020, even after inclusion of all known controls. Of these 6 counties, 5 of them are in portions of California that have current state implementation plans that reflect an attainment date of 2024. After including known controls as described above, the analysis predicted that the remaining 655 counties would attain the current standard by 2020. The baseline forms the foundation for the cost-benefit analysis conducted in this RIA, where EPA compares more stringent primary ozone standard alternatives incrementally to national attainment of the current standard.

Figure 3.4: Baseline Projected 8-Hour Ozone Air Quality in 2020[a, b, c, d]



[a] Modeled emissions reflect the expected reductions from federal programs including the Clean Air Interstate Rule (EPA, 2005b), the Clean Air Mercury Rule (EPA, 2005c), the Clean Air Visibility Rule (EPA, 2005d), 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 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.

[b] Controls applied are illustrative. States may choose to apply different control strategies for implementation.

[c] The current standard of 0.08 ppm is effectively expressed as 0.084 ppm when rounding conventions are applied.

[d] Modeled design values in ppm are only interpreted up to 3 decimal places.

3.1.3 National Baseline Sensitivity Analysis

Circular A-4 of the Office of Management and Budget's (OMB) guidance under Executive Order 12866 defines a no-action baseline as "what the world will be like if the proposed rule is not adopted." The illustrative analysis in this RIA assesses the costs and benefits of moving from this "no-action" baseline to a suite of possible new standards. Circular A-4 states that the choice of an appropriate baseline may require consideration of a wide range of potential factors, including:

- evolution of the market,

- changes in external factors affecting expected benefits and costs,
- changes in regulations promulgated by the agency or other government entities, and
- the degree of compliance by regulated entities with other regulations (OMB, 2003).

Circular A-4 also recommends that:

> "When more than one baseline is reasonable and the choice of baseline will significantly affect estimated benefits and costs, you should consider measuring benefits and costs against alternative baselines. In doing so you can analyze the effects on benefits and costs of making different assumptions about other agencies' regulations, or the degree of compliance with your own existing rules." (OMB 2003)

In Appendix 7a, we describe a sensitivity analysis that we conducted to provide information about how the no-action baseline would differ under different assumptions about mobile technologies. It also assesses nationally what the change would be to costs and benefits of a new standard of 0.075 ppm and alternate primary standards of 0.079, 0.070, and 0.065 ppm. See Appendix 7a for more details.

3.2 Developing the Modeled Control Strategy Analysis

After developing the baseline, EPA developed a hypothetical control strategy to illustrate one possible national control strategy that could be adopted to reach an alternative primary standard by 2020. The stricter standard alternative of 0.070 ppm was chosen as being representative of the set of alternatives being considered by EPA in its notice of proposed rulemaking on the ozone NAAQS. The 2020 baseline air quality modeling for proposal resulted in 203 counties with projected design values exceeding 0.070 ppm. In the final rule modeling of the 2020 baseline there are 89 counties projected to exceed 0.070 ppm. The reduction in the number of counties projected to exceed 0.070 between proposal and final reflects the net effect of the updates to the air quality modeling platform, as described in Chapter 2, and the additional emissions controls in the final rule baseline modeling compared to proposal.

Controls for five sectors were used in developing the control analysis, as discussed previously: nonEGU point, Area, onroad mobile and nonroad mobile, along with EGUs. Reductions in both NOx and VOC ozone precursors were needed in all sectors to meet a tighter standard.

As depicted in the flow diagram in Figure 1.1, the control strategy modeled in this RIA first applied known controls to reach attainment. For the control strategy, controls for five sectors were used in developing the control analysis, as discussed previously: nonEGU point, Area, onroad mobile and nonroad mobile, along with EGUs. Reductions in both NOx and VOC ozone precursors were needed in all sectors to meet a tighter standard. The emissions for this control strategy were input to the CMAQ model as part of the process to project ozone design values for the 2020 control strategy. The results of modeling the control strategy indicate that there were some areas projected not to attain 0.070 ppm in 2020 using all known control measures. To complete the analysis, EPA was then required to extrapolate the additional emission reductions required to reach attainment. The methodology used to develop those estimates and those calculations are presented in Chapter 4. Appendix 7a presents a sensitivity analysis of three mobile source control measures that could be included in the control strategy to illustrate attainment.

Table 3.2: Controls Applied, by Sector, for the 0.070 ppm Control Strategy (Incremental to Baseline)

Sector	Control Measures	
	NOx	**VOC**
NonEGU Point	Biosolid Injection Technology LNB (Low NOx Burner) LNB + FGR (Flu Gas Recirculation) LNB + SCR (Selective Catalytic Reduction) NSCR (Non-selective Catalytic Reduction) OXY-Firing SCR SCR + Steam Injection SCR + Water Injection SNCR (Selective Non-catalytic Reduction) SNCR—Urea SNCR—Urea Based	Permanent Total Enclosure (PTE) Work Practices, Use of Low VOC Coatings (NonEGU Point Sources)
Area	RACT to 25 tpy (LNB) Switch to Low Sulfur Fuel Water Heater + LNB Space Heaters	CARB Long-Term Limits Catalytic Oxidizer Equipment and Maintenance Gas Collection (SCAQMD/BAAQMD) Incineration >100,000 lbs bread Low Pressure/Vacuum Relief Valve OTC Mobile Equipment Repair and Refinishing Rule OTC Solvent Cleaning Rule SCAQMD—Low VOC SCAQMD Limits SCAQMD Rule 1168 Work Practices, Use of Low VOC Coatings (Area Sources) Switch to Emulsified Asphalts
Onroad Mobile[a]	Increased Penetration of Onroad SCR and DPF from 25% to 75% Continuous Inspection and Maintenance (OBD)	
Nonroad Mobile[a]	Increased Penetration of Nonroad SCR and DPF from 25% to 75%	
EGU	-Lower ozone season nested caps in OTC and MWRPO states while retaining the current CAIR cap and a new cap for Eastern Texas. -Application of local controls (SCR and SNCR) nationally to coal fired units in and around NA counties covering the combination of CBSA (Core based Statistical Areas) and CSA (Combined Statistical Areas)B outside of OTC and, MWRPO, and East Texas.	None

[a] Onroad and Nonroad Mobile Source control measures applied for the Baseline analysis were applied to additional geographic areas in the 0.070 ppm analysis. SCR and DPF retrofits market penetration was increased from 25% to 75% for all areas outside of California.

[b] For the definition and current lists of CBSA and CSAs, see http://www.census.gov/population/www/estimates/metrodef.html

3.2.1 Controls Applied for the Modeled Control Strategy: NonEGU Point and Area Sectors

NonEGU point and Area control measures were identified using AirControlNET 4.1.[9,10] To reduce NOx and VOC emissions, all known control measures, below a cost cap, were applied, allowing for the largest emission reduction per source over the widest geographic area. Because all available controls up to the cost cap were used in counties needing emission reductions, ordering of which controls were applied first was not relevant. In areas where residual nonattainment remained after the modeled control strategy, some known controls above the cost cap were analyzed and applied to achieve additional emissions reductions as a portion of the extrapolated cost analysis. See Chapter 5 for more information on how we selected our cost cap and the extrapolated cost analysis.

Supplemental controls, which estimated additional emissions control based on similar technology for NonEGU point and Areas sources were included in the analysis prior to the extrapolating costs of unknown controls. Supplemental controls are described in further detail in Appendix 3.

NOx nonEGU point and Area controls were applied to counties that were projected to have concentrations of greater than 0.070 ppm in the 2020 baseline. Additional controls were applied in surrounding counties within 200 km of the county projected to be out of attainment (at 0.070 ppm), but not crossing state boundaries. In addition, controls were applied to large nonEGU point sources outside the 200km buffer zones. The criteria for control of these large nonEGU point sources was as follows: the plant level emissions exceeded 1,000 tons of NOx in 2020, the plant was in a county that touches the 200km buffer, and the plant was close to a nonattainment county that had difficulty attaining 0.070 ppm in the ozone NAAQS proposal RIA.

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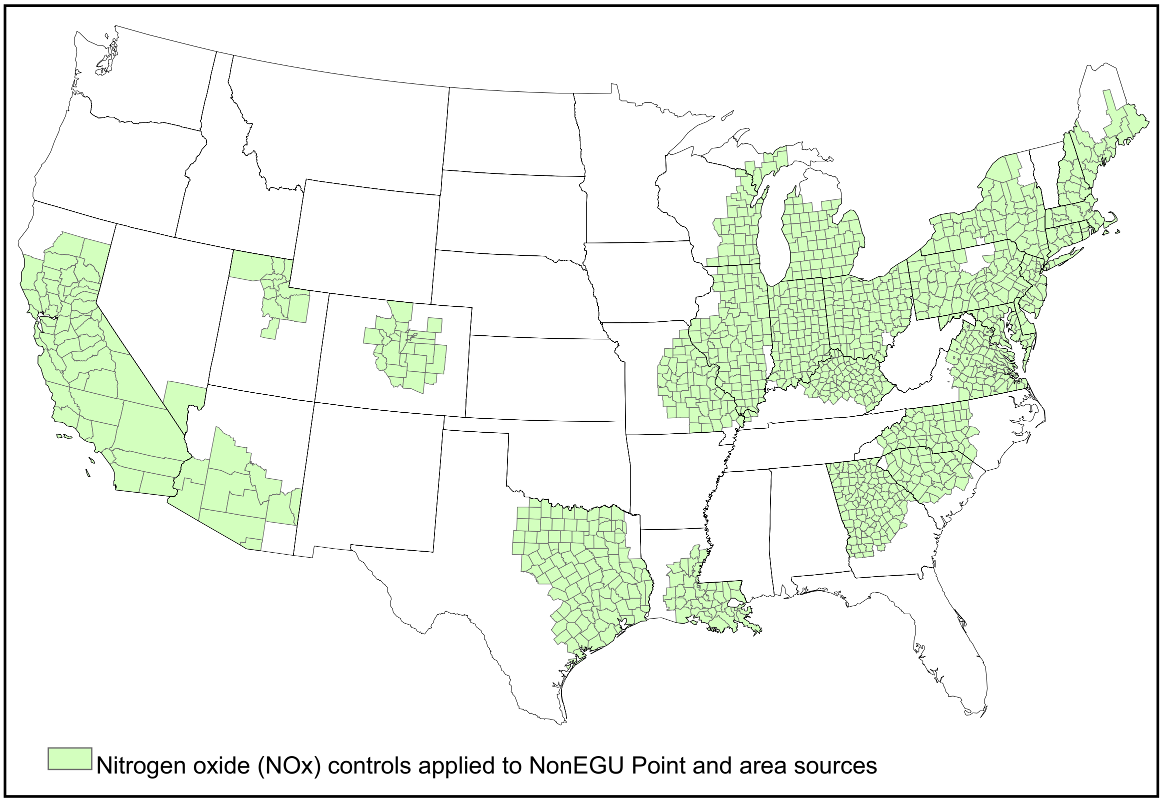
[9] See http://www.epa.gov/ttnecas1/AirControlNET.htm for a description of how AirControlNET operates and what data is included in this tool.

[10] 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 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.

Figure 3.5: Counties Where Controls for Nitrogen Oxides (NOx) Were Applied to NonEGU Point and Areas Sources for the RIA Modeled Control Strategy (Incremental to Baseline)



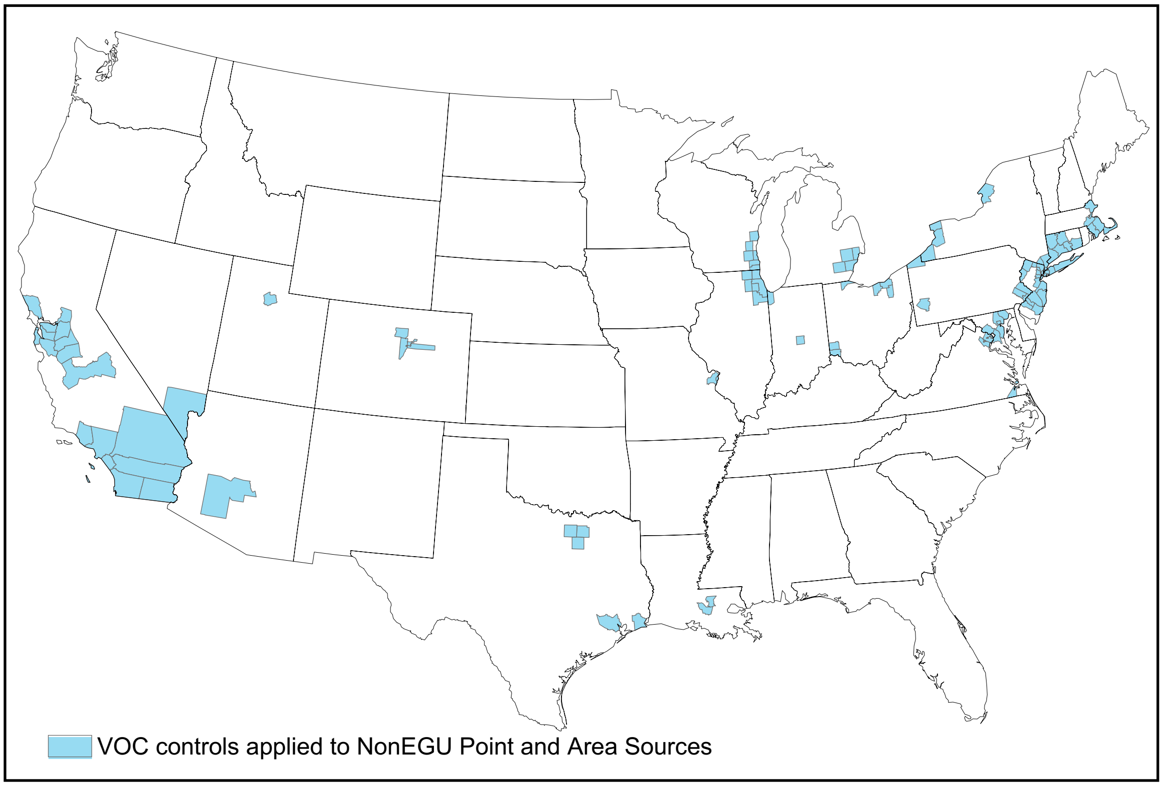
VOC controls were applied in select counties where the following criteria were met (including the counties which included VOC controls in their baselines): VOC emissions were high (>5,000 tpy or >25tpy/sq. mi), the county design value was projected to be ≥ 0.070 ppm in the 2020 (See Figure 3.6), and the area had some historical evidence that VOC controls would appreciably lower ozone in the local region. This evidence came from internal EPA modeling or State-submitted modeling.

3.2.2 Controls Applied for the Modeled Control Strategy: EGU Sector

In the Proposal RIA, a control strategy was applied for the EGU sector for the East only, (EGU controls for the West were already included in the ozone baseline since they were applied for the hypothetical national control strategy in the PM NAAQS RIA.) In the proposed RIA, emissions reductions were targeted in the OTC and MWRPO states through lower "nested caps" and "command and control" application in the non-attainment counties outside of the OTC and MWRPO within CAIR.

For the Final RIA, we have employed an enhanced strategy, both in terms of the quantity of reductions and the geographic extent of the areas covered. Figure 3.7 depicts the areas covered for the EGU sector emission reduction strategy.

Figure 3.6: Counties Where VOC Controls Were Applied to NonEGU Point and Areas Sources for the Modeled Control (Incremental to Baseline)



Annual and ozone season CAIR caps remained unchanged, but coal-fired units were targeted for this shifted strategy within those caps. This strategy was appropriate to consider because transport of NOx pollution is more of a concern in the East, and NOx from EGUs still accounts for a significant portion of emissions in this region. California, while in need of reductions as well, was not included in this strategy because all known controls (including EGU controls) had already been applied in the baseline. The development of an EGU-component to this control strategy was based exclusively on NOx emissions during the ozone season, although the hypothetical controls applied would operate year-round. The EGU sector used the Integrated Planning Model (IPM) to evaluate the reductions that are predicted from a specific control strategy. Details of this tool and subsequent analysis can be found in Appendix 3.4.

Reductions in the EGU sector are influenced significantly by the 2003 Clean Air Interstate Rule (CAIR) (see Appendix 3.4 for more details on CAIR). CAIR will bring significant emission reductions in NOx, and a result, ambient ozone concentrations in the eastern U.S. by 2020.[11] A map of the CAIR region is presented in Appendix 3.4. Emissions and air quality impacts of CAIR are documented in detail in the Regulatory Impact Analysis of the Final Clean Air Interstate Rule.[12]

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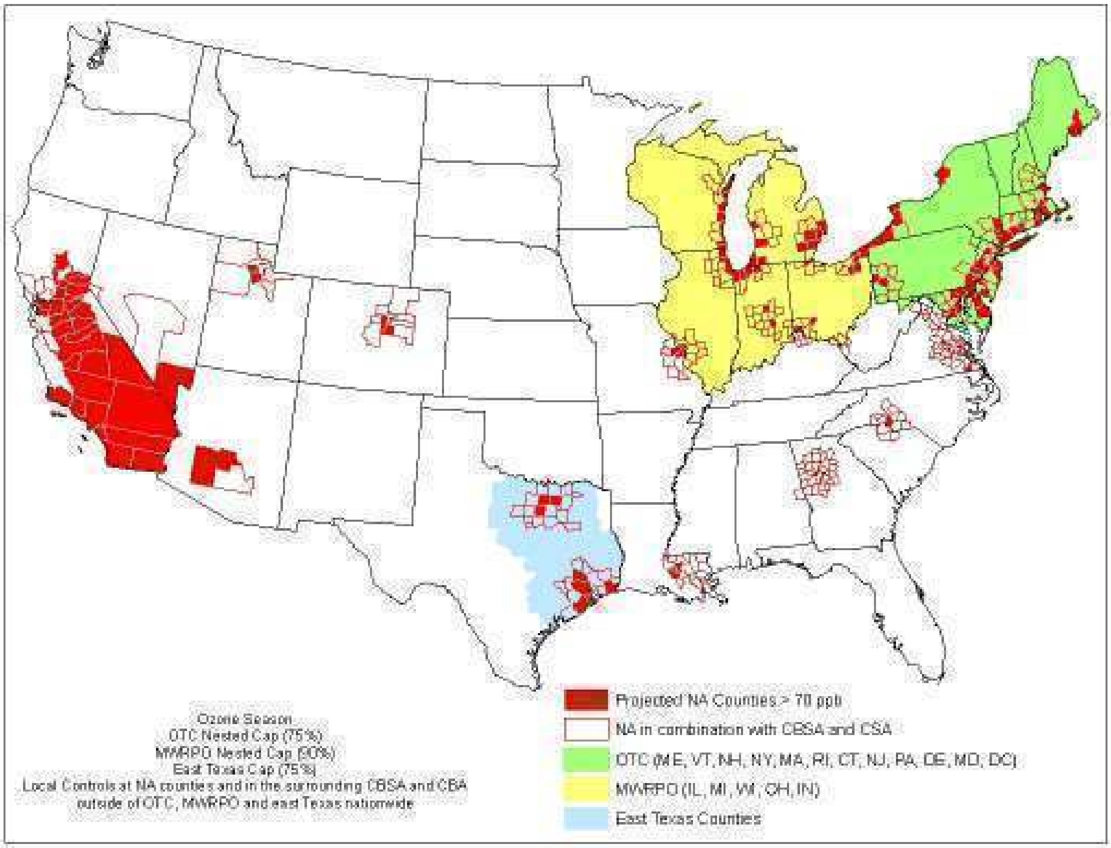
[11] See http://www.epa.gov/airmarkets/progress/progress-reports.html for more information
[12] See http://www.epa.gov/CAIR/technical.html

Figure 3.7: Geographic Areas where NOx Controls were Applied to Electrical Generating Units (EGUs) for the Modeled Control Strategy (Incremental to Baseline)



To address nonattainment in the CAIR region (especially the Midwest, Mid-Atlantic,, and Northeast), and East Texas[13] lower nested ozone season caps (a limit lower than the current CAIR cap) were applied in these areas for NOx, while holding the CAIR cap unchanged for the entire region. This provides an opportunity to reduce emissions in a cost effective manner in targeted regions. Three geographic regions were targeted for cap-and-trade type emissions reductions: the Midwest Regional Planning Organization (MWRPO) consisting WI, IL, IN, MI, and OH; and the Ozone Transport Commission (OTC), consisting of DC, MD, PA, DE, NJ, CT, NY, RI, MA, VT, NH, and ME; and East Texas consisting the counties shown in Figure 3.7. These areas were chosen because the MWRPO and OTC states are currently investigating ways of reducing EGU emissions further in their states and because most of the potential ozone nonattainment areas are found within these two regions. East Texas has also non-attainment areas, and the state is looking for strategies to reduce emissions. Considering transport, as well as the local effects, reducing emissions in these areas is expected to help bringing the Lake Michigan and Northeast corridor as well as East Texas non-attainment areas into attainment.

Lower nested caps were applied in the MWRPO and OTC states and in East Texas, for the ozone season only. The caps that were applied lead to reductions that could be obtained by installing

[13] East Texas geographic area was defined to be identical to the geographic area for other sectors.

post-combustion controls, such as Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR), to all of the coal-fired units that were not projected to have previously installed post-combustion controls in the base-case. Following this, 75% of the reducti[14]on that could be obtained from these units was subtracted from the sum of State level ozone control season NOx caps for the OTC and East Texas regions, and 90% for the MWRPO states in CAIR.[15] The CAIR cap for the entire region was kept unchanged.

In order to address nonattainment elsewhere in the West and CAIR region outside of the MWRPO, and OTC, and East Texas a "command and control" type strategy for coal-fired units has been designed. Annual and ozone season CAIR caps remained unchanged in the East, and coal-fired units were targeted for this reduction. Preliminary analysis showed that most of the needed NOx reductions in the EGU sector can be achieved through application of post-combustion controls on coal units that are projected to remain without controls under the CAIR/CAMR/CAVR cap-and-trade scheme. All non-attainment areas nationwide, outside of the OTC, MWRPO, and East Texas were subject to this local command-and-control strategy, covering the CBSA and CSA counties in and around nonattainment counties.

At this time, ***we are in the process of improving our ability to achieve additional reductions available in NOx emissions from EGUs and corresponding air quality benefits, especially on high energy demand days (HEDDs) through energy efficiency measures. We were not able to apply such control strategies as part of this RIA. A Technical Support Document (TSD) is available summarizing the previous and ongoing work in this area.***

3.2.3 Controls Applied for the Modeled Control Strategy: Onroad and Nonroad Mobile Sectors

As in other sectors, there are several mobile source control strategies that have been, or are expected to be, implemented through previous national or regional rules. Although many expected reductions from these rules are included in the baseline, additional mobile source controls were required to illustrate attainment of an alternate primary standard (See Figure 3.8). Information on mobile source control measures for the modeled control strategy analysis were derived from various EPA studies and from running EPA's National Mobile Inventory Model (NMIM), which includes the MOBILE6 Onroad model and the NONROAD model. See www.epa.gov/otaq/nmim.htm for more information on NMIM and see Appendix 3.3 for more information on mobile source controls included in the modeled control strategy analysis.

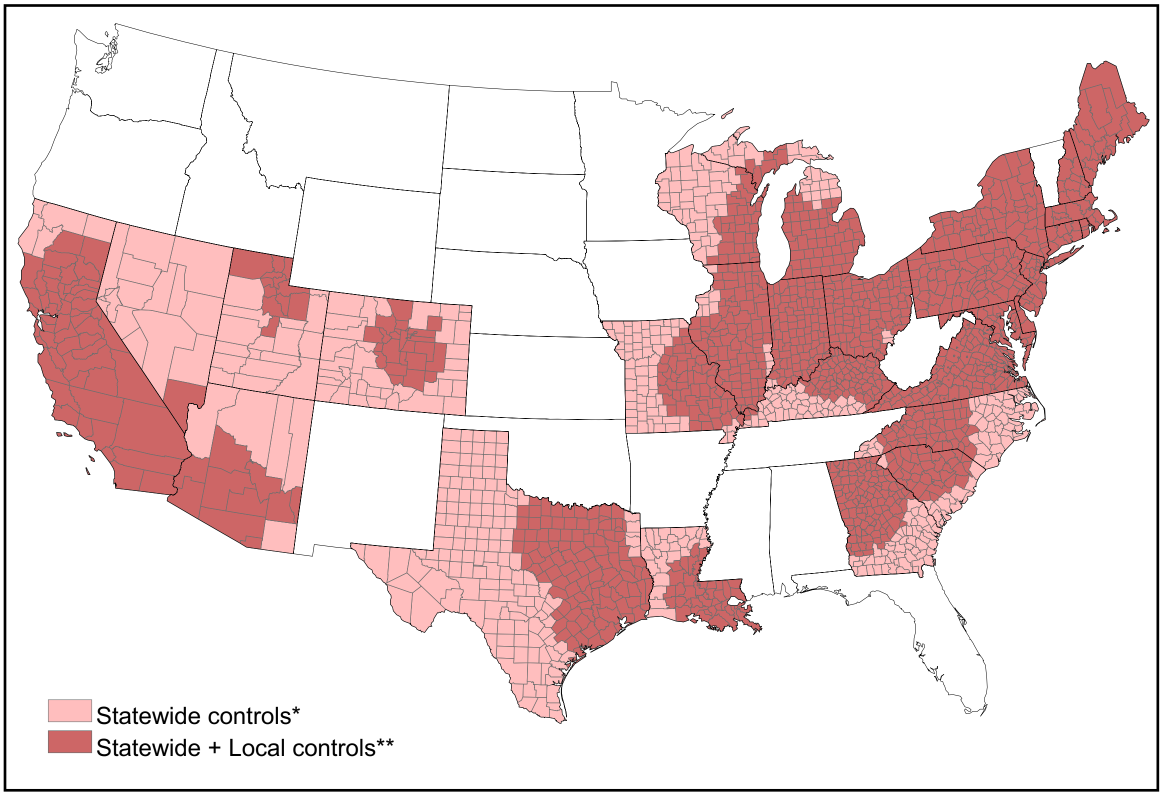
All of the local mobile source controls included in the ozone baseline were expanded for the hypothetical national control strategy to attain an alternate primary standard. In the case of onroad and nonroad Selective Catalytic Reduction (SCR) and Diesel Particulate Filters (DPF),

[14] Potential for Reducing NOx Emissions from EGU Sources on High Energy Demand Days with Energy Efficiency Measures. Technical Support Document for the Final Ozone NAAQS Regulatory Impact Analysis. U.S. Environmental Protection Agency, Office of Air and Radiation. March 2008.

[15] Detailed analysis showed that 75%–90% reduction provides the most cost-effective way of reducing emissions at the targeted non-attainment areas, considering transport, with the most air quality impacts.

the measure was applied at a greater penetration rate—to 75% of the modeled equipment population. 75% was the highest cost-effective penetration rate that EPA felt could be reasonably accomplished. All local and statewide measures were applied to sources in additional geographic areas beyond the areas controlled in the baseline. Descriptions of the mobile source rules and measures can be found in Appendix 3.3.

Figure 3.8: Areas Where NOx and VOC Controls Were Applied to Mobile Onroad and Nonroad Sources in Addition to National Mobile Controls for the Modeled Control Strategy (incremental to Baseline)



*Onroad retrofits, elimination of long duration idling, and lower Reid Vapor Pressure (RVP) gasoline.

**Nonroad retrofits, continuous inspection and maintenance, and commuter programs.

As in the baseline, some mobile source controls were applied statewide for all states with a county projected to exceed 0.070 ppm. 'Local' controls were applied to counties within a 200 km buffer from counties projected to exceed 0.070 ppm with the following exceptions:

- counties in neighboring states were omitted from the buffer zone
- controls were applied statewide to Ozone Transport Commission (OTC) states, with the exception of Vermont

As stated at the beginning of this section, additional reductions were needed to complete the analysis of the alternate standard. In addition to the emission reductions accounted for in the extrapolation approach described in Chapter 4, Appendix 7a presents a sensitivity analysis of three mobile source control measures that could be included in the control strategy to illustrate attainment of the alternate standard.

3.2.4 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. EPA is working on approaches to quantify the uncertainties in these areas and will incorporate them in future RIAs as appropriate.

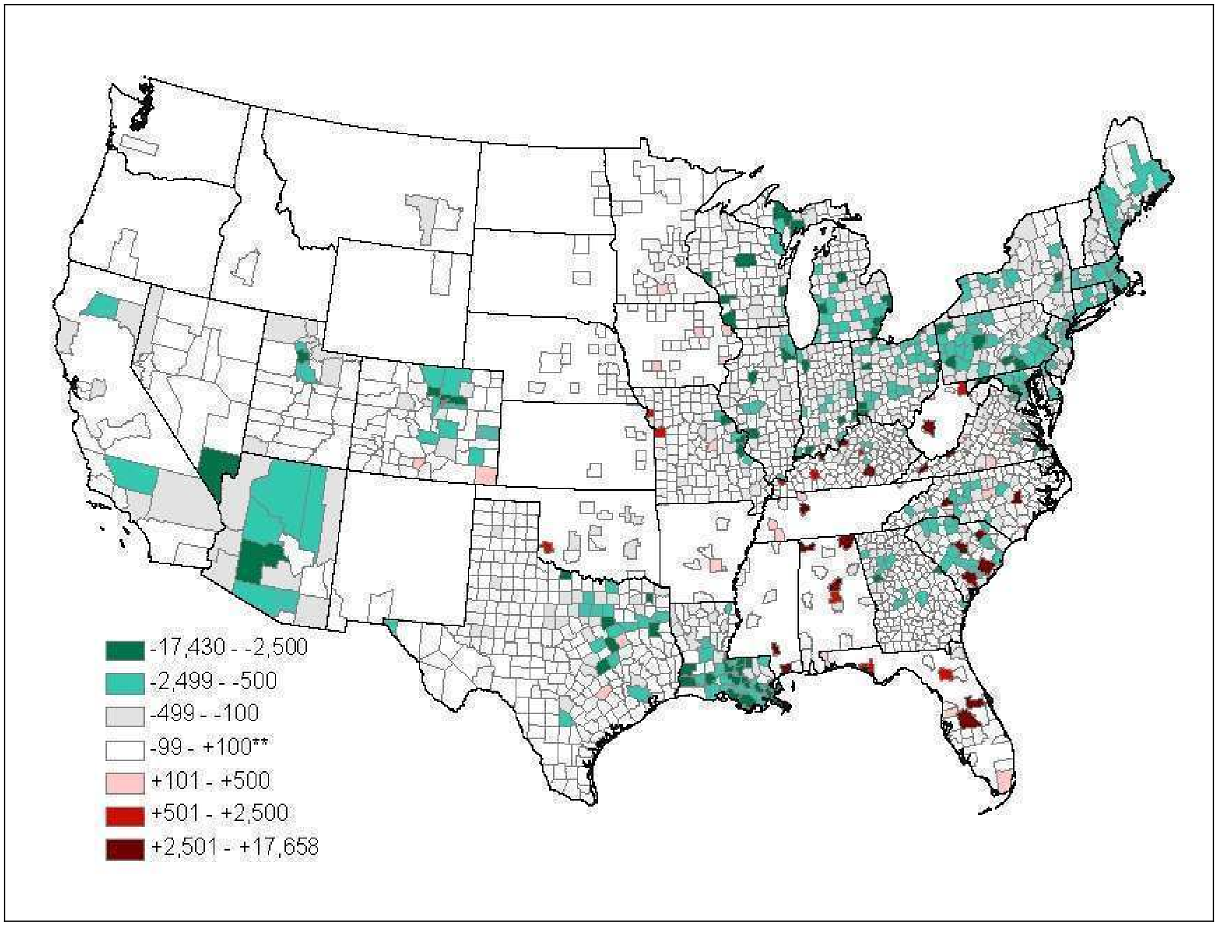
3.3 Geographic Distribution of Emissions Reductions

The following maps break out NOx and VOC reductions into the controlling sectors. The maps for NOx and VOC reductions are presented in Figures 3.9 and 3.11, respectively. Figures 3.10 and 3.12 indicate the emission reductions attributed to each sector. Appendix 3 contains maps of emissions reductions by sector, nationwide.

Prior to reading the maps, there is an important caveat to consider. The control strategy above focuses on reducing emissions of VOC and NOx, the two precursors to ozone formation. However, in some cases, the application of the control strategy actually increased the level of NOx or VOC emissions. This is due to controls that affect multiple pollutants and complex interactions between air pollutants, as well as trading aspects under the CAIR rule.

With respect to the baseline (CAIR/CAMR/CAVR), total emissions of NOx is lower. At the same time emissions shift geographically and hence do not decrease everywhere within the cap-and-trade regions. However, EGU NOx emissions do decrease substantially everywhere compared to the pre-CAIR levels. Substantial EGU NOx emission reductions are already being achieved through CAIR/CAMR/CAVR. This strategy focuses reductions under trading programs where they are needed most, with the result that some areas get less reductions than might have been otherwise expected within the. CAIR region. As explained earlier, the NOx EGU control strategy was designed to achieve emission reductions specifically in the non-attainment areas, while retaining the overall CAIR cap. Application of nested and lower (ozone season) caps (for the states in the MWRPO, and OTC, and East Texas) regions and local controls (SCR and SNCR) on the uncontrolled coal units in the non-attainment counties (and surrounding CBSA and CSA) outside of the trading regions OTC and MWRPO within CAIR region result in emission shifts increase of emissions elsewhere within or outside of CAIR region compared to the base line (CAIR/CAMR/CAVR). While there are substantial total NOx emission reductions (roughly 53,000 tons within the OTC, and MWRPO, and East Texas; and roughly 16,000 tons nationwide) expected for the 2020 ozone season (roughly 55,500 tons) compared to the base line (CAIR/CAMR/CAVR) as a result of cap-and-trade program with lower caps and local command-and-control reductions in other non-attainment counties where uncontrolled coal units exist, there are emission shifts geographically and there is the possibility of increases in emission from the remainder of sources within and outside of the CAIR region. This approach provides a cost effective opportunity for reducing emissions where the reductions are most needed to help reach attainment. It is important to recall that this is a hypothetical control strategy, and the states or other authorities may take additional steps to minimize these increases if warranted.

Figure 3.9: Annual Tons of NOx Emission Reductions for the Modeled Control Strategy (Incremental to the Baseline)*



* Reductions are negative and increases are positive.

** The −99– +100 range is shown without color because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences less than 1 ton.

Figure 3.10: Percentage of 2020 Annual NOx Emissions Reduced by Sector Incremental to the Baseline

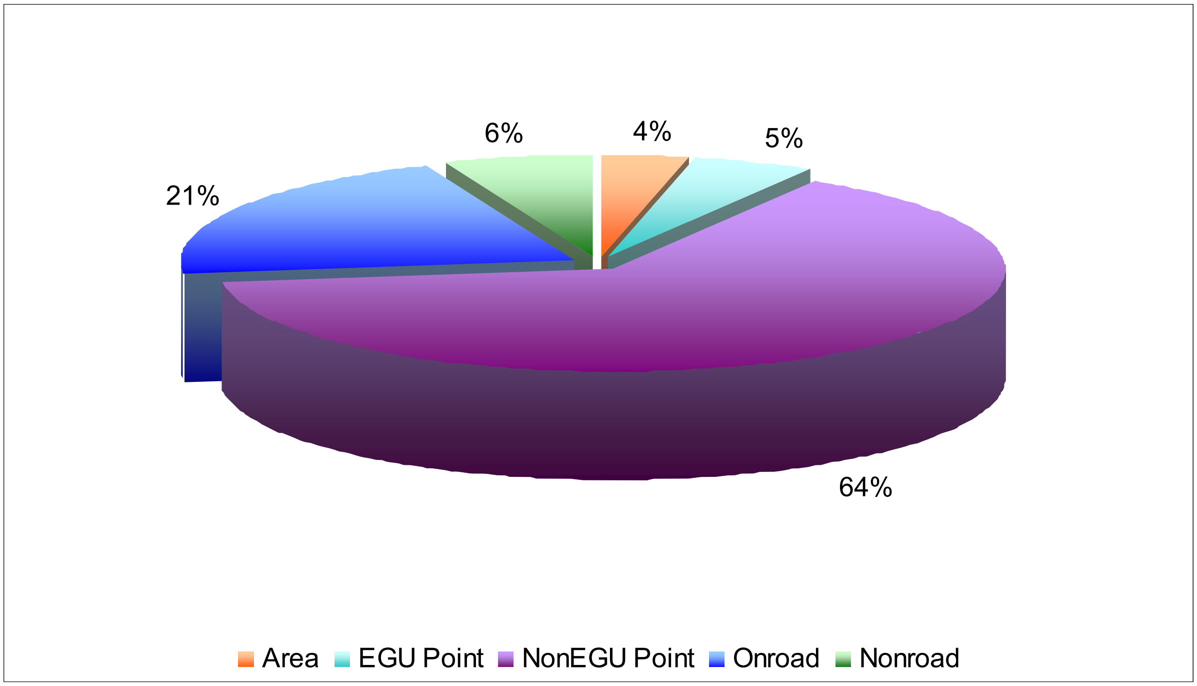
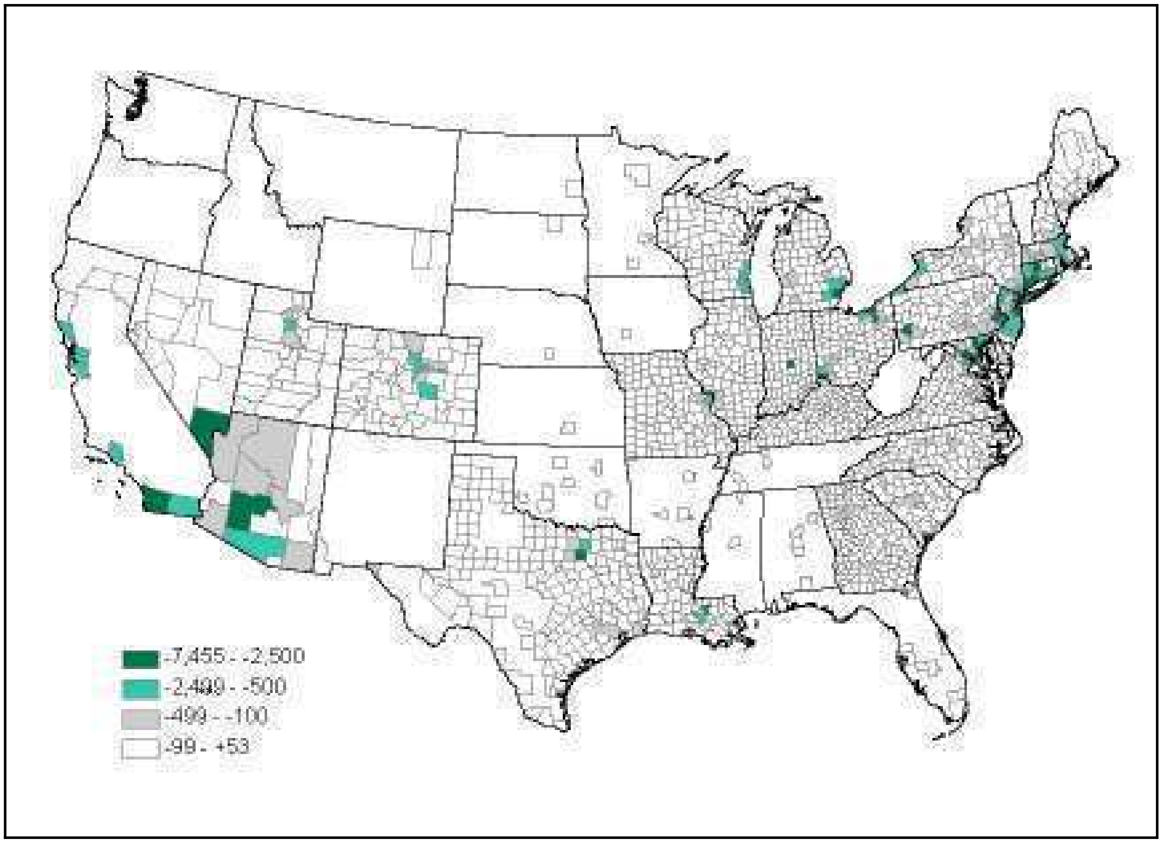


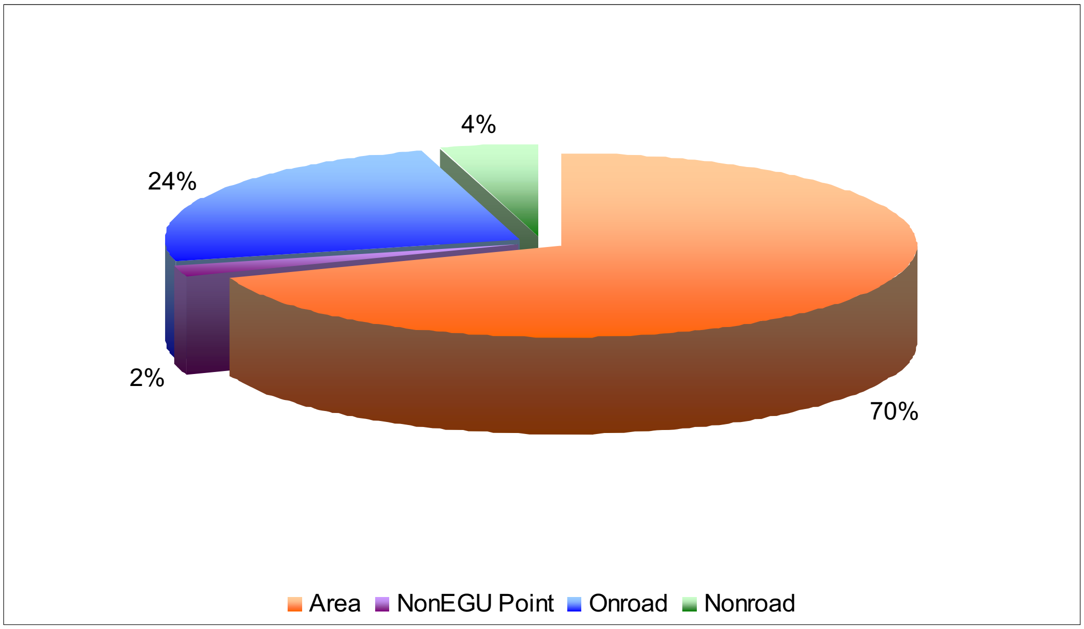
Figure 3.11: Annual Tons of VOC Emission Reductions for the Modeled Control Strategy (Incremental to the Baseline)*



* Reductions are negative and increases are positive

** The −99–+53 range is shown without color because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

Figure 3.12: Percentage of 2020 Annual VOC Emissions Reduced by Sector



3.4 Ozone Design Values for Partial Attainment

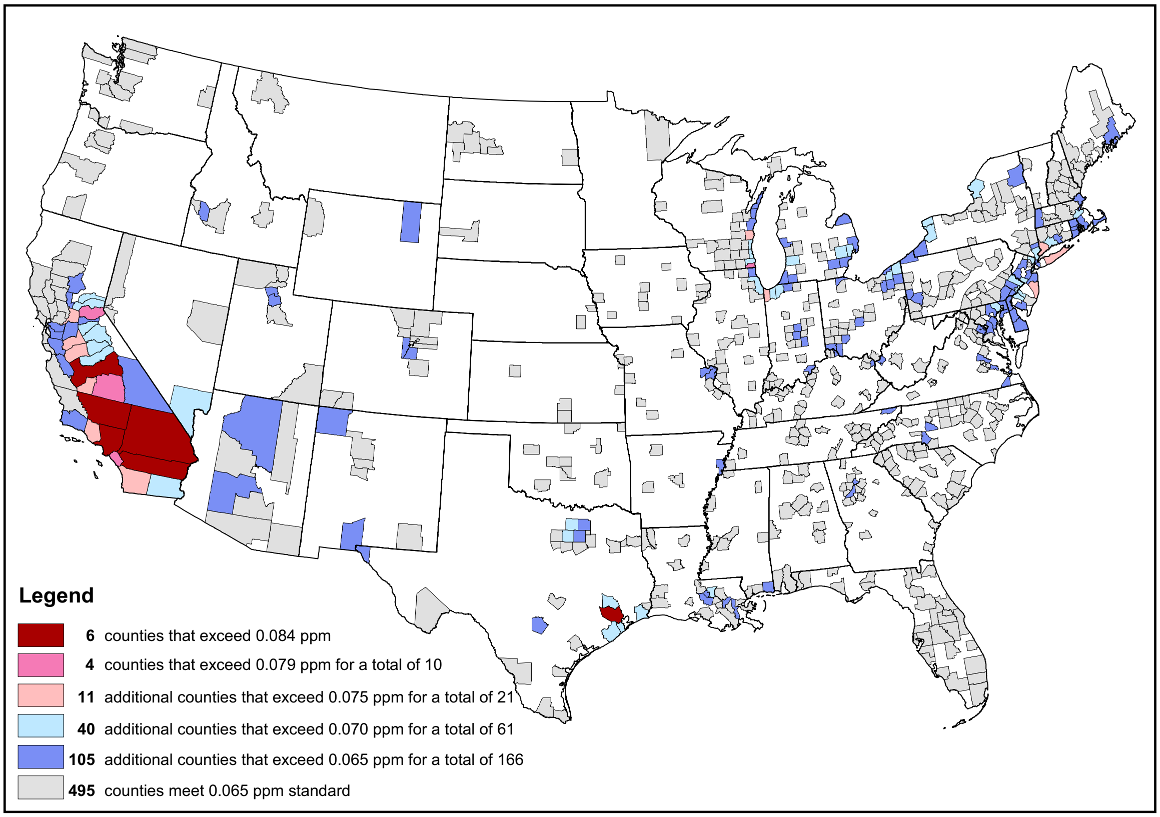
After determining the emissions reductions from NOx and VOC, we used modeling tools (see Section 2.3.2) to determine ozone design values for 2020. Figure 3.13 shows a map of the design values after the modeled control strategy. The map legend is broken out to demonstrate under this control strategy, with no adjustments, which counties would reach the targeted standard of 0.070 ppm, the more stringent alternative standard analyzed (0.065 ppm), and the other end of the proposal range (0.075 ppm, and 0.079 ppm). It is understood that this illustrative strategy would not be the exact hypothetical strategy used to try to attain either of these alternative standards, due to over- and under-attainment in many counties. (Chapter 4 describes EPA's methodology for estimating tons of reductions needed to hypothetically attain these other two possible alternative standards.) In addition, because ozone formation is dependent on a variety of factors, it is not possible to directly attribute changes in predicted ozone concentrations to emission reductions of a specific precursor from a specific sector.

A full listing of the counties and their design values is provided in Appendix 3.

Table 3.3 shows the tons of emissions reduced from the modeled control strategy, incremental to the baseline. Figure 3.14 shows the tons of emissions remaining after application of the hypothetical modeled control strategy, by sector.

Using this strategy, it is possible to reach attainment in 600 counties. However, there are still 61 counties that will remain out of attainment with an alternative standard of 0.070 ppm using this control strategy. All known controls were applied to this scenario, but attainment was not achieved everywhere. Because of this partial attainment outcome, it will be necessary to identify additional reductions in NOx and VOC. Chapter 4 will address the methodology for determining the additional tons that were needed to reach full attainment.

Figure 3.13: Projected 8-Hour Ozone Air Quality in 2020 From Applying the Modeled Control Strategy[a, b, c, d, e,]



[a] Modeled emissions reflect the expected reductions from federal programs including the Clean Air Interstate Rule (EPA, 2005b), the Clean Air Mercury Rule (EPA, 2005c), the Clean Air Visibility Rule (EPA, 2005d), the Clean Air Nonroad Diesel Rule (EPA, 2004), the Light-Duty Vehicle Tier 2 Rule (EPA, 1999), the Heavy Duty Diesel Rule (EPA, 2000), Locomotive and Marine Vessels (EPA, 2007a) and for Small Spark-Ignition Engines (EPA, 2007b), and 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.

[b] Controls applied are illustrative. States may choose to apply different control strategies for implementation.

[c] The current standard of 0.08 ppm is effectively expressed as 0.084 ppm when rounding conventions are applied.

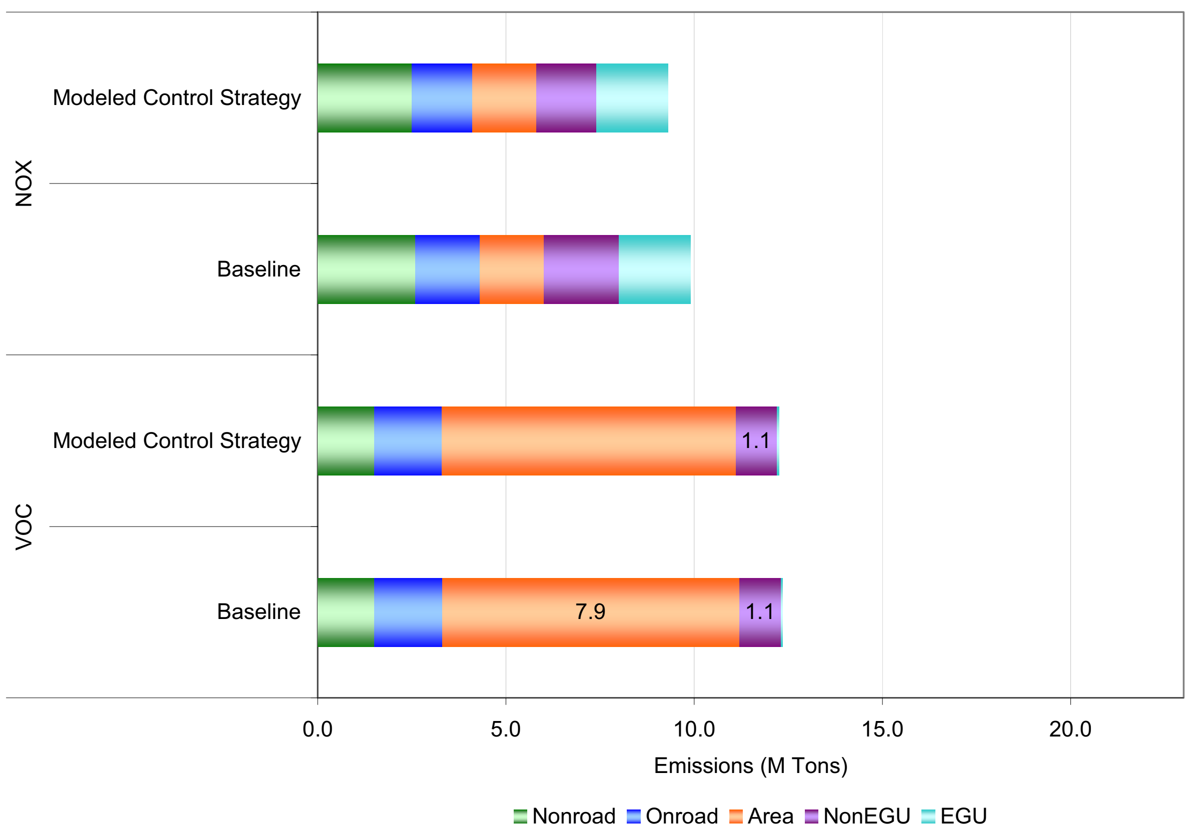
[d] Modeled design values in ppm are only interpreted up to 3 decimal places.

Table 3.3: Emissions and Reductions (2020) From Applying the Modeled Control Strategy by Region (Incremental to the Baseline)

Emissions Sector	Baseline Annual Emissions (annual tons/year)		Modeled Control Strategy Emission Reductions (annual tons/year)					
			East		West		California[a]	
	VOC	NOX	VOC	NOX	VOC	NOX	VOC	NOX
Area	1,700,000	7,900,000	140,000	20,000	15,000	1,100	10,000	35
NonEGU Point	1,900,000	49,000	4,000	350,000	280	19,000	260	1,600
EGU Point	2,000,000	1,100,000	-	7,500	-	19,000	-	1,400
Onroad	1,700,000	1,800,000	50,000	110,000	10,000	15,000	45	71
Nonroad	2,600,000	1,500,000	10,000	32,000	1,500	3,300	19	140

[a] A majority of the control measures were applied for the baseline in California.

Figure 3.14: National Annual Emissions Remaining (2020) after Application of Controls for the Baseline and Modeled Control Strategy



3.5 References

Michigan Department of Environmental Quality and Southeast Michigan Council of Governments. *Proposed Revision to State of Michigan State Implementation Plan for 7.0 Low Vapor Pressure Gasoline Vapor Request for Southeast Michiga*n. May 24, 2006.

National Ambient Air Quality Standards for Particulate Matter, 40 CFR Part 50 (2006).

Rule To Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions to Acid Rain Program; Revisions to the NOX SIP Call; Final Rule, 40 CFR Parts 51, 72, 73, 74, 77, 78 and 96 (2005).

Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units, 40 CFR Parts 60, 63, 72, and 75 (2005).

Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations, 40 CFR Part 51 (2005).

Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder, Proposed rule, 40 CFR Parts 92, 94, 1033, 1039, 1042, 1065 and 1068 (2007).

Control of Emissions from Nonroad Spark-Ignition Engines and Equipment; proposed rule, 40 CFR Parts 60, 63, 85, 89, 90, 91, 1027, 1045, 1048, 1051, 1054, 1060, 1065, 1068, and 1074 (2007).

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

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

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

U.S. Environmental Protection Agency (EPA), 2005a. *Guide on Federal and State Summer RVP Standards for Conventional Gasoline Only.* EPA420-B-05-012. November 2005.

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

U.S. Environmental Protection Agency (EPA). 2005c. *Emissions Inventory and Emissions Processing for the Clean Air Mercury Rule (CAMR),* U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, March 2005. Available at http://www.epa.gov/ttn/atw/utility/emiss_inv_oar-2002-0056-6129.pdf

U.S. Environmental Protection Agency (EPA). 2005d. *Regulatory Impact Analysis for the Final Clean Air Visibility Rule or the Guidelines for Best Available Retrofit Technology (BART) Determinations Under the Regional Haze Regulations,* U.S. Environmental Protection Agency, Office of Air and Radiation, June 2005. EPA-452-R-05-004. Available at http://www.epa.gov/visibility/pdfs/bart_ria_2005_6_15.pdf

U.S. Environmental Protection Agency (EPA). 2007a, Regulatory Announcement: EPA Proposal for More Stringent Emissions Standards for Locomotives and Marine Compression-Ignition Engines. EPA420-F-07-015.

U.S. Environmental Protection Agency (EPA). 2007b, Proposed Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels. EPA420-F-07-032.

U.S. Environmental Protection Agency (EPA). 2008a. Air Quality Modeling Platform for the Ozone National Ambient Air Quality Standard Final Rule Regulatory Impact Assessment.

U.S. Environmental Protection Agency (EPA). 2008b. Technical Support Document: Preparation of Emissions Inventories For the 2002-based Platform, Version 3, Criteria Air Pollutants, USEPA, January, 2008.

U.S. Office of Management and Budget. September 2003. Circular A-4, Regulatory Analysis Guidance sent to the Heads of Executive Agencies and Establishments. Washington, DC. http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf.

Appendix 3: Additional Control Strategy Information

3a.1 NonEGU Point and Area Source Controls

3a.1.1 NonEGU Point and Area Source Control Strategies for Ozone NAAQS Final

In the NonEGU point and Area Sources portion of the control strategy, maximum control scenarios were used from the existing control measure dataset from AirControlNET 4.1 for 2020 (for geographic areas defined for each level of the standard being analyzed). This existing control measure dataset reflects changes and updates made as a result of the reviews performed for the final PM2.5 RIA. Following this, an internal review was performed by the OAQPS engineers in the Sector Policies and Programs Division (SPPD) to examine the controls applied by AirControlNET and decide if these controls were sufficient or could be more aggressive in their application, given the 2020 analysis year. This review was performed for nonEGU point NOx control measures. The result of this review was an increase in control efficiencies applied for many control measures, and more aggressive control measures for over 70 SCC's. For example, SPPD recommended that we apply SCR to cement kilns to reduce NOx emissions in 2020. Currently, there are no SCRs in operation at cement kilns in the U.S., but there are several SCRs in operation at cement kilns in France now. Based on the SCR experience at cement kilns in France, SPPD believes SCR could be applied at U.S. cement kilns by 2020. Following this, it was recommended that supplemental controls could be applied to 8 additional SCC's from nonEGU point NOx sources. We also looked into sources of controls for highly reactive VOC nonEGU point sources. Four additional controls were applied for highly reactive VOC nonEGU point sources not in AirControlNET.

3a.1.2 NOx Control Measures for NonEGU Point Sources.

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

Besides industrial boilers, other nonEGU point source categories covered in this RIA include petroleum refineries, kraft pulp mills, cement kilns, stationary internal combustion engines, glass manufacturing, combustion turbines, and incinerators. NOx control measures available for petroleum refineries, particularly process heaters at these plants, include LNB, SNCR, FGR, and SCR along with combinations of these technologies. NOx control measures available for kraft pulp mills include those available to industrial boilers, namely LNB, SCR, SNCR, along with water injection (WI). NOx control measures available for cement kilns include those available to industrial boilers, namely LNB, SCR, and SNCR. Non-selective catalytic reduction (NSCR) can be used on stationary internal combustion engines. OXY-firing, a technique to modify combustion at glass manufacturing plants, can be used to reduce NOx at such plants. LNB, SCR, and SCR + steam injection (SI) are available measures for combustion turbines. Finally, SNCR is an available control technology at incinerators. Table 3a.1 contains a complete list of the NOx nonEGU point control measures applied and their associated emission reductions obtained in the modeled control strategy for the alternate primary standard. For more information on these measures, please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.1: NOx NonEGU Point Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
Biosolid Injection Technology	Cement Kilns	1,200
LNB	Asphaltic Conc; Rotary Dryer; Conv Plant	120
	Ceramic Clay Mfg; Drying	370
	Conv Coating of Prod; Acid Cleaning Bath	440
	Fuel Fired Equip; Furnaces; Natural Gas	170
	In-Process Fuel Use; Natural Gas	1,300
	In-Process Fuel Use; Residual Oil	39
	In-Process; Process Gas; Coke Oven Gas	190
	Lime Kilns	5,900
	Sec Alum Prod; Smelting Furn	62
	Steel Foundries; Heat Treating	13
	Surf Coat Oper; Coating Oven Htr; Nat Gas	30
LNB + FGR	Fluid Cat Cracking Units	3,600
	Fuel Fired Equip; Process Htrs; Process Gas	700
	In-Process; Process Gas; Coke Oven Gas	880
	Iron & Steel Mills—Galvanizing	35
	Iron & Steel Mills—Reheating	1,100
	Iron Prod; Blast Furn; Blast Htg Stoves	1,000
	Sand/Gravel; Dryer	11
	Steel Prod; Soaking Pits	100
LNB + SCR	Iron & Steel Mills—Annealing	270
	Process Heaters—Distillate Oil	2,300
	Process Heaters—Natural Gas	27,000
	Process Heaters—Other Fuel	14
	Process Heaters—Process Gas	4,200
	Process Heaters—Residual Oil	37
NSCR	Rich Burn IC Engines—Gas	22,000
	Rich Burn IC Engines—Gas, Diesel, LPG	3,700
	Rich Burn Internal Combustion Engines—Oil	11,000
OXY-Firing	Glass Manufacturing—Containers	7,600
	Glass Manufacturing—Flat	18,000
	Glass Manufacturing—Pressed	3,900
SCR	Ammonia—NG-Fired Reformers	5,800
	Cement Manufacturing—Dry	25,000
	Cement Manufacturing—Wet	22,000
	IC Engines—Gas	54,000
	ICI Boilers—Coal/Cyclone	2,200
	ICI Boilers—Coal/Wall	22,000
	ICI Boilers—Coke	490
	ICI Boilers—Distillate Oil	4,800

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
	ICI Boilers—Liquid Waste	730
	ICI Boilers—LPG	280
	ICI Boilers—Natural Gas	36,000
	ICI Boilers—Process Gas	8,600
	ICI Boilers—Residual Oil	17,000
	Natural Gas Prod; Compressors	810
	Space Heaters—Distillate Oil	22
	Space Heaters—Natural Gas	640
	Sulfate Pulping—Recovery Furnaces	9,900
SCR + Steam Injection	Combustion Turbines—Natural Gas	18,000
SCR + Water Injection	Combustion Turbines—Jet Fuel	—
	Combustion Turbines—Natural Gas	—
	Combustion Turbines—Oil	210
SNCR	By-Product Coke Mfg; Oven Underfiring	4,300
	Comm./Inst. Incinerators	1,400
	ICI Boilers—Coal/Stoker	7,000
	Indust. Incinerators	250
	Medical Waste Incinerators	—
	In-Process Fuel Use; Bituminous Coal	32
	Municipal Waste Combustors	4,400
	Nitric Acid Manufacturing	3,100
	Solid Waste Disp; Gov; Other Inc	95
SNCR—Urea	ICI Boilers—MSW/Stoker	120
SNCR—Urea Based	ICI Boilers—Coal/FBC	100
	ICI Boilers—Wood/Bark/Stoker—Large	5,500
	In-Process; Bituminous Coal; Cement Kilns	300
	In-Process; Bituminous Coal; Lime Kilns	31

3a.1.3 VOC Control Measures for NonEGU Point Sources.

VOC controls were applied to a variety of nonEGU point sources as defined in the emissions inventory in this RIA. The first control is: permanent total enclosure (PTE) applied to paper and web coating operations and fabric operations, and incinerators or thermal oxidizers applied to wood products and marine surface coating operations. A PTE confines VOC emissions to a particular area where can be destroyed or used in a way that limits emissions to the outside atmosphere, and an incinerator or thermal oxidizer destroys VOC emissions through exposure to high temperatures (2,000 degrees Fahrenheit or higher). The second control applied is petroleum and solvent evaporation applied to printing and publishing sources as well as to surface coating operations. Table 3a.2 contains the emissions reductions for these measures in the modeled control strategy for the alternate primary standard. For more information on these measures, refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.2: VOC NonEGU Point Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
Permanent Total Enclosure (PTE)	Fabric Printing, Coating and Dyeing	43
	Paper and Other Web Coating	490
Petroleum and Solvent Evaporation	Printing and Publishing	3,600
	Surface Coating	400

3a.1.4 NOx Control Measures for Area Sources

There were three control measures applied for NOx emissions from area sources. The first is RACT (reasonably available control technology) to 25 tpy (LNB). This control is the addition of a low NOx burner to reduce NOx emissions. This control is applied to industrial oil, natural gas, and coal combustion sources. The second control is water heaters plus LNB space heaters. This control is based on the installation of low-NOx space heaters and water heaters in commercial and institutional sources for the reduction of NOx emissions. The third control was switching to low sulfur fuel for residential home heating. This control is primarily designed to reduce sulfur dioxide, but has a co-benefit of reducing NOx. Table 3a.3 contains the listing of control measures and associated reductions for the modeled control strategy. For additional information regarding these controls please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.3: NOx Area Source Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
RACT to 25 tpy (LNB)	Industrial Coal Combustion	5,400
	Industrial NG Combustion	3,000
	Industrial Oil Combustion	570
Switch to Low Sulfur Fuel	Residential Home Heating	970
Water Heater + LNB Space Heaters	Commercial/Institutional—NG	4,300
	Residential NG	6,700

3a.1.5 VOC Control Measures for Area Source.

The most frequently applied control to reduce VOC emissions from area sources was CARB Long-Term Limits. This control, which represents controls available in VOC rules promulgated by the California Air Resources Board, applies to commercial solvents and commercial adhesives, and depends on future technological innovation and market incentive methods to achieve emission reductions. The next most frequently applied control was the use of low or no VOC materials for graphic art source categories. The South Coast Air District's SCAQMD Rule 1168 control applies to wood furniture and solvent source categories sets limits for adhesive and sealant VOC content. The OTC solvent cleaning rule control establishes hardware and operating requirements for specified vapor cleaning machines, as well as solvent volatility limits and operating practices for cold cleaners. The Low Pressure/Vacuum Relief Valve control measure is the addition of low pressure/vacuum (LP/V) relief valves to gasoline storage tanks at service stations with Stage II control systems. LP/V relief valves prevent breathing emissions from gasoline storage tank vent pipes. SCAQMD Limits control establishes VOC content limits for metal coatings along with application procedures and equipment requirements. Switch to Emulsified Asphalts control is a generic control measure replacing VOC-containing cutback asphalt with VOC-free emulsified asphalt. The equipment and maintenance control measure applies to oil and natural gas production. The Reformulation—FIP Rule control measure intends to reach the VOC limits by switching to and/or encouraging the use of low-VOC pesticides and better Integrated Pest Management (IPM) practices. Table 3a.4 contains the control measures and associated emission reductions described above for the modeled control strategy. For additional information regarding these controls please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.4: VOC Area Source Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
CARB Long-Term Limits	Consumer Solvents	78,000
Catalytic Oxidizer	Conveyorized Charbroilers	250
Equipment and Maintenance	Oil and Natural Gas Production	450
Gas Collection (SCAQMD/BAAQMD)	Municipal Solid Waste Landfill	1,100
Incineration >100,000 lbs bread	Bakery Products	2,700
Low Pressure/Vacuum Relief Valve	Stage II Service Stations	9,900
	Stage II Service Stations—Underground Tanks	9,800
OTC Mobile Equipment Repair and Refinishing Rule	Aircraft Surface Coating	720
	Machn, Electric, Railroad Ctng	4,400
OTC Solvent Cleaning Rule	Cold Cleaning	10,000
SCAQMD—Low VOC	Rubber and Plastics Mfg	1,700
SCAQMD Limits	Metal Furniture, Appliances, Parts	6,300
SCAQMD Rule 1168	Adhesives—Industrial	22,000
Solvent Utilization	Large Appliances	8,200
	Metal Furniture	7,600
	Surface Coating	2,900
Switch to Emulsified Asphalts	Cutback Asphalt	3,300

3a.1.6 Supplemental Controls

Table 3a.5 below summarizes the supplemental control measures added to our control measures database by providing the pollutant it controls and its control efficiency (CE). These controls were applied not as part of the modeled control strategy, but as supplemental measures prior to extrapolating unknown control costs. However, these controls are not currently located in AirControlNET. These measures are primarily found in draft SIP technical documents and have not been fully assessed for inclusion in AirControlNET.

Table 3a.5: Supplemental Emissions Control Measures Added to the Control Measures Database

Poll	Control Technology	SCC	SCC Description	Percent Reduction (%)
NOx	LEC	20200252	Internal Comb. Engines/Industrial/ Natural Gas/2-cycle Lean Burn	87
		20200254	Internal Comb. Engines/Industrial/ Natural Gas/4-cycle Lean Burn	87
VOC	Enhanced LDAR	3018001-	Fugitive Leaks	50
		30600701 30600999 -	Flares	98
	LDAR	3018001 -	Fugitive Leaks	80
	Monitoring Program	30600702-	Cooling towers	No general estimate
	Inspection and Maintenance Program (Separators) Water Seals (Drains)	30600503-	Wastewater Drains and Separators	65
	Work Practices, Use of Low VOC Coatings (Area Sources)	2401025000 2401030000 2401060000 2425010000 2425030000 2425040000 2461050000	Solvent Utilization	90
	Work Practices, Use of Low VOC Coatings (NonEGU Point)	307001199 Surface Coating Operations within SCC 4020000000, Printing/Publishing processes within SCC 4050000000	Petroleum and Solvent Evaporation	90

Low Emission Combustion (LEC)

Overview: LEC technology is defined as the modification of a natural gas fueled, spark ignited, reciprocating internal combustion engine to reduce emissions of NOx by utilizing ultra-lean air-fuel ratios, high energy ignition systems and/or pre-combustion chambers, increased turbocharging or adding a turbocharger, and increased cooling and/or adding an intercooler or aftercooler, resulting in an engine that is designed to achieve a consistent NO_x emission rate of not more than 1.5-3.0 g/bhp-hr at full capacity (usually 100 percent speed and 100 percent load). This type of retrofit technology is fairly widely available for stationary internal combustion engines.

For CE, EPA estimates that it ranges from 82 to 91 percent for LEC technology applications. The EPA believes application of LEC would achieve average NO_x emission levels in the range of 1.5-3.0 g/bhp-hr. This is an 82-91 percent reduction from the average uncontrolled emission levels reported in the ACT document. An EPA memorandum summarizing 269 tests shows that

96 percent of IC engines with installed LEC technology achieved emission rates of less than 2.0 g/bhp-hr.[1] The 2000 EC/R report on IC engines summarizes 476 tests and shows that 97% of the IC engines with installed LEC technology achieve emission rates of 2.0 g/bhp-hr or less.[2]

Major Uncertainties: The EPA acknowledges that specific values will vary from engine to engine. The amount of control desired and number of operating hours will make a difference in terms of the impact had from a LEC retrofit. Also, the use of LEC may yield improved fuel economy and power output, both of which may affect the emissions generated by the device.

Leak Detection and Repair (LDAR) for Fugitive Leaks

Overview: This control measure is a program to reduce leaks of fugitive VOC emissions from chemical plants and refineries. The program includes special "sniffer" equipment to detect leaks, and maintenance schedules that affected facilities are to adhere to. This program is one that is contained within the Houston-Galveston-Brazoria 8-hour Ozone SIP.

Major Uncertainties: The degree of leakage from pipes and processes at chemical plants is always difficult to quantify given the large number of such leaks at a typical chemical manufacturing plant. There are also growing indications based on tests conducted by TCEQ and others in Harris County, Texas that fugitive leaks have been underestimated from chemical plants by a factor of 6 to 20 or greater. [3]

Enhanced LDAR for Fugitive Leaks

Overview: This control measure is a more stringent program to reduce leaks of fugitive VOC emissions from chemical plants and refineries that presumes that an existing LDAR program already is in operation.

Major Uncertainties: The calculations of CE and cost presume use of LDAR at a chemical plant. This should not be an unreasonable assumption, however, given that most chemical plants are under some type of requirement to have an LDAR program. However, as mentioned earlier, there is growing evidence that fugitive leak emissions are underestimated from chemical plants by a factor of 6 to 20 or greater.[4]

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[1] "Stationary Reciprocating Internal Combustion Engines Technical Support Document for NOx SIP Call Proposal," U.S. Environmental Protection Agency. September 5, 2000. Available on the Internet at http://www.epa.gov/ttn/naaqs/ozone/rto/sip/data/tsd9-00.pdf.
[2] "Stationary Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," Ec/R Incorporated, Chapel Hill, NC. September 1, 2000. Available on the Internet at http://www.epa.gov/ttn/naaqs/ozone/ozonetech/ic_engine_nox_update_09012000.pdf.
[3] VOC Fugitive Losses: New Monitors, Emissions Losses, and Potential Policy Gaps. 2006 International Workshop. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Solid Waste and Emergency Response. October 25-27, 2006.
[4] VOC Fugitive Losses: New Monitors, Emissions Losses, and Potential Policy Gaps. 2006 International Workshop. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Solid Waste and Emergency Response. October 25-27, 2006.

Flare Gas Recovery

Overview: This control measure is a condenser that can recover 98 percent of the VOC emitted by flares that emit 20 tons per year or more of the pollutant.

Major Uncertainties: Flare gas recovery is just gaining commercial acceptance in the US and is only in use at a small number of refineries.

Cooling Towers

Overview: The control measure is continuous monitoring of VOC from the cooling water return to a level of 10 ppb. This monitoring is accomplished by using a continuous flow monitor at the inlet to each cooling tower.

There is not a general estimate of CE for this measure; one is to apply a continuous flow monitor until VOC emissions have reached a level of 1.7 tons/year for a given cooling tower.[5]

Major Uncertainties: The amount of VOC leakage from each cooling tower can greatly affect the overall cost-effectiveness of this control measure.

Wastewater Drains and Separators

Overview: This control measure includes an inspection and maintenance program to reduce VOC emissions from wastewater drains and water seals on drains. This measure is a more stringent version of measures that underlie existing NESHAP requirements for such sources.

Major Uncertainties: The reference for this control measures notes that the VOC emissions inventories for the five San Francisco Bay Area refineries whose data was a centerpiece of this report are incomplete. In addition, not all VOC species from these sources were included in the VOC data that is a basis for these calculations.[6]

Work Practices or Use of Low VOC Coatings

Overview: The control measure is either application of work practices (e.g., storing VOC-containing cleaning materials in closed containers, minimizing spills) or using coatings that have much lower VOC content. These measures, which are of relatively low cost compared to other VOC area source controls, can apply to a variety of processes, both for non-EGU point and area sources, in different industries and is defined in the proposed control techniques guidelines (CTG) for paper, film and foil coatings, metal furniture coatings, and large appliance coatings published by the US EPA in July 2007.[7]

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[5] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.
[6] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.
[7] U.S. Environmental Protection Agency. Consumer and Commercial Products: Control Techniques Guidelines in Lieu of Regulations for Paper, Film, and Foil Coatings; Metal

The estimated CE expected to be achieved by either of these control measures is 90 percent.

Major Uncertainties: The greatest uncertainty is in how many potentially affected processes are implementing or already implemented these control measures. This may be particularly true in California. Also, there are nine States that have many of the above work practices in effect for paper, film and foil coatings processes, but the work practices are not meant to achieve a specific emissions limit.[8] Hence, it is uncertain how much VOC reduction is occurring from this control measure in this case.

In addition to the new supplemental controls presented above, there were a number of changes made to existing AirControlNET controls. These changes were made based upon an internal review performed by EPA engineers to examine the controls applied by AirControlNET and determine if these controls were sufficient or could be more aggressive in their application, given the 2020 analysis year. This review was performed for nonEGU point NOx control measures. The result of this review was an increase in control efficiencies applied for many control measures, and more aggressive control measures for over 70 SCCs. The changes apply to the control strategies performed for the Eastern US only. These changes are listed in Table 3a.6.

Table 3a.6: Supplemental Emission Control Measures—Changes to Control Technologies Currently in our Control Measures Database For Application in 2020

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	10200104 10200204 10200205 10300207 10300209 10200217 10300216	ICI Boilers—Coal-Stoker	SNCR	SCR	90	40
NOX	10200901 10200902 10200903 10200907 10300902 10300903	ICI Boilers—Wood/Bark/ Waste	SNCR	SCR	90	55
NOX	10200401 10200402 10200404 10200405 10300401	ICI Boilers—Residual Oil	SCR	SCR	90	80

Furniture Coatings; and Large Appliance Coatings. 40 CFR 59. July 10, 2007. Available on the Intenet at http://www.epa.gov/ttncaaa1/t1/fr_notices/ctg_ccp092807.pdf. It should be noted that this CTG became final in October 2007.

[8] U.S. Environmental Protection Agency. Consumer and Commercial Products: Control Techniques Guidelines in Lieu of Regulations for Paper, Film, and Foil Coatings; Metal Furniture Coatings; and Large Appliance Coatings. 40 CFR 59. July 10, 2007, p. 37597. Available on the Intenet at http://www.epa.gov/ttncaaa1/t1/fr_notices/ctg_ccp092807.pdf.

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	10200501 10200502 10200504	ICI Boilers—Distillate Oil	SCR	SCR	90	80
NOX	10200601 10200602 10200603 10200604 10300601 10300602 10300603 10500106 10500206	ICI Boilers—Natural Gas	SCR	SCR	90	80
NOX	30500606	Cement Manufacturing—Dry	SCR	SCR	90	80
NOX	30500706	Cement Manufacturing—Wet	SCR	SCR	90	80
NOX	30300934	Iron & Steel Mills—Annealing	SCR	SCR	90	85
NOX	10200701 10200704 10200707 10200710 10200799 10201402 10300701 10300799	ICI Boilers—Process Gas	SCR	SCR	90	80
NOX	10200802 10200804	ICI Boilers—Coke	SCR	SCR	90	70
NOX	10201002	ICI Boilers—LPG	SCR	SCR	90	80
NOX	10201301 10201302	ICI Boilers—Liquid Waste	SCR	SCR	90	80
NOX	30700110	Sulfate Pulping—Recovery Furnaces	SCR	SCR	90	80
NOX	30100306	Ammonia Production—Pri. Reformer, Nat. Gas	SCR	SCR	90	80
	30500622 30500623	Cement Kilns	Biosolid Injection	Biosolid Injection	40	23
NOX	30590013 30190013 30190014 39990013	Industrial and Manufacturing Incinerators	SNCR	SCR	90	45
NOX	30101301 30101302	Nitric Acid Manufacturing	SNCR	SCR	90	60 to 98
NOX	30600201	Fluid Cat. Cracking Units	LNB + FGR	SCR	90	55
NOX	30590003	Process Heaters—Process Gas	LNB + SCR	LNB + SCR	90	88
NOX	30600101 30600103 30600111	Process Heaters—Distillate Oil	LNB + SCR	LNB + SCR	90	90
NOX	30600106 30600199	Process Heaters—Residual Oil	LNB + SCR	LNB + SCR	90	80
NOX	30600102 30600105	Process Heaters—Natural Gas	LNB + SCR	LNB + SCR	90	80

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	30700104	Sulfate Pulping—Recovery Furnaces	SCR	SCR	90	80
NOX	30790013	Pulp and Paper—Natural Gas—Incinerators	SNCR	SCR	90	45
NOX	39000201	In-Process; Bituminous Coal; Cement Kiln	SNCR—urea based	SCR	90	50
NOX	39000203	In-Process; Bituminous Coal; Lime Kiln	SNCR—urea based	SCR	90	50
NOX	39000289	In-Process Fuel Use; Bituminous Coal; Gen	SNCR	SCR	90	40
NOX	39000489	In-Process Fuel Use; Residual Oil; Gen	LNB	SCR	90	37
NOX	39000689	In-Process Fuel Use; Natural Gas; Gen	LNB	SCR	90	50
NOX	39000701	In-Proc; Process Gas; Coke Oven/Blast Furn	LNB + FGR	SCR	90	55
NOX	39000789	In-Process; Process Gas; Coke Oven Gas	LNB	SCR	90	50
NOX	50100101 50100506 50200506 50300101 50300102 50300104 50300506 50100102	Solid Waste Disp; Gov; Other Incin; Sludge	SNCR	SCR	90	45

The last category of supplemental controls is control technologies currently in our control measures database being applied to SCCs not controlled currently in AirControlNET.

Table 3a.7: Supplemental Emission Control Technologies Currently in our Control Measures Database Applied to New Source Types

Pollutant	SCC	SCC Description	Control Technology	CE
NOX	39000602	Cement Manufacturing—Dry	SCR	90
NOX	30501401	Glass Manufacturing—General	OXY-Firing	85
NOX	30302351 30302352 30302359	Taconite Iron Ore Processing—Induration—Coal or Gas	SCR	90
NOX	10100101	External Combustion Boilers; Electric Generation; Anthracite Coal; Pulverized Coal	SNCR	40
NOX	10100202	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Bituminous Coal)	SNCR	40
NOX	10100204	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Spreader Stoker (Bituminous Coal)	SNCR	40
NOX	10100212	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Tangential) (Bituminous Coal)	SNCR	40

Pollutant	SCC	SCC Description	Control Technology	CE
NOX	10100401	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Normal Firing	SNCR	50
NOX	10100404	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Tangential Firing	SNCR	50
NOX	10100501	External Combustion Boilers; Electric Generation; Distillate Oil; Grades 1 and 2 Oil	SNCR	50
NOX	10100601	External Combustion Boilers; Electric Generation; Natural Gas; Boilers > 100 Million Btu/hr except Tangential	NGR	50
NOX	10100602	External Combustion Boilers; Electric Generation; Natural Gas; Boilers < 100 Million Btu/hr except Tangential	NGR	50
NOX	10100604	External Combustion Boilers; Electric Generation; Natural Gas; Tangentially Fired Units	NGR	50
NOX	10101202	External Combustion Boilers; Electric Generation; Solid Waste; Refuse Derived Fuel	SNCR	50
NOX	20200253	Internal Comb. Engines/Industrial/Natural Gas/4-cycle Rich Burn	NSCR	90

3a.2 Mobile Control Measures Used in Control Scenarios

Tables 3a.8 and 3a.9 summarize the emission reductions for the mobile source control measures discussed in this section.

Table 3a.8: NOx Mobile Emission Reductions by Control Measure

Sector	Control Measure	Modeled Control Strategy Reductions (annual tons/year)
Onroad	Eliminate Long Duration Truck Idling	5,800
	Reduce Gasoline RVP	880
	Diesel Retrofits	91,000
	Continuous Inspection and Maintenance	20,000
	Commuter Programs	4,100
Nonroad	Diesel Retrofits and Engine Rebuilds	35,000

Table 3a.9: VOC Mobile Emission Reductions by Control Measure

Sector	Control Measure	Modeled Control Strategy Reductions (annual tons/year)
Onroad	Reduce Gasoline RVP	17,000
	Diesel Retrofits	8,400
	Continuous Inspection and Maintenance	28,000
	Commuter Programs	7,000
Nonroad	Reduce Gasoline RVP	6,300
	Diesel Retrofits and Engine Rebuilds	5,200

3a.2.1 Diesel Retrofits and Engine Rebuilds

Retrofitting heavy-duty diesel vehicles and equipment manufactured before stricter standards are in place—in 2007–2010 for highway engines and in 2011–2014 for most nonroad equipment—can provide NO_X and HC benefits. The retrofit strategies included in the RIA retrofit measure are:

- Installation of emissions after-treatment devices called selective catalytic reduction ("SCRs")
- Rebuilding nonroad engines ("rebuild/upgrade kit")

We chose to focus on these strategies due to their high NOx emissions reduction potential and widespread application. Additional retrofit strategies include, but are not limited to, lean NOx catalyst systems—which are another type of after-treatment device—and alternative fuels. Additionally, SCRs are currently the most likely type of control technology to be used to meet EPA's NOx 2007–2010 requirements for HD diesel trucks and 2008–2011 requirements for nonroad equipment. Actual emissions reductions may vary significantly by strategy and by the type and age of the engine and its application.

To estimate the potential emissions reductions from this measure, we applied a mix of two retrofit strategies (SCRs and rebuild/upgrade kits) for the 2020 inventory of:

- Heavy-duty highway trucks class 6 & above, Model Year 1995–2009
- All diesel nonroad engines, Model Year 1991–2007, except for locomotive, marine, pleasure craft, & aircraft engines

Class 6 and above trucks comprise the bulk of the NOx emissions inventory from heavy-duty highway vehicles, so we did not include trucks below class 6. We chose not to include locomotive and marine engines in our analysis since EPA has proposed regulations to address these engines, which will significantly impact the emissions inventory and emission reduction potential from retrofits in 2020. There was also not enough data available to assess retrofit strategies for existing aircraft and pleasure craft engines, so we did not include them in this analysis. In addition, EPA is in the process of negotiating standards for new aircraft engines.

The lower bound in the model year range—1995 for highway vehicles and 1991 for nonroad engines—reflects the first model year in which emissions after-treatment devices can be reliably applied to the engines. Due to a variety of factors, devices are at a higher risk of failure for earlier model years. We expect the engines manufactured before the lower bound year that are still in existence in 2020 to be retired quickly due to natural turnover, therefore, we have not included strategies for pre-1995/1991 engines because of the strategies' relatively small impact on emissions. The upper bound in the model year range reflects the last year before more stringent emissions standards will be fully phased-in.

We chose the type of strategy to apply to each model year of highway vehicles and nonroad equipment based on our technical assessment of which strategies would achieve reliable results at the lowest cost. After-treatment devices can be more cost-effective than rebuild and vice versa depending on the emissions rate, application, usage rates, and expected life of the engine. The performance of after-treatment devices, for example, depends heavily upon the model year of the engine; some older engines may not be suitable for after-treatment devices and would be better candidates for rebuild/upgrade kit. In certain cases, nonroad engines may not be suitable for either after-treatment devices or rebuild, which is why we estimate that retrofits are not suitable for 5% of the nonroad fleet. The mix of strategies employed in this RIA for highway vehicles and nonroad engines are presented in Table 3a.10 and Table 3a.11, respectively. The groupings of model years for highway vehicles reflect changes in EPA's published emissions standards for new engines.

Table 3a.10: Application of Retrofit Strategy for Highway Vehicles by Percentage of Fleet

Model Year	SCR
<1995	0%
1995–2006	100%
2007–2009	50%
>2009	0%

Table 3a.11: Application of Retrofit Strategy for Nonroad Equipment by Percentage of Fleet

Model Year	Rebuild/Upgrade kit	SCR
1991–2007	50%	50%

The expected emissions reductions from SCR's are based on data derived from EPA regulations (Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-duty Highway Engines and Vehicles published October 2000), interviews with component manufacturers, and EPA's Summary of Potential Retrofit Technologies. This information is available at www.epa.gov/otaq/retrofit/retropotentialtech.htm. The estimates for highway vehicles and nonroad engines are presented in Table 3a.12 and Table 3a.13, respectively.

Table 3a.12: Percentage Emissions Reduction by Highway Vehicle Retrofit Strategy

	PM	CO	HC	NOx
SCR (+DPF)	90%	90%	90%	70%

Table 3a.13: Percentage Emissions Reduction by Nonroad Equipment Retrofit Strategy

Strategy	PM	CO	HC	NOx
SCR (+DPF)	90%	90%	90%	70%
Rebuild/Upgrade Kit	30%	15%	70%	40%

It is important to note that there is a great deal of variability among types of engines (especially nonroad), the applicability of retrofit strategies, and the associated emissions reductions. We applied the retrofit emissions reduction estimates to engines across the board (e.g., retrofits for bulldozers are estimated to produce the same percentage reduction in emissions as for agricultural mowers). We did this in order to simplify model runs, and, in some cases, where we did not have enough data to differentiate emissions reductions for different types of highway vehicles and nonroad equipment. We believe the estimates used in the RIA, however, reflect the best available estimates of emissions reductions that can be expected from retrofitting the heavy-duty diesel fleet.

Using the retrofit module in EPA's National Mobile Inventory Model (NMIM) available at http://www.epa.gov/otaq/nmim.htm, we calculated the total percentage reduction in emissions (PM, NOx, HC, and CO) from the retrofit measure for each relevant engine category (source category code, or SCC) for each county in 2020. To evaluate this change in the emissions inventory, we conducted both a baseline and control analysis. Both analyses were based on NMIM 2005 (version NMIM20060310), NONROAD2005 (February 2006), and MOBILE6.2.03 which included the updated diesel PM file PMDZML.csv dated March 17, 2006.

For the control analysis, we applied the retrofit measure corresponding to the percent reductions of the specified pollutants in Tables 3a.12 and 3a.13 to the specified model years in Tables 3a.10 and 3a.11 of the relevant SCCs. Fleet turnover rates are modeled in the NMIM, so we applied the retrofit measure to the 2007 fleet inventory, and then evaluated the resulting emissions inventory in 2020. The timing of the application of the retrofit measure is not a factor; retrofits only need to take place prior to the attainment date target (2020 for this RIA). For example, if retrofit devices are installed on 1995 model year bulldozers in 2007, the only impact on emissions in 2020 will be from the expected inventory of 1995 model year bulldozer emissions in 2020.

We then compared the baseline and control analyses to determine the percent reduction in emissions we estimate from this measure for the relevant SCC codes in the targeted nonattainment areas.

3a.2.2 Implement Continuous Inspection and Maintenance Using Remote Onboard Diagnostics (OBD)

Continuous Inspection and Maintenance (I/M) is a new way to check the status of OBD systems on light-duty OBD-equipped vehicles. It involves equipping subject vehicles with some type of transmitter that attaches to the OBD port. The device transmits the status of the OBD system to receivers distributed around the I/M area. Transmission may be through radio-frequency, cellular or wi-fi means. Radio frequency and cellular technologies are currently being used in the states of Oregon, California and Maryland.

Current I/M programs test light-duty vehicles on a periodic basis—either annually or biennially. Emission reduction credit is assigned based on test frequency. Using Continuous I/M, vehicles are continuously monitored as they are operated throughout the non-attainment area. When a vehicle experiences an OBD failure, the motorist is notified and is required to get repairs within the normal grace period—typically about a month. Thus, Continuous I/M will result in repairs happening essentially whenever a malfunction occurs that would cause the check engine light to illuminate. The continuous I/M program is applied to the same fleet of vehicles as the current periodic I/M programs. Currently, MOBILE6 provides an increment of benefit when going from a biennial program to an annual program. The same increment of credit applies going from an annual program to a continuous program.

Source Categories Affected by Measure:

- All 1996 and newer light-duty gasoline vehicles and trucks:
- All 1996 and newer (SCC 2201001000) Light Duty Gasoline Vehicles (LDGV), Total: All Road Types
- All 1996 and newer (SCC 2201020000) Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
- All 1996 and newer (SCC 2201040000) Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types

OBD systems on light duty vehicles are required to illuminate the malfunction indicator lamp whenever emissions of HC, CO or NOx would exceed 1.5 times the vehicle's certification standard. Thus, the benefits of this measure will affect all three criteria pollutants. MOBILE6 was used to estimate the emission reduction benefits of Continuous I/M, using the methodology discussed above.

3a.2.3 Eliminating Long Duration Truck Idling

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

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

TSE can eliminate idling when trucks are resting at truck stops or public rest areas and while trucks are waiting to perform a task at private distribution terminals. When truck spaces are electrified, truck drivers can shut down their engines and use electricity to power equipment which supplies air conditioning, heat, and electrical power for on-board appliances.

MIRTs can eliminate long duration idling from trucks that are stopped away from these central sites. For a more complete list of MIRTs see EPA's Idle Reduction Technology page at http://www.epa.gov/otaq/smartway/idlingtechnologies.htm.

This measure demonstrates the potential emissions reductions if every class 8a and 8b truck is equipped with a MIRT or has dependable access to sites with TSE in 2020.

To estimate the potential emissions reduction from this measure, we applied a reduction equal to the full amount of the emissions attributed to long duration idling in the MOBILE model, which is estimated to be 3.4% of the total NOx emissions from class 8a and 8b heavy duty diesel trucks. Since the MOBILE model does not distinguish between idling and operating emissions, EPA estimates idling emissions in the inventory based on fuel conversion factors. The inventory in the MOBILE model, however, does not fully capture long duration idling emissions. There is evidence that idling may represent a much greater share than 3.4% of the real world inventory, based on engine control module data from long haul trucking companies. As such, we believe the emissions reductions demonstrated from this measure in the RIA represent ambitious but realistic targets. For more information on determining baseline idling activity see EPA's "Guidance for Quantifying and Using Long-Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity" available at http://www.epa.gov/smartway/idle-guid.htm.

Pollutants and Source Categories Affected by Measure: NO_x

Table 3a.14: Class 8a and 8b Heavy Duty Diesel Trucks (decrease NOx for all SCCs)

SCC	Note: All SCC Descriptions below begin with "Mobile Sources; Highway Vehicles—Diesel"
2230074110	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Interstate: Total
2230074130	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Other Principal Arterial: Total
2230074150	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Minor Arterial: Total
2230074170	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Major Collector: Total
2230074190	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Minor Collector: Total
2230074210	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Local: Total
2230074230	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Interstate: Total
2230074250	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Other Freeways and Expressways: Total
2230074270	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Other Principal Arterial: Total
2230074290	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Minor Arterial: Total
2230074310	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Collector: Total
2230074330	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Local: Total

Estimated Emissions Reduction from Measure (%): 3.4 % decrease in NOx for all SCCs affected by measure

3a.2.4 Commuter Programs

Commuter programs recognize and support employers who provide incentives to employees to reduce light-duty vehicle emissions. Employers implement a wide range of incentives to affect change in employee commuting habits including transit subsidies, bike-friendly facilities, telecommuting policies, and preferred parking for vanpools and carpools. The commuter measure in this RIA reflects a mixed package of incentives.

This measure demonstrates the potential emissions reductions from providing commuter incentives to 10% and 25% of the commuter population in 2020.

We used the findings from a recent Best Workplaces for Commuters survey, which was an EPA sponsored employee trip reduction program, to estimate the potential emissions reductions from this measure.[9] The BWC survey found that, on average, employees at workplaces with comprehensive commuter programs emit 15% fewer emissions than employees at workplaces that do not offer a comprehensive commuter program.

[9] Herzog, E., Bricka, S., Audette, L., and Rockwell, J., 2005. *Do Employee Commuter Benefits Reduce Vehicle Emissions and Fuel Consumption? Results of the Fall 2004 Best Workplaces for Commuters Survey*, Transportation Research Record, Journal of the Transportation Research Board: Forthcoming.

We believe that getting 10%–25% of the workforce involved in commuter programs is realistic. For modeling purposes, we divided the commuter programs measure into two program penetration rates: 10% and 25%. This was meant to provide flexibility to model a lower penetration rate for areas that need only low levels of emissions reductions to achieve attainment.

According to the 2001 National Household Transportation Survey (NHTS) published by DOT, commute VMT represents 27% of total VMT. Based on this information, we calculated that BWC would reduce light-duty gasoline emissions by 0.4% and 1% with a 10% and 25% program penetration rate, respectively.

Pollutants and Source Categories Affected by Measure (SCC): NO_x, and VOC

Table 3a.15: All Light-Duty Gasoline Vehicles and Trucks

SCC	Note: All SCC Descriptions below begin with "Mobile Sources; Highway Vehicles—Gasoline"
2201001110	Light Duty Gasoline Vehicles (LDGV); Rural Interstate: Total
2201001130	Light Duty Gasoline Vehicles (LDGV); Rural Other Principal Arterial: Total
2201001150	Light Duty Gasoline Vehicles (LDGV); Rural Minor Arterial: Total
2201001170	Light Duty Gasoline Vehicles (LDGV); Rural Major Collector: Total
2201001190	Light Duty Gasoline Vehicles (LDGV); Rural Minor Collector: Total
2201001210	Light Duty Gasoline Vehicles (LDGV); Rural Local: Total
2201001230	Light Duty Gasoline Vehicles (LDGV); Urban Interstate: Total
2201001250	Light Duty Gasoline Vehicles (LDGV); Urban Other Freeways and Expressways: Total
2201001270	Light Duty Gasoline Vehicles (LDGV); Urban Other Principal Arterial: Total
2201001290	Light Duty Gasoline Vehicles (LDGV); Urban Minor Arterial: Total
2201001310	Light Duty Gasoline Vehicles (LDGV); Urban Collector: Total
2201001330	Light Duty Gasoline Vehicles (LDGV); Urban Local: Total
2201020110	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Interstate: Total
2201020130	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Other Principal Arterial: Total
2201020150	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Minor Arterial: Total
2201020170	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Major Collector: Total
2201020190	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Minor Collector: Total
2201020210	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Local: Total
2201020230	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Interstate: Total
2201020250	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Other Freeways and Expressways: Total
2201020270	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Other Principal Arterial: Total
2201020290	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Minor Arterial: Total
2201020310	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Collector: Total
2201020330	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Local: Total
2201040110	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Interstate: Total
2201040130	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Other Principal Arterial: Total
2201040150	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Minor Arterial: Total
2201040170	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Major Collector: Total
2201040190	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Minor Collector: Total
2201040210	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Local: Total
2201040230	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Interstate: Total
2201040250	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Other Freeways and Expressways: Total
2201040270	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Other Principal Arterial: Total
2201040290	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Minor Arterial: Total
2201040310	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Collector: Total
2201040330	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Local: Total

Estimated Emissions Reduction from Measure (%):
With a 10% program penetration rate: 0.4%
With a 25% program penetration rate: 1%

3a.2.5 Reduce Gasoline RVP from 7.8 to 7.0 in Remaining Nonattainment Areas

Volatility is the property of a liquid fuel that defines its evaporation characteristics. RVP is an abbreviation for "Reid vapor pressure," a common measure of gasoline volatility, as well as a generic term for gasoline volatility. EPA regulates the vapor pressure of all gasoline during the summer months (June 1 to September 15 at retail stations). Lower RVP helps to reduce VOCs, which are a precursor to ozone formation. This control measure represents the use of gasoline with a RVP limit of 7.0 psi from May through September in counties with an ozone season RVP value greater than 7.0 psi.

Under section 211(c)(4)(C) of the CAA, EPA may approve a non-identical state fuel control as a SIP provision, if the state demonstrates that the measure is necessary to achieve the national primary or secondary ambient air quality standard (NAAQS) that the plan implements. EPA can approve a state fuel requirement as necessary only if no other measures would bring about timely attainment, or if other measures exist but are unreasonable or impracticable.

Source Categories Affected by Measure:

- All light-duty gasoline vehicles and trucks: Affected SCC:
  - 2201001000 Light Duty Gasoline Vehicles (LDGV), Total: All Road Types
  - 2201020000 Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
  - 2201040000 Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types
  - 2201070000 Heavy Duty Gasoline Vehicles (HDGV), Total: All Road Types
  - 2201080000 Motorcycles (MC), Total: All Road Types

3a.3 EGU Controls Used in the Control Strategy

Table 3a.21 contains the ozone season emissions from all fossil EGU sources (greater than 25 megawatts) for the baseline and the control strategy.

Table 3a.16: NOx EGU Ozone Season Emissions (All Fossil Units >25MW) (1,000 Tons)[a]

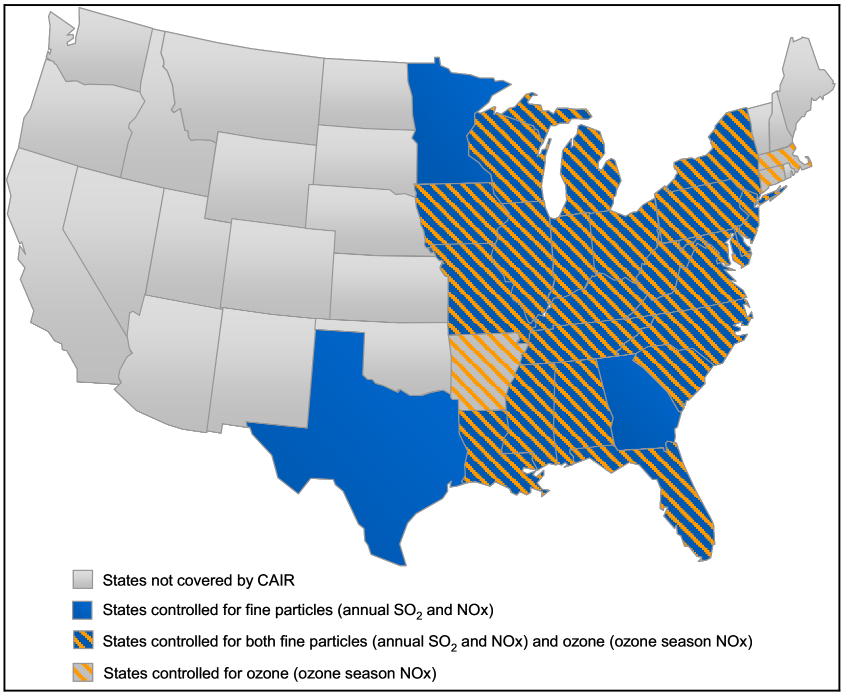
	OTC	MWRPO	East TX	National	CAIR Region	CAIR Cap
Baseline (CAIR/CAMR/CAVR)	73	154	43	828	463	485
Control Strategy	65 (−11%)	113 (−26%)	33 (−23%)	812 (−2%)	470	482

[a] Numbers in parentheses are the percentage change in emissions.

3a.3.1 CAIR

The data and projections presented in Section 3.2.2 cover the electric power sector, an industry that will achieve significant emission reductions under the Clean Air Interstate Rule (CAIR) over the next 10 to 15 years. Based on an assessment of the emissions contributing to interstate transport of air pollution and available control measures, EPA determined that achieving required reductions in the identified States by controlling emissions from power plants is highly cost effective. CAIR will permanently cap emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the eastern United States. CAIR achieves large reductions of SO_2 and/or NO_x emissions across 28 eastern states and the District of Columbia.

Figure 3a.1: CAIR Affected Region



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

Based on the final State rules that have been submitted and the proposed State rules that EPA has reviewed, EPA believes that all States intend to use the CAIR trading programs as their mechanism for meeting the emission reduction requirements of CAIR.

The analysis in this section reflects these realities and attempts to show, in an illustrative fashion, the costs and impacts of meeting a proposed 8-hr ozone standard of 0.070 ppm for the power sector.

3a.3.2 Integrated Planning Model and Background

CAIR was designed to achieve significant emissions reductions in a highly cost-effective manner to reduce the transport of fine particles that have been found to contribute to nonattainment. EPA analysis has found that the most efficient method to achieve the emissions reduction targets is through a cap-and-trade system on the power sector that States have the option of adopting. The modeling done with IPM assumes a region-wide cap and trade system on the power sector for the States covered.

It is important to note that the proposal RIA analysis used the Integrated Planning Model (IPM) v2.1.9 to ensure consistency with the analysis presented in 2006 PM NAAQS RIA and report incremental results. EPA's IPM v2.1.9 incorporated Federal and State rules and regulations adopted before March 2004 and various NSR settlements.

Final RIA analysis uses the latest version of IPM (v3.0) as part of the updated modeling platform. 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 NSR settlements. A detailed discussion of uncertainties associated with the EGU sector modeling can be found in 2006 PM NAAQS RIA (pg. 3-50)

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

3a.3.3 EGU NOx Emission Control Technologies

IPM v3.0 includes SO_2, NO_x, and mercury (Hg) emission control technology options for meeting existing and future federal, regional, and state, SO_2, NO_x and Hg emission limits. The NOx control technology options include Selective Catalytic Reduction (SCR) system and Selective Non-Catalytic Reduction (SNCR) systems. 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. Table 3a.22 summarizes retrofit NOx emission control performance assumptions.

Table 3a.17: Summary of Retrofit NOx Emission Control Performance Assumptions

	Selective Catalytic Reduction (SCR)		Selective Non-Catalytic Reduction (SNCR)	
Unit Type	**Coal**	**Oil/Gas[a]**	**Coal**	**Oil/Gas[a]**
Percent Removal	90% down to 0.06 lb/mmBtu	80%	35%	50%
Size Applicability	Units. 100 MW	Units. 25 MW	Units. 25 MW and Units < 200 MW	Units. 25 MW

[a] Controls to oil- or gas-fired EGUs are not applied as part of the EGU control strategy included in this RIA.

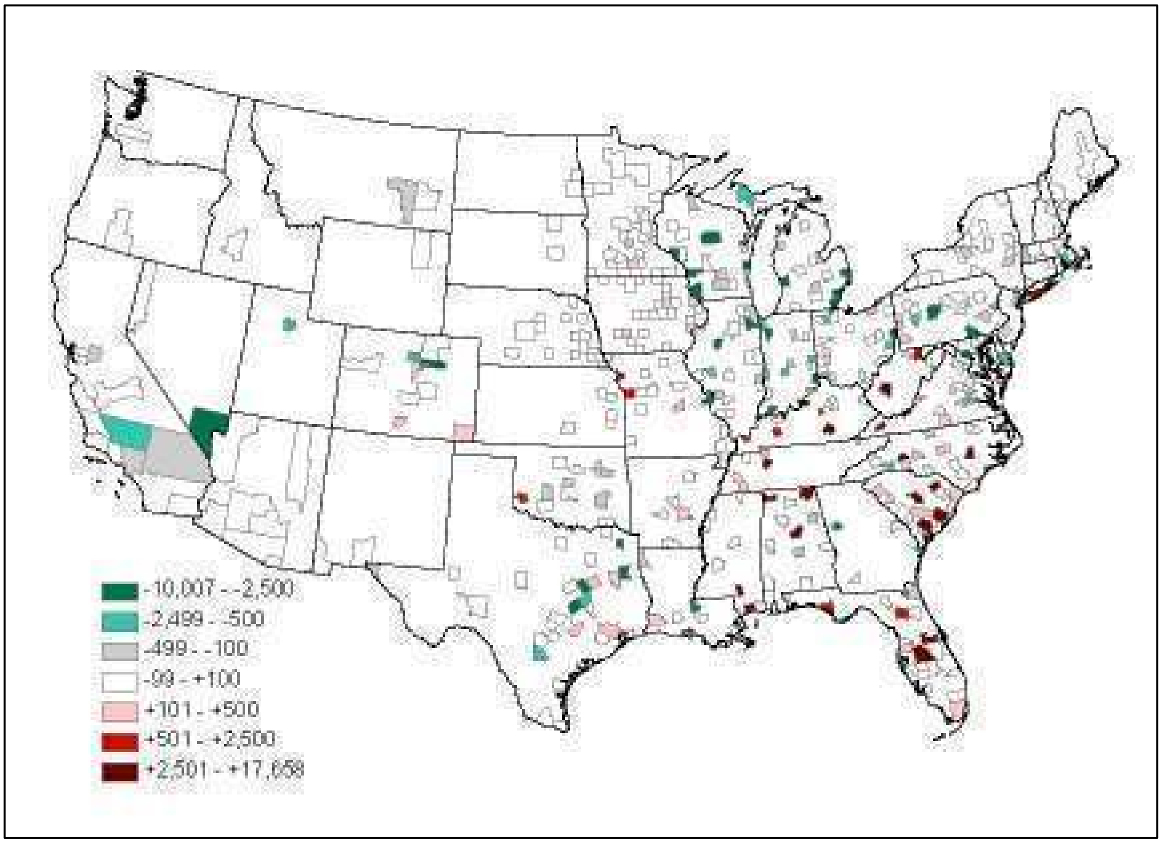
Existing coal-fired units that are retrofit with SCR have a NOx removal efficiency of 90%, with a minimum controlled NOx emission rate of 0.06 lb/mmBtu in IPM v2.1.9. Potential (new) coal-fired, combined cycle, and IGCC units are modeled to be constructed with SCR systems and designed to have emission rates ranging between 0.02 and 0.06 lb NOx/mmBtu.

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

3a.4 Emissions Reductions by Sector

Figures 3a.2–3a.6 show the NOx reductions for each sector and Figures 3a.7–3a.10 show the VOC reductions for each sector under the modeled control strategy.

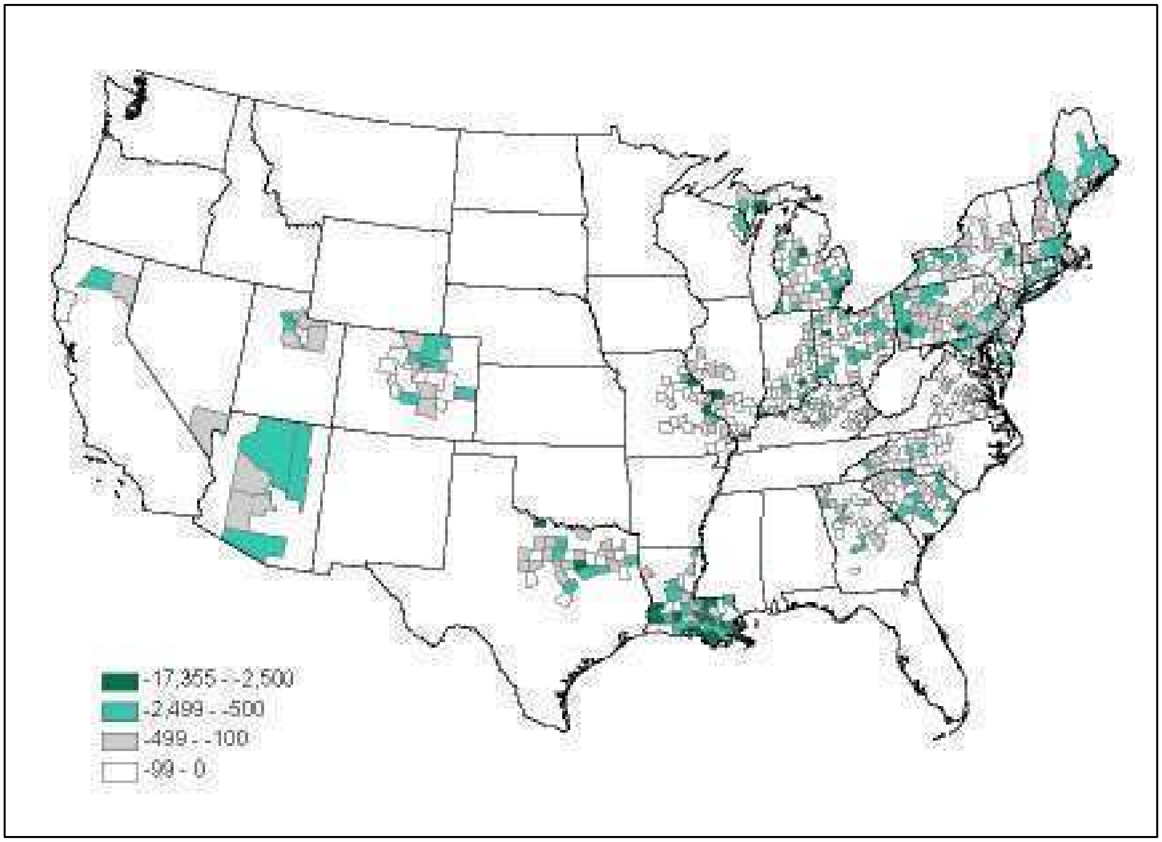
Figure 3a.2: Annual Tons of NOx Emissions Reduced from EGU Sources*



* Reductions are negative and increases are positive.

** The −99–+100 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

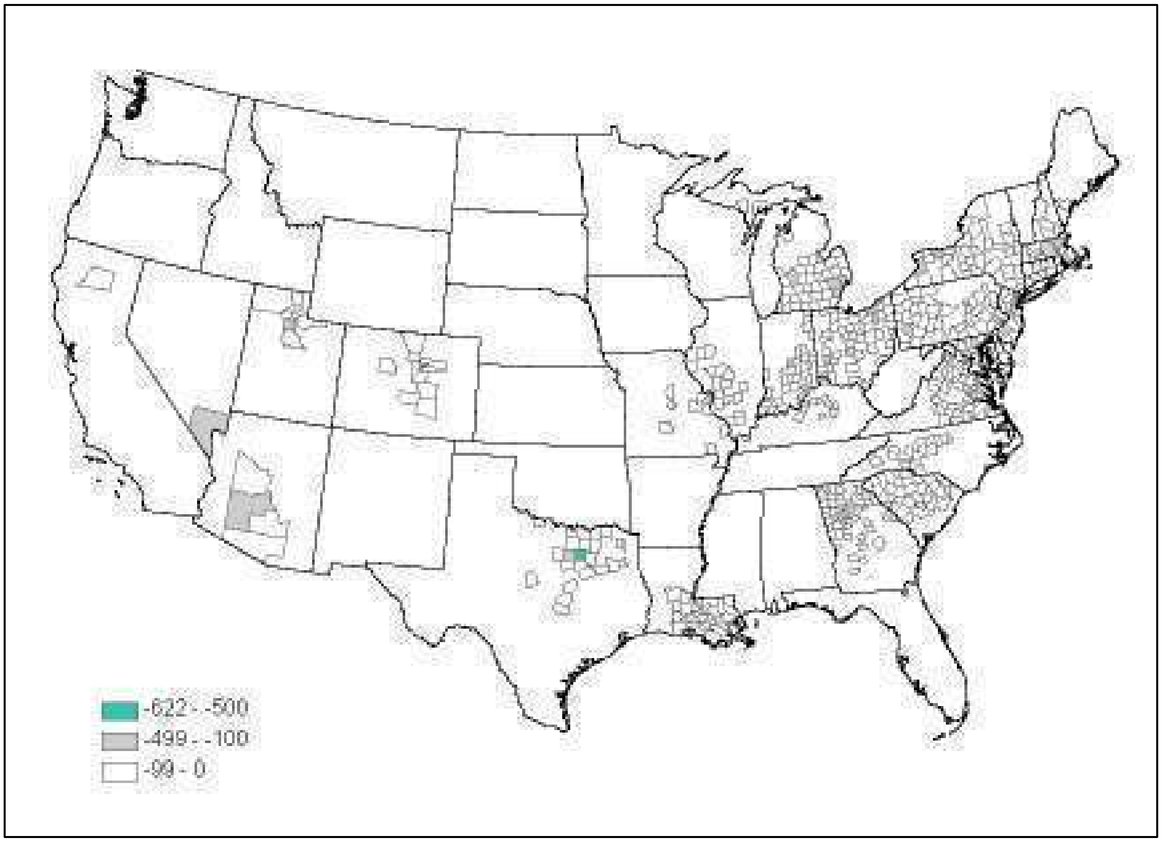
Figure 3a.3: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from NonEGU Point Sources*



* Reductions are negative and increases are positive.

** The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

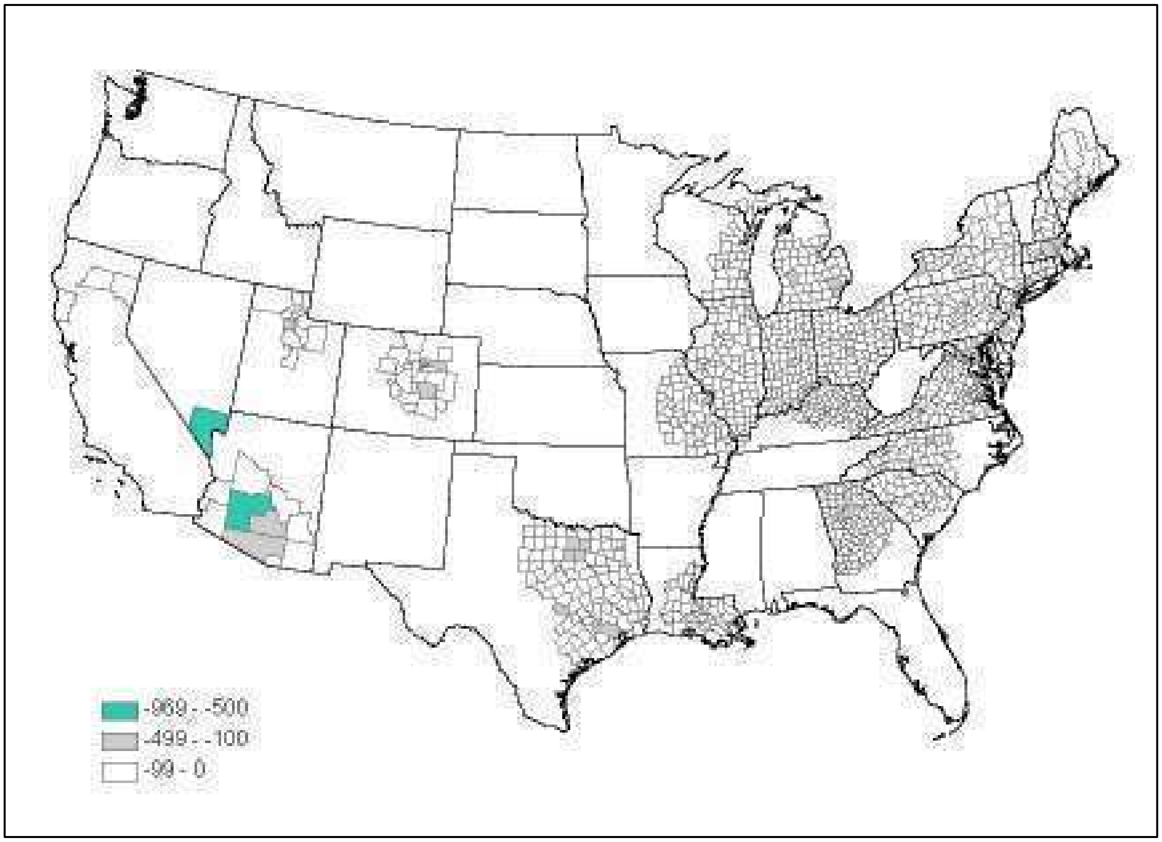
Figure 3a.4: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Area Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

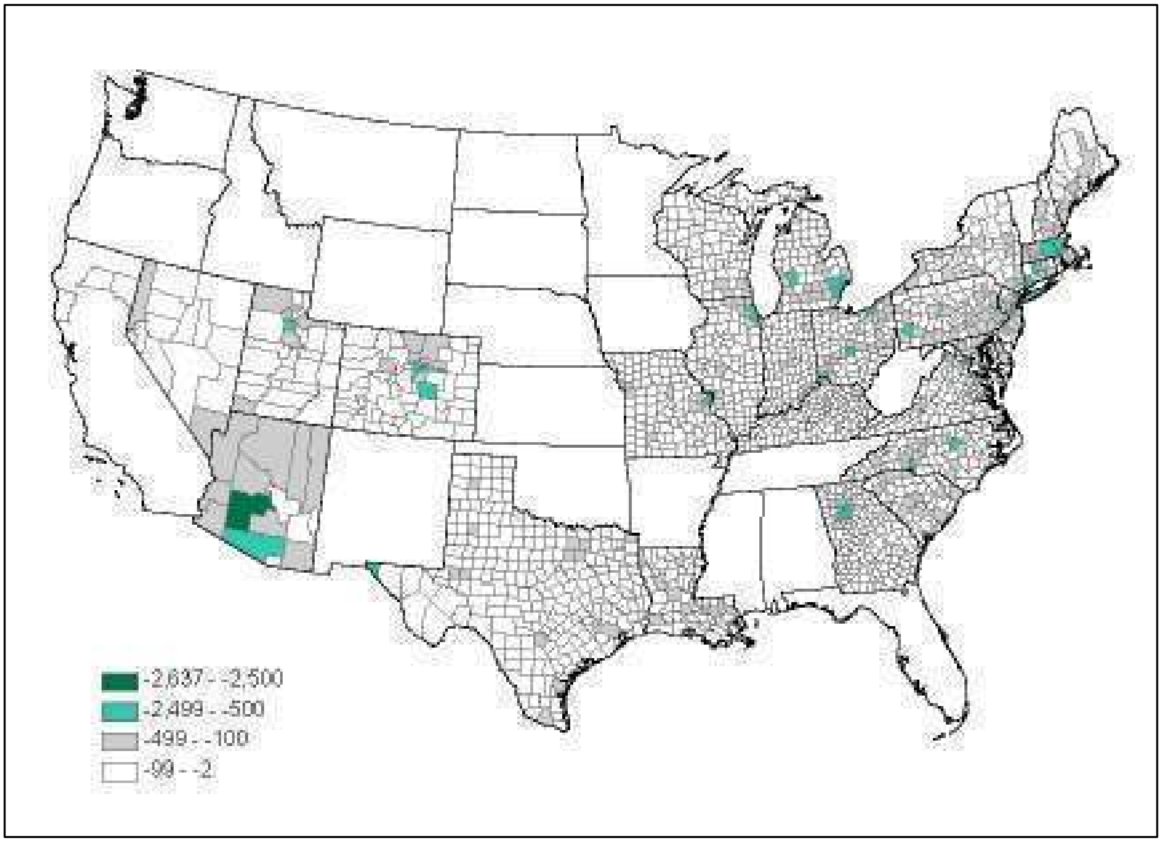
Figure 3a.5: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Nonroad Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

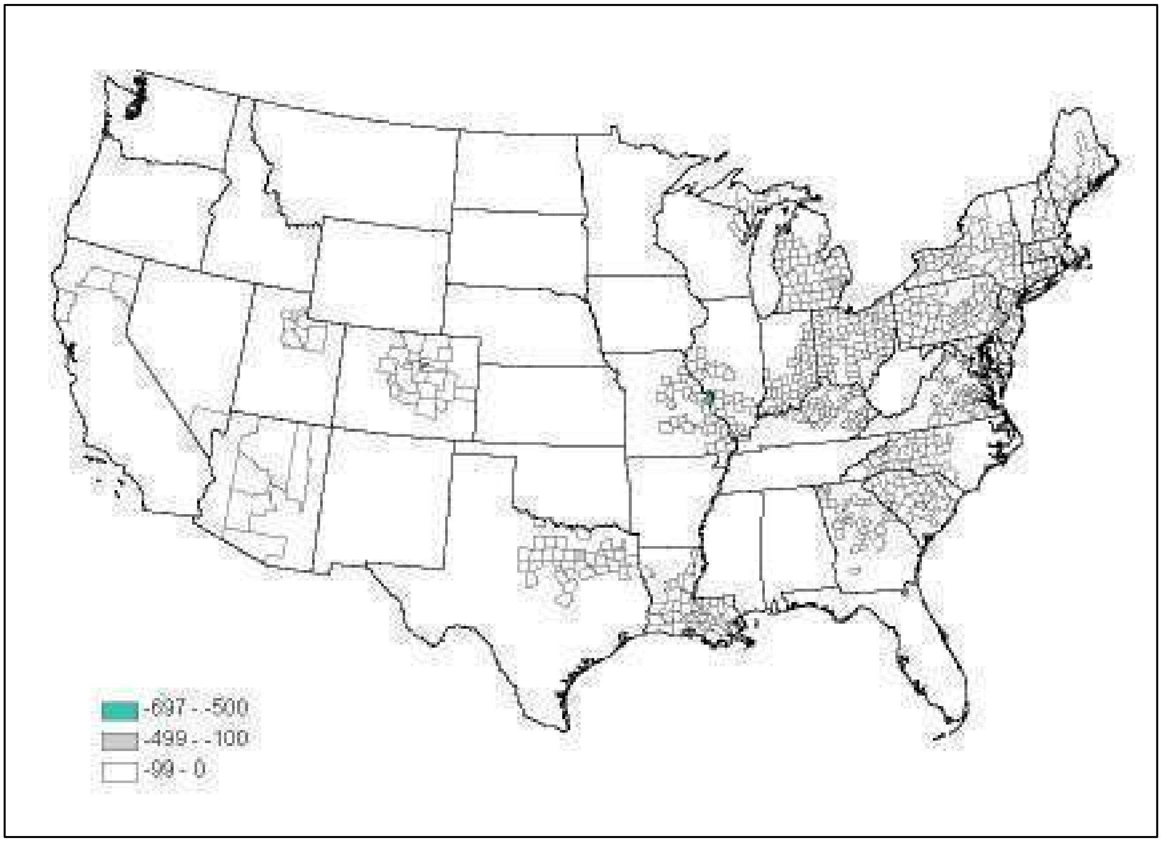
Figure 3a.6: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Onroad Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

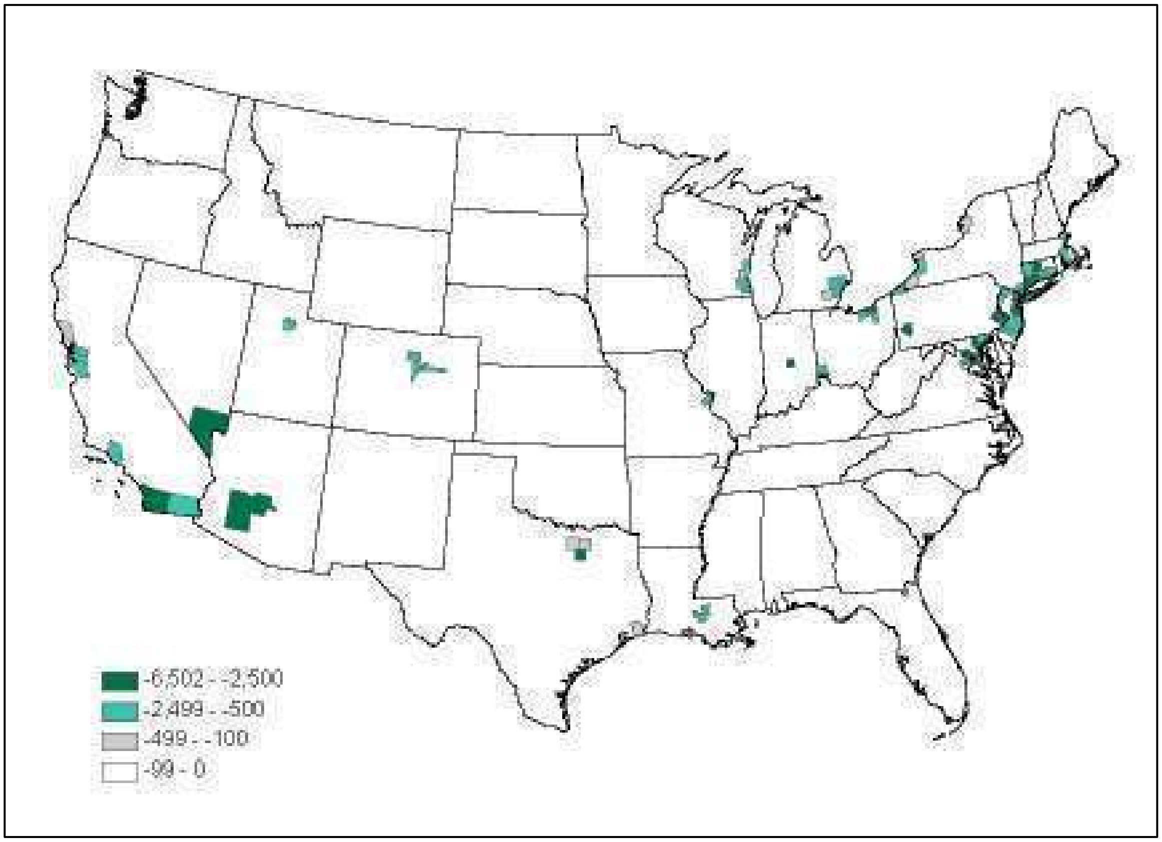
Figure 3a.7: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from NonEGU Point Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates

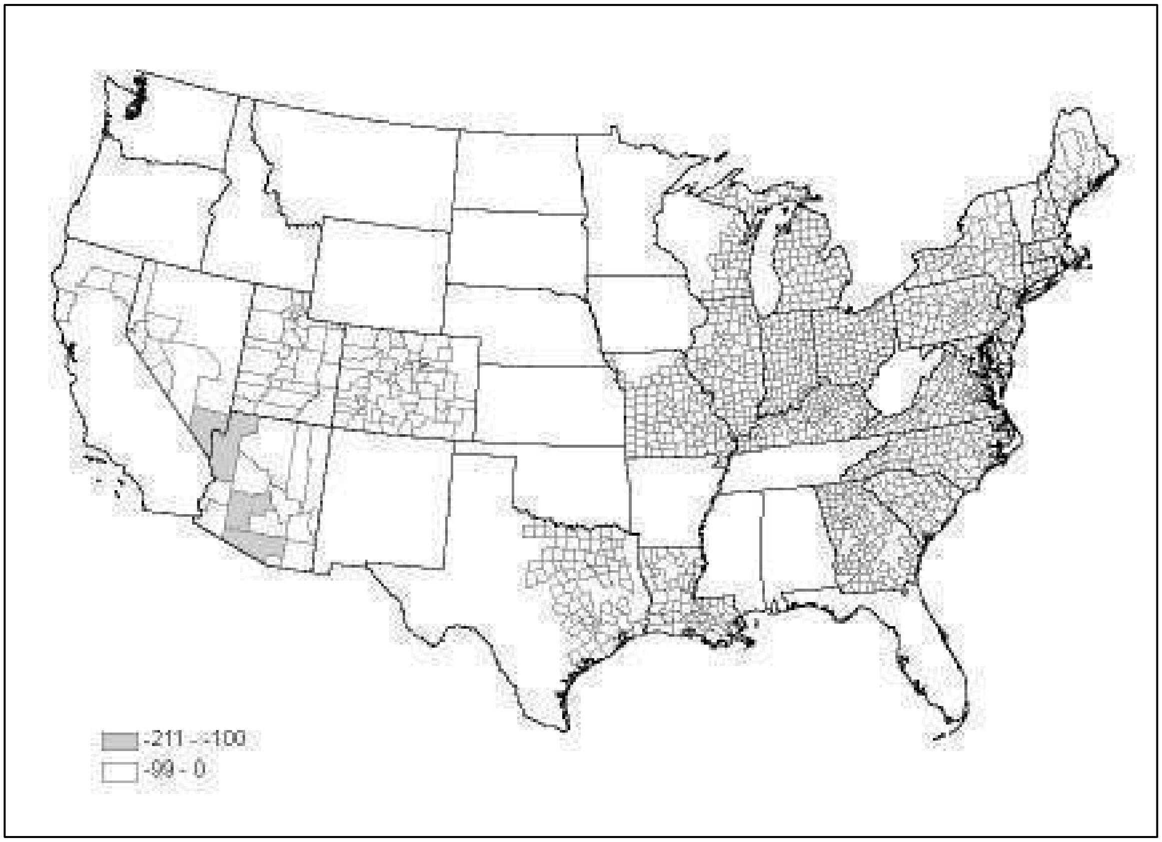
Figure 3a.8: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Area Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

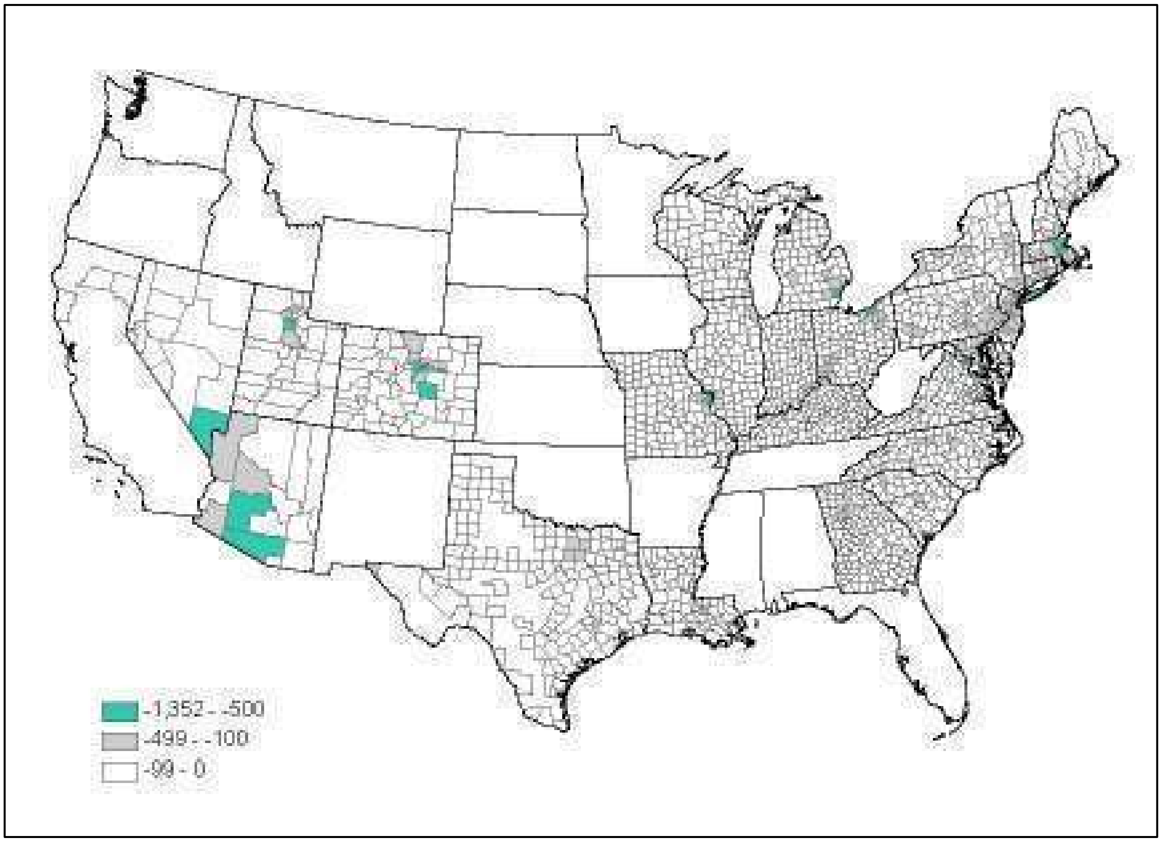
Figure 3a.9: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Nonroad Mobile Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

Figure 3a.10: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Onroad Mobile Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

3a.5 Change in Ozone Concentrations Between Baseline and Modeled Control Strategy

Table 3a.23 provides the projected 8-hour ozone design values for the 2020 baseline and 2020 control strategy scenarios for each monitored county. The changes in ozone in 2020 between the baseline and the control strategy are also provided in this table.

Table 3a.18: Changes in Ozone Concentrations between Baseline and Modeled Control Strategy

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Alabama	Baldwin	0.064	0.064	0.000
Alabama	Clay	0.057	0.056	−0.001
Alabama	Elmore	0.055	0.055	0.001
Alabama	Etowah	0.054	0.053	−0.001
Alabama	Jefferson	0.059	0.061	0.001
Alabama	Lawrence	0.055	0.056	0.001
Alabama	Madison	0.057	0.058	0.001
Alabama	Mobile	0.064	0.064	0.000
Alabama	Montgomery	0.055	0.055	0.000
Alabama	Morgan	0.060	0.061	0.001
Alabama	Shelby	0.061	0.063	0.002
Alabama	Sumter	0.051	0.051	0.000
Alabama	Tuscaloosa	0.052	0.052	0.000
Arizona	Cochise	0.065	0.065	0.000
Arizona	Coconino	0.067	0.067	0.000
Arizona	Maricopa	0.070	0.068	−0.002
Arizona	Navajo	0.058	0.058	−0.001
Arizona	Pima	0.064	0.063	−0.001
Arizona	Pinal	0.065	0.063	−0.002
Arizona	Yavapai	0.065	0.065	0.000
Arkansas	Crittenden	0.068	0.069	0.000
Arkansas	Montgomery	0.051	0.051	0.000
Arkansas	Newton	0.060	0.060	0.000
Arkansas	Pulaski	0.061	0.062	0.000
California	Alameda	0.069	0.069	0.000
California	Amador	0.067	0.067	0.000
California	Butte	0.069	0.068	0.000
California	Calaveras	0.072	0.072	0.000
California	Colusa	0.058	0.058	0.000
California	Contra Costa	0.070	0.069	0.000
California	El Dorado	0.081	0.081	0.000
California	Fresno	0.091	0.091	0.000
California	Glenn	0.058	0.058	0.000
California	Imperial	0.071	0.071	0.000
California	Inyo	0.068	0.068	0.000
California	Kern	0.097	0.096	0.000
California	Kings	0.076	0.076	0.000
California	Lake	0.054	0.054	0.000
California	Los Angeles	0.105	0.104	0.000
California	Madera	0.076	0.076	0.000
California	Marin	0.041	0.041	0.000
California	Mariposa	0.072	0.072	0.000
California	Mendocino	0.046	0.046	0.000
California	Merced	0.079	0.079	0.000
California	Monterey	0.055	0.055	0.000
California	Napa	0.051	0.051	0.000
California	Nevada	0.075	0.075	0.000
California	Orange	0.081	0.081	0.000

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
California	Placer	0.076	0.076	0.000
California	Riverside	0.102	0.102	0.000
California	Sacramento	0.077	0.077	0.000
California	San Benito	0.066	0.066	0.000
California	San Bernardino	0.123	0.123	0.000
California	San Diego	0.077	0.077	0.000
California	San Francisco	0.046	0.046	0.000
California	San Joaquin	0.067	0.067	0.000
California	San Luis Obispo	0.060	0.060	0.000
California	San Mateo	0.051	0.051	0.000
California	Santa Barbara	0.068	0.068	0.000
California	Santa Clara	0.066	0.066	0.000
California	Santa Cruz	0.055	0.055	0.000
California	Shasta	0.058	0.058	0.000
California	Solano	0.057	0.057	0.000
California	Sonoma	0.048	0.048	0.000
California	Stanislaus	0.077	0.077	0.000
California	Sutter	0.068	0.068	0.000
California	Tehama	0.066	0.065	−0.001
California	Tulare	0.083	0.083	0.000
California	Tuolumne	0.073	0.073	0.000
California	Ventura	0.077	0.077	0.000
California	Yolo	0.065	0.064	0.000
Colorado	Adams	0.057	0.053	−0.004
Colorado	Arapahoe	0.069	0.065	−0.005
Colorado	Boulder	0.063	0.058	−0.004
Colorado	Denver	0.064	0.060	−0.004
Colorado	Douglas	0.072	0.068	−0.005
Colorado	El Paso	0.062	0.060	−0.003
Colorado	Jefferson	0.073	0.068	−0.005
Colorado	La Plata	0.052	0.051	0.000
Colorado	Larimer	0.067	0.062	−0.005
Colorado	Montezuma	0.062	0.062	0.000
Colorado	Weld	0.064	0.060	−0.004
Connecticut	Fairfield	0.079	0.077	−0.002
Connecticut	Hartford	0.066	0.063	−0.003
Connecticut	Litchfield	0.064	0.062	−0.003
Connecticut	Middlesex	0.073	0.071	−0.003
Connecticut	New Haven	0.076	0.074	−0.003
Connecticut	New London	0.068	0.066	−0.002
Connecticut	Tolland	0.068	0.065	−0.003
Delaware	Kent	0.069	0.067	−0.002
Delaware	New Castle	0.071	0.068	−0.003
Delaware	Sussex	0.070	0.068	−0.002
D.C.	Washington	0.069	0.065	−0.004
Florida	Alachua	0.056	0.057	0.000
Florida	Baker	0.055	0.054	−0.001
Florida	Bay	0.061	0.063	0.002
Florida	Brevard	0.051	0.052	0.001
Florida	Broward	0.054	0.054	0.000

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Florida	Collier	0.057	0.056	0.000
Florida	Columbia	0.053	0.052	0.000
Florida	Duval	0.053	0.052	0.000
Florida	Escambia	0.065	0.065	0.000
Florida	Highlands	0.054	0.054	0.000
Florida	Hillsborough	0.065	0.065	0.000
Florida	Holmes	0.055	0.055	0.000
Florida	Lake	0.055	0.056	0.001
Florida	Lee	0.056	0.056	0.000
Florida	Leon	0.055	0.055	0.000
Florida	Manatee	0.061	0.061	0.000
Florida	Marion	0.058	0.058	0.000
Florida	Miami-Dade	0.053	0.053	0.000
Florida	Orange	0.056	0.058	0.002
Florida	Osceola	0.053	0.054	0.001
Florida	Palm Beach	0.055	0.054	0.000
Florida	Pasco	0.058	0.058	0.000
Florida	Pinellas	0.061	0.061	0.000
Florida	Polk	0.058	0.059	0.001
Florida	St Lucie	0.052	0.052	0.000
Florida	Santa Rosa	0.063	0.064	0.000
Florida	Sarasota	0.060	0.061	0.000
Florida	Seminole	0.057	0.058	0.001
Florida	Volusia	0.051	0.051	0.000
Florida	Wakulla	0.059	0.059	0.000
Georgia	Bibb	0.065	0.063	−0.001
Georgia	Chatham	0.053	0.052	0.000
Georgia	Cherokee	0.053	0.051	−0.002
Georgia	Clarke	0.054	0.052	−0.002
Georgia	Cobb	0.063	0.061	−0.002
Georgia	Coweta	0.065	0.060	−0.006
Georgia	Dawson	0.056	0.054	−0.002
Georgia	De Kalb	0.067	0.065	−0.002
Georgia	Douglas	0.064	0.062	−0.002
Georgia	Fayette	0.062	0.060	−0.002
Georgia	Fulton	0.070	0.068	−0.002
Georgia	Glynn	0.054	0.054	−0.001
Georgia	Gwinnett	0.061	0.059	−0.002
Georgia	Henry	0.064	0.062	−0.002
Georgia	Murray	0.059	0.058	−0.001
Georgia	Muscogee	0.054	0.052	−0.002
Georgia	Paulding	0.060	0.058	−0.002
Georgia	Richmond	0.064	0.059	−0.005
Georgia	Rockdale	0.064	0.062	−0.002
Georgia	Sumter	0.054	0.053	−0.001
Idaho	Ada	0.069	0.069	0.000
Idaho	Butte	0.065	0.065	0.000
Idaho	Canyon	0.059	0.059	0.000
Idaho	Elmore	0.060	0.060	0.000
Illinois	Adams	0.060	0.056	−0.004

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Illinois	Champaign	0.058	0.057	−0.001
Illinois	Clark	0.053	0.053	−0.001
Illinois	Cook	0.074	0.073	−0.001
Illinois	Du Page	0.061	0.059	−0.001
Illinois	Effingham	0.057	0.056	−0.001
Illinois	Hamilton	0.059	0.057	−0.002
Illinois	Jersey	0.067	0.065	−0.002
Illinois	Kane	0.062	0.061	−0.001
Illinois	Lake	0.071	0.070	−0.001
Illinois	McHenry	0.067	0.065	−0.001
Illinois	McLean	0.057	0.056	−0.001
Illinois	Macon	0.056	0.055	−0.001
Illinois	Macoupin	0.057	0.055	−0.002
Illinois	Madison	0.066	0.064	−0.003
Illinois	Peoria	0.063	0.062	−0.001
Illinois	Randolph	0.059	0.058	−0.001
Illinois	Rock Island	0.055	0.054	−0.001
Illinois	St Clair	0.066	0.064	−0.002
Illinois	Sangamon	0.054	0.053	−0.001
Illinois	Will	0.062	0.060	−0.001
Illinois	Winnebago	0.058	0.057	−0.001
Indiana	Allen	0.067	0.065	−0.002
Indiana	Boone	0.067	0.066	−0.002
Indiana	Carroll	0.062	0.061	−0.001
Indiana	Clark	0.068	0.067	−0.002
Indiana	Delaware	0.064	0.063	−0.002
Indiana	Elkhart	0.066	0.064	−0.002
Indiana	Floyd	0.066	0.065	−0.002
Indiana	Gibson	0.051	0.050	−0.001
Indiana	Greene	0.063	0.061	−0.001
Indiana	Hamilton	0.070	0.068	−0.002
Indiana	Hancock	0.067	0.066	−0.002
Indiana	Hendricks	0.065	0.063	−0.002
Indiana	Huntington	0.064	0.062	−0.002
Indiana	Jackson	0.062	0.060	−0.002
Indiana	Johnson	0.064	0.063	−0.002
Indiana	Lake	0.078	0.077	−0.001
Indiana	La Porte	0.074	0.073	−0.001
Indiana	Madison	0.067	0.066	−0.002
Indiana	Marion	0.069	0.067	−0.002
Indiana	Morgan	0.066	0.064	−0.002
Indiana	Porter	0.075	0.074	−0.001
Indiana	Posey	0.061	0.060	−0.002
Indiana	St Joseph	0.068	0.067	−0.002
Indiana	Shelby	0.069	0.067	−0.002
Indiana	Vanderburgh	0.060	0.058	−0.002
Indiana	Vigo	0.066	0.065	−0.002
Indiana	Warrick	0.064	0.061	−0.003
Iowa	Bremer	0.059	0.059	0.000
Iowa	Clinton	0.063	0.062	−0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Iowa	Harrison	0.062	0.062	0.000
Iowa	Linn	0.058	0.057	−0.001
Iowa	Montgomery	0.056	0.056	0.000
Iowa	Palo Alto	0.054	0.054	0.000
Iowa	Polk	0.047	0.046	0.000
Iowa	Scott	0.061	0.060	−0.001
Iowa	Story	0.049	0.048	0.000
Iowa	Van Buren	0.059	0.058	−0.001
Iowa	Warren	0.049	0.049	0.000
Kansas	Linn	0.060	0.060	0.000
Kansas	Sedgwick	0.064	0.064	0.000
Kansas	Sumner	0.063	0.062	0.000
Kansas	Trego	0.055	0.055	0.000
Kansas	Wyandotte	0.063	0.062	0.000
Kentucky	Bell	0.056	0.056	−0.001
Kentucky	Boone	0.063	0.061	−0.002
Kentucky	Boyd	0.071	0.069	−0.002
Kentucky	Bullitt	0.062	0.060	−0.002
Kentucky	Campbell	0.070	0.068	−0.003
Kentucky	Carter	0.058	0.057	−0.001
Kentucky	Christian	0.058	0.058	0.000
Kentucky	Daviess	0.059	0.058	−0.001
Kentucky	Edmonson	0.059	0.058	−0.001
Kentucky	Fayette	0.057	0.056	−0.002
Kentucky	Graves	0.060	0.059	−0.001
Kentucky	Greenup	0.065	0.063	−0.001
Kentucky	Hancock	0.063	0.064	0.001
Kentucky	Hardin	0.058	0.056	−0.001
Kentucky	Henderson	0.060	0.058	−0.003
Kentucky	Jefferson	0.065	0.063	−0.002
Kentucky	Jessamine	0.057	0.056	−0.001
Kentucky	Kenton	0.066	0.063	−0.003
Kentucky	Livingston	0.061	0.061	−0.001
Kentucky	McCracken	0.064	0.063	−0.001
Kentucky	McLean	0.059	0.058	−0.001
Kentucky	Oldham	0.063	0.061	−0.002
Kentucky	Perry	0.055	0.055	−0.001
Kentucky	Pike	0.055	0.053	−0.001
Kentucky	Pulaski	0.059	0.061	0.002
Kentucky	Scott	0.050	0.049	−0.001
Kentucky	Simpson	0.057	0.056	0.000
Kentucky	Trigg	0.052	0.053	0.000
Kentucky	Warren	0.060	0.059	−0.001
Louisiana	Ascension	0.069	0.065	−0.004
Louisiana	Beauregard	0.062	0.059	−0.003
Louisiana	Bossier	0.061	0.060	−0.001
Louisiana	Caddo	0.059	0.057	−0.001
Louisiana	Calcasieu	0.066	0.064	−0.002
Louisiana	East Baton Rouge	0.077	0.074	−0.003
Louisiana	Grant	0.060	0.058	−0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Louisiana	Iberville	0.073	0.069	−0.004
Louisiana	Jefferson	0.069	0.067	−0.002
Louisiana	Lafayette	0.066	0.061	−0.005
Louisiana	Lafourche	0.065	0.062	−0.003
Louisiana	Livingston	0.069	0.064	−0.004
Louisiana	Orleans	0.058	0.056	−0.001
Louisiana	Ouachita	0.061	0.060	−0.001
Louisiana	Pointe Coupee	0.064	0.057	−0.007
Louisiana	St Bernard	0.063	0.062	−0.001
Louisiana	St Charles	0.066	0.064	−0.002
Louisiana	St James	0.064	0.061	−0.003
Louisiana	St John The Baptist	0.069	0.066	−0.003
Louisiana	St Mary	0.061	0.058	−0.004
Louisiana	West Baton Rouge	0.074	0.070	−0.004
Maine	Cumberland	0.063	0.061	−0.002
Maine	Hancock	0.071	0.069	−0.003
Maine	Kennebec	0.060	0.058	−0.002
Maine	Knox	0.063	0.061	−0.002
Maine	Oxford	0.050	0.049	−0.001
Maine	Penobscot	0.064	0.062	−0.002
Maine	Sagadahoc	0.060	0.057	−0.002
Maine	York	0.067	0.064	−0.002
Maryland	Anne Arundel	0.072	0.069	−0.003
Maryland	Baltimore	0.071	0.068	−0.003
Maryland	Carroll	0.065	0.062	−0.003
Maryland	Cecil	0.071	0.068	−0.003
Maryland	Charles	0.065	0.062	−0.003
Maryland	Frederick	0.066	0.061	−0.004
Maryland	Harford	0.077	0.074	−0.003
Maryland	Kent	0.070	0.067	−0.003
Maryland	Montgomery	0.064	0.061	−0.003
Maryland	Prince Georges	0.069	0.066	−0.003
Maryland	Washington	0.064	0.061	−0.003
Massachusetts	Barnstable	0.071	0.068	−0.002
Massachusetts	Berkshire	0.069	0.067	−0.002
Massachusetts	Bristol	0.069	0.067	−0.003
Massachusetts	Essex	0.070	0.068	−0.002
Massachusetts	Hampden	0.068	0.066	−0.003
Massachusetts	Hampshire	0.066	0.064	−0.002
Massachusetts	Middlesex	0.065	0.062	−0.003
Massachusetts	Norfolk	0.074	0.072	−0.002
Massachusetts	Suffolk	0.069	0.067	−0.002
Massachusetts	Worcester	0.065	0.063	−0.002
Michigan	Allegan	0.073	0.072	−0.001
Michigan	Benzie	0.067	0.065	−0.001
Michigan	Berrien	0.071	0.069	−0.001
Michigan	Cass	0.068	0.067	−0.002
Michigan	Clinton	0.065	0.063	−0.002
Michigan	Genesee	0.066	0.065	−0.002
Michigan	Huron	0.069	0.067	−0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Michigan	Ingham	0.064	0.062	−0.002
Michigan	Kalamazoo	0.063	0.061	−0.002
Michigan	Kent	0.065	0.063	−0.002
Michigan	Lenawee	0.067	0.065	−0.002
Michigan	Macomb	0.075	0.073	−0.002
Michigan	Mason	0.066	0.064	−0.001
Michigan	Missaukee	0.062	0.061	−0.001
Michigan	Muskegon	0.070	0.069	−0.001
Michigan	Oakland	0.072	0.071	−0.001
Michigan	Ottawa	0.067	0.065	−0.002
Michigan	St Clair	0.070	0.068	−0.002
Michigan	Schoolcraft	0.063	0.062	−0.001
Michigan	Washtenaw	0.069	0.067	−0.002
Michigan	Wayne	0.071	0.069	−0.002
Minnesota	St Louis	0.059	0.059	0.000
Mississippi	Adams	0.060	0.060	−0.001
Mississippi	Bolivar	0.057	0.057	0.000
Mississippi	De Soto	0.062	0.062	0.000
Mississippi	Hancock	0.063	0.062	−0.001
Mississippi	Harrison	0.063	0.065	0.003
Mississippi	Hinds	0.051	0.050	0.000
Mississippi	Jackson	0.067	0.068	0.000
Mississippi	Lauderdale	0.051	0.051	0.000
Mississippi	Lee	0.056	0.058	0.002
Mississippi	Madison	0.054	0.054	0.000
Mississippi	Warren	0.052	0.052	0.000
Missouri	Cass	0.061	0.061	0.000
Missouri	Cedar	0.064	0.063	−0.001
Missouri	Clay	0.065	0.064	−0.001
Missouri	Greene	0.059	0.058	−0.001
Missouri	Jefferson	0.067	0.064	−0.003
Missouri	Monroe	0.060	0.059	−0.001
Missouri	Platte	0.063	0.063	−0.001
Missouri	St Charles	0.071	0.069	−0.002
Missouri	Ste Genevieve	0.065	0.063	−0.002
Missouri	St Louis	0.070	0.068	−0.003
Missouri	St Louis City	0.071	0.068	−0.002
Montana	Flathead	0.053	0.053	0.000
Nebraska	Douglas	0.056	0.056	0.000
Nebraska	Lancaster	0.046	0.046	0.000
Nevada	Clark	0.072	0.071	−0.001
Nevada	Douglas	0.059	0.059	0.000
Nevada	Washoe	0.064	0.063	0.000
Nevada	White Pine	0.066	0.065	0.000
Nevada	Carson City	0.063	0.063	0.000
New Hampshire	Belknap	0.060	0.058	−0.002
New Hampshire	Carroll	0.055	0.054	−0.001
New Hampshire	Cheshire	0.057	0.055	−0.002
New Hampshire	Grafton	0.058	0.057	−0.001
New Hampshire	Hillsborough	0.065	0.063	−0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
New Hampshire	Merrimack	0.058	0.056	−0.002
New Hampshire	Rockingham	0.064	0.061	−0.002
New Hampshire	Strafford	0.060	0.058	−0.002
New Hampshire	Sullivan	0.061	0.060	−0.001
New Jersey	Atlantic	0.067	0.065	−0.002
New Jersey	Bergen	0.074	0.072	−0.002
New Jersey	Camden	0.077	0.075	−0.003
New Jersey	Cumberland	0.072	0.069	−0.003
New Jersey	Essex	0.053	0.051	−0.002
New Jersey	Gloucester	0.076	0.073	−0.003
New Jersey	Hudson	0.066	0.064	−0.002
New Jersey	Hunterdon	0.071	0.068	−0.003
New Jersey	Mercer	0.076	0.073	−0.003
New Jersey	Middlesex	0.073	0.070	−0.003
New Jersey	Monmouth	0.073	0.071	−0.002
New Jersey	Morris	0.071	0.068	−0.003
New Jersey	Ocean	0.080	0.077	−0.003
New Jersey	Passaic	0.067	0.065	−0.003
New Mexico	Bernalillo	0.065	0.065	0.000
New Mexico	Dona Ana	0.069	0.068	−0.001
New Mexico	Eddy	0.064	0.063	0.000
New Mexico	Sandoval	0.064	0.063	0.000
New Mexico	San Juan	0.070	0.069	0.000
New Mexico	Valencia	0.057	0.057	0.000
New York	Albany	0.065	0.061	−0.003
New York	Bronx	0.069	0.067	−0.002
New York	Chautauqua	0.073	0.070	−0.003
New York	Chemung	0.062	0.060	−0.002
New York	Dutchess	0.069	0.066	−0.003
New York	Erie	0.075	0.072	−0.003
New York	Essex	0.069	0.067	−0.002
New York	Hamilton	0.063	0.062	−0.001
New York	Herkimer	0.059	0.058	−0.001
New York	Jefferson	0.073	0.072	−0.002
New York	Madison	0.062	0.061	−0.002
New York	Monroe	0.067	0.065	−0.002
New York	Niagara	0.075	0.074	−0.002
New York	Oneida	0.063	0.061	−0.002
New York	Onondaga	0.068	0.066	−0.002
New York	Orange	0.064	0.061	−0.003
New York	Oswego	0.054	0.052	−0.002
New York	Putnam	0.071	0.068	−0.003
New York	Queens	0.070	0.068	−0.002
New York	Rensselaer	0.067	0.064	−0.003
New York	Richmond	0.074	0.071	−0.002
New York	Saratoga	0.067	0.064	−0.003
New York	Schenectady	0.062	0.059	−0.002
New York	Suffolk	0.080	0.078	−0.002
New York	Ulster	0.064	0.062	−0.002
New York	Wayne	0.066	0.064	−0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
New York	Westchester	0.074	0.071	−0.003
North Carolina	Alexander	0.062	0.062	0.000
North Carolina	Avery	0.059	0.058	−0.001
North Carolina	Buncombe	0.061	0.060	−0.001
North Carolina	Caldwell	0.061	0.060	0.000
North Carolina	Caswell	0.061	0.060	−0.001
North Carolina	Chatham	0.059	0.058	−0.001
North Carolina	Cumberland	0.062	0.060	−0.001
North Carolina	Davie	0.064	0.062	−0.002
North Carolina	Duplin	0.060	0.059	−0.001
North Carolina	Durham	0.062	0.060	−0.001
North Carolina	Edgecombe	0.063	0.062	−0.001
North Carolina	Forsyth	0.064	0.062	−0.002
North Carolina	Franklin	0.063	0.062	−0.001
North Carolina	Granville	0.065	0.063	−0.001
North Carolina	Guilford	0.060	0.059	−0.001
North Carolina	Haywood	0.065	0.064	−0.001
North Carolina	Jackson	0.064	0.063	−0.001
North Carolina	Johnston	0.060	0.059	−0.001
North Carolina	Lenoir	0.060	0.060	−0.001
North Carolina	Lincoln	0.065	0.065	0.001
North Carolina	Martin	0.060	0.059	−0.001
North Carolina	Mecklenburg	0.072	0.071	−0.001
North Carolina	New Hanover	0.057	0.057	0.001
North Carolina	Northampton	0.062	0.061	−0.002
North Carolina	Person	0.063	0.062	−0.001
North Carolina	Pitt	0.059	0.058	−0.001
North Carolina	Randolph	0.058	0.057	−0.001
North Carolina	Rockingham	0.062	0.061	−0.001
North Carolina	Rowan	0.069	0.067	−0.002
North Carolina	Swain	0.053	0.053	−0.001
North Carolina	Union	0.062	0.061	−0.001
North Carolina	Wake	0.064	0.063	−0.001
North Carolina	Yancey	0.063	0.062	−0.001
North Dakota	Billings	0.054	0.054	0.000
North Dakota	Cass	0.056	0.055	0.000
North Dakota	Dunn	0.054	0.054	0.000
North Dakota	McKenzie	0.058	0.058	0.000
North Dakota	Mercer	0.055	0.055	0.000
North Dakota	Oliver	0.051	0.051	0.000
Ohio	Allen	0.068	0.066	−0.003
Ohio	Ashtabula	0.076	0.073	−0.003
Ohio	Butler	0.068	0.065	−0.003
Ohio	Clark	0.067	0.063	−0.004
Ohio	Clermont	0.069	0.066	−0.003
Ohio	Clinton	0.069	0.067	−0.003
Ohio	Cuyahoga	0.068	0.066	−0.002
Ohio	Delaware	0.067	0.064	−0.002
Ohio	Franklin	0.069	0.066	−0.002
Ohio	Geauga	0.077	0.074	−0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Ohio	Greene	0.066	0.062	−0.004
Ohio	Hamilton	0.069	0.066	−0.003
Ohio	Jefferson	0.064	0.062	−0.002
Ohio	Knox	0.065	0.062	−0.002
Ohio	Lake	0.073	0.070	−0.002
Ohio	Lawrence	0.065	0.064	−0.001
Ohio	Licking	0.065	0.063	−0.002
Ohio	Lorain	0.067	0.065	−0.002
Ohio	Lucas	0.070	0.068	−0.002
Ohio	Madison	0.065	0.062	−0.003
Ohio	Mahoning	0.065	0.063	−0.002
Ohio	Medina	0.067	0.065	−0.002
Ohio	Miami	0.065	0.062	−0.003
Ohio	Montgomery	0.066	0.063	−0.003
Ohio	Portage	0.069	0.066	−0.002
Ohio	Preble	0.060	0.058	−0.003
Ohio	Stark	0.066	0.063	−0.003
Ohio	Summit	0.071	0.069	−0.003
Ohio	Trumbull	0.069	0.066	−0.003
Ohio	Warren	0.069	0.065	−0.003
Ohio	Washington	0.061	0.061	−0.001
Ohio	Wood	0.068	0.065	−0.003
Oklahoma	Canadian	0.057	0.056	−0.001
Oklahoma	Cleveland	0.060	0.059	−0.001
Oklahoma	Comanche	0.061	0.060	−0.002
Oklahoma	Dewey	0.058	0.057	−0.002
Oklahoma	Kay	0.061	0.060	−0.001
Oklahoma	Mc Clain	0.062	0.060	−0.001
Oklahoma	Oklahoma	0.061	0.060	−0.001
Oklahoma	Ottawa	0.063	0.062	−0.001
Oklahoma	Pittsburg	0.061	0.060	0.000
Oklahoma	Tulsa	0.066	0.066	−0.001
Oregon	Clackamas	0.063	0.063	0.000
Oregon	Columbia	0.056	0.056	0.000
Oregon	Jackson	0.061	0.061	0.000
Oregon	Lane	0.060	0.060	0.000
Oregon	Marion	0.055	0.055	0.000
Pennsylvania	Adams	0.060	0.056	−0.003
Pennsylvania	Allegheny	0.072	0.069	−0.003
Pennsylvania	Armstrong	0.068	0.066	−0.003
Pennsylvania	Beaver	0.071	0.069	−0.003
Pennsylvania	Berks	0.066	0.063	−0.003
Pennsylvania	Blair	0.061	0.058	−0.002
Pennsylvania	Bucks	0.078	0.075	−0.003
Pennsylvania	Cambria	0.064	0.061	−0.003
Pennsylvania	Centre	0.062	0.060	−0.002
Pennsylvania	Chester	0.071	0.068	−0.003
Pennsylvania	Clearfield	0.065	0.062	−0.003
Pennsylvania	Dauphin	0.065	0.061	−0.005
Pennsylvania	Delaware	0.071	0.068	−0.003

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Pennsylvania	Erie	0.070	0.068	−0.003
Pennsylvania	Franklin	0.067	0.064	−0.003
Pennsylvania	Greene	0.064	0.062	−0.002
Pennsylvania	Lackawanna	0.062	0.060	−0.002
Pennsylvania	Lancaster	0.068	0.063	−0.005
Pennsylvania	Lawrence	0.058	0.055	−0.002
Pennsylvania	Lehigh	0.067	0.064	−0.003
Pennsylvania	Luzerne	0.062	0.060	−0.002
Pennsylvania	Lycoming	0.061	0.059	−0.002
Pennsylvania	Mercer	0.068	0.065	−0.003
Pennsylvania	Montgomery	0.071	0.069	−0.003
Pennsylvania	Northampton	0.067	0.063	−0.004
Pennsylvania	Perry	0.062	0.059	−0.003
Pennsylvania	Philadelphia	0.077	0.075	−0.003
Pennsylvania	Tioga	0.065	0.063	−0.002
Pennsylvania	Washington	0.067	0.064	−0.003
Pennsylvania	Westmoreland	0.069	0.066	−0.003
Pennsylvania	York	0.067	0.062	−0.005
Rhode Island	Kent	0.070	0.067	−0.003
Rhode Island	Providence	0.069	0.067	−0.003
Rhode Island	Washington	0.071	0.068	−0.003
South Carolina	Abbeville	0.060	0.059	−0.001
South Carolina	Aiken	0.062	0.058	−0.003
South Carolina	Anderson	0.064	0.062	−0.001
South Carolina	Barnwell	0.059	0.057	−0.002
South Carolina	Berkeley	0.053	0.053	0.000
South Carolina	Charleston	0.055	0.054	−0.001
South Carolina	Cherokee	0.061	0.060	−0.001
South Carolina	Chester	0.059	0.058	−0.001
South Carolina	Chesterfield	0.059	0.058	−0.001
South Carolina	Colleton	0.058	0.057	−0.001
South Carolina	Darlington	0.061	0.060	−0.001
South Carolina	Edgefield	0.059	0.057	−0.002
South Carolina	Oconee	0.061	0.059	−0.001
South Carolina	Pickens	0.060	0.059	−0.001
South Carolina	Richland	0.066	0.065	−0.002
South Carolina	Spartanburg	0.063	0.061	−0.002
South Carolina	Union	0.059	0.057	−0.001
South Carolina	Williamsburg	0.052	0.052	−0.001
South Carolina	York	0.060	0.059	−0.001
South Dakota	Pennington	0.062	0.062	0.000
Tennessee	Anderson	0.059	0.058	0.000
Tennessee	Blount	0.065	0.064	−0.001
Tennessee	Davidson	0.057	0.057	0.000
Tennessee	Hamilton	0.062	0.062	0.000
Tennessee	Haywood	0.060	0.063	0.003
Tennessee	Jefferson	0.062	0.061	0.000
Tennessee	Knox	0.062	0.061	0.000
Tennessee	Lawrence	0.056	0.059	0.002
Tennessee	Meigs	0.061	0.061	−0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Tennessee	Putnam	0.062	0.061	−0.001
Tennessee	Rutherford	0.058	0.058	0.000
Tennessee	Sevier	0.066	0.065	−0.001
Tennessee	Shelby	0.066	0.066	0.000
Tennessee	Sullivan	0.066	0.066	0.000
Tennessee	Sumner	0.062	0.062	0.000
Tennessee	Williamson	0.061	0.060	0.000
Tennessee	Wilson	0.060	0.060	0.000
Texas	Bexar	0.068	0.067	−0.001
Texas	Brazoria	0.074	0.073	−0.001
Texas	Brewster	0.054	0.054	−0.001
Texas	Cameron	0.053	0.052	−0.001
Texas	Collin	0.070	0.068	−0.002
Texas	Dallas	0.069	0.067	−0.002
Texas	Denton	0.075	0.072	−0.002
Texas	Ellis	0.063	0.059	−0.004
Texas	El Paso	0.069	0.068	−0.001
Texas	Galveston	0.074	0.073	−0.002
Texas	Gregg	0.068	0.064	−0.004
Texas	Harris	0.089	0.088	−0.001
Texas	Harrison	0.061	0.059	−0.003
Texas	Hidalgo	0.062	0.062	−0.001
Texas	Hood	0.058	0.057	−0.002
Texas	Jefferson	0.074	0.071	−0.003
Texas	Johnson	0.066	0.063	−0.003
Texas	Kaufman	0.055	0.053	−0.002
Texas	Montgomery	0.074	0.073	−0.001
Texas	Nueces	0.065	0.064	−0.001
Texas	Orange	0.066	0.064	−0.003
Texas	Parker	0.063	0.062	−0.002
Texas	Rockwall	0.062	0.060	−0.002
Texas	Smith	0.064	0.062	−0.002
Texas	Tarrant	0.075	0.073	−0.002
Texas	Travis	0.063	0.062	−0.001
Texas	Victoria	0.061	0.060	−0.001
Texas	Webb	0.054	0.053	−0.001
Utah	Box Elder	0.064	0.062	−0.002
Utah	Cache	0.056	0.055	−0.002
Utah	Davis	0.070	0.068	−0.003
Utah	Salt Lake	0.070	0.067	−0.002
Utah	San Juan	0.064	0.064	0.000
Utah	Utah	0.067	0.065	−0.002
Utah	Weber	0.065	0.063	−0.002
Vermont	Bennington	0.061	0.058	−0.003
Vermont	Chittenden	0.063	0.062	−0.001
Virginia	Arlington	0.072	0.069	−0.004
Virginia	Caroline	0.059	0.057	−0.002
Virginia	Charles City	0.069	0.067	−0.002
Virginia	Chesterfield	0.066	0.064	−0.002
Virginia	Fairfax	0.071	0.068	−0.004

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Virginia	Fauquier	0.058	0.057	−0.002
Virginia	Frederick	0.062	0.060	−0.002
Virginia	Hanover	0.070	0.068	−0.002
Virginia	Henrico	0.068	0.066	−0.002
Virginia	Loudoun	0.067	0.063	−0.004
Virginia	Madison	0.063	0.061	−0.002
Virginia	Page	0.058	0.057	−0.002
Virginia	Prince William	0.063	0.060	−0.003
Virginia	Roanoke	0.062	0.061	−0.001
Virginia	Rockbridge	0.057	0.056	−0.001
Virginia	Stafford	0.063	0.060	−0.002
Virginia	Wythe	0.060	0.060	0.000
Virginia	Alexandria City	0.067	0.063	−0.003
Virginia	Hampton City	0.071	0.070	−0.001
Virginia	Suffolk City	0.070	0.069	−0.001
Washington	Clallam	0.041	0.041	0.000
Washington	Clark	0.062	0.062	0.000
Washington	King	0.064	0.064	0.000
Washington	Klickitat	0.062	0.060	−0.002
Washington	Mason	0.050	0.050	0.000
Washington	Pierce	0.066	0.066	0.000
Washington	Skagit	0.045	0.045	0.000
Washington	Spokane	0.060	0.060	0.000
Washington	Thurston	0.059	0.059	0.000
Washington	Whatcom	0.052	0.052	0.000
West Virginia	Berkeley	0.062	0.060	−0.002
West Virginia	Cabell	0.069	0.067	−0.001
West Virginia	Greenbrier	0.060	0.060	−0.001
West Virginia	Hancock	0.064	0.062	−0.003
West Virginia	Kanawha	0.062	0.062	0.000
West Virginia	Monongalia	0.056	0.055	−0.001
West Virginia	Ohio	0.063	0.061	−0.002
West Virginia	Wood	0.062	0.061	−0.001
Wisconsin	Brown	0.065	0.064	−0.001
Wisconsin	Columbia	0.060	0.059	−0.001
Wisconsin	Dane	0.060	0.059	−0.001
Wisconsin	Dodge	0.063	0.062	−0.001
Wisconsin	Door	0.072	0.071	−0.001
Wisconsin	Florence	0.058	0.057	−0.001
Wisconsin	Fond Du Lac	0.061	0.060	−0.001
Wisconsin	Green	0.059	0.059	−0.001
Wisconsin	Jefferson	0.063	0.061	−0.001
Wisconsin	Kenosha	0.081	0.080	−0.001
Wisconsin	Kewaunee	0.071	0.070	−0.001
Wisconsin	Manitowoc	0.069	0.068	−0.001
Wisconsin	Marathon	0.058	0.057	−0.001
Wisconsin	Milwaukee	0.074	0.073	−0.001
Wisconsin	Oneida	0.057	0.056	−0.001
Wisconsin	Outagamie	0.061	0.060	−0.001
Wisconsin	Ozaukee	0.075	0.073	−0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Wisconsin	Racine	0.075	0.074	−0.001
Wisconsin	Rock	0.064	0.063	−0.001
Wisconsin	St Croix	0.060	0.060	0.000
Wisconsin	Sauk	0.057	0.057	−0.001
Wisconsin	Sheboygan	0.077	0.076	−0.001
Wisconsin	Vernon	0.060	0.059	−0.001
Wisconsin	Vilas	0.057	0.056	−0.001
Wisconsin	Walworth	0.064	0.063	−0.001
Wisconsin	Washington	0.065	0.064	−0.001
Wisconsin	Waukesha	0.063	0.062	−0.001
Wisconsin	Winnebago	0.066	0.064	−0.001
Wyoming	Campbell	0.067	0.067	0.000
Wyoming	Teton	0.063	0.063	0.000

Appendix 3: Additional Control Strategy Information

3a.1 NonEGU Point and Area Source Controls

3a.1.1 NonEGU Point and Area Source Control Strategies for Ozone NAAQS Final

In the NonEGU point and Area Sources portion of the control strategy, maximum control scenarios were used from the existing control measure dataset from AirControlNET 4.1 for 2020 (for geographic areas defined for each level of the standard being analyzed). This existing control measure dataset reflects changes and updates made as a result of the reviews performed for the final PM2.5 RIA. Following this, an internal review was performed by the OAQPS engineers in the Sector Policies and Programs Division (SPPD) to examine the controls applied by AirControlNET and decide if these controls were sufficient or could be more aggressive in their application, given the 2020 analysis year. This review was performed for nonEGU point NOx control measures. The result of this review was an increase in control efficiencies applied for many control measures, and more aggressive control measures for over 70 SCC's. For example, SPPD recommended that we apply SCR to cement kilns to reduce NOx emissions in 2020. Currently, there are no SCRs in operation at cement kilns in the U.S., but there are several SCRs in operation at cement kilns in France now. Based on the SCR experience at cement kilns in France, SPPD believes SCR could be applied at U.S. cement kilns by 2020. Following this, it was recommended that supplemental controls could be applied to 8 additional SCC's from nonEGU point NOx sources. We also looked into sources of controls for highly reactive VOC nonEGU point sources. Four additional controls were applied for highly reactive VOC nonEGU point sources not in AirControlNET.

3a.1.2 NOx Control Measures for NonEGU Point Sources.

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

Besides industrial boilers, other nonEGU point source categories covered in this RIA include petroleum refineries, kraft pulp mills, cement kilns, stationary internal combustion engines, glass manufacturing, combustion turbines, and incinerators. NOx control measures available for petroleum refineries, particularly process heaters at these plants, include LNB, SNCR, FGR, and SCR along with combinations of these technologies. NOx control measures available for kraft pulp mills include those available to industrial boilers, namely LNB, SCR, SNCR, along with water injection (WI). NOx control measures available for cement kilns include those available to industrial boilers, namely LNB, SCR, and SNCR. Non-selective catalytic reduction (NSCR) can be used on stationary internal combustion engines. OXY-firing, a technique to modify combustion at glass manufacturing plants, can be used to reduce NOx at such plants. LNB, SCR, and SCR + steam injection (SI) are available measures for combustion turbines. Finally, SNCR is an available control technology at incinerators. Table 3a.1 contains a complete list of the NOx nonEGU point control measures applied and their associated emission reductions obtained in the modeled control strategy for the alternate primary standard. For more information on these measures, please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.1: NOx NonEGU Point Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
Biosolid Injection Technology	Cement Kilns	1,200
LNB	Asphaltic Conc; Rotary Dryer; Conv Plant	120
	Ceramic Clay Mfg; Drying	370
	Conv Coating of Prod; Acid Cleaning Bath	440
	Fuel Fired Equip; Furnaces; Natural Gas	170
	In-Process Fuel Use; Natural Gas	1,300
	In-Process Fuel Use; Residual Oil	39
	In-Process; Process Gas; Coke Oven Gas	190
	Lime Kilns	5,900
	Sec Alum Prod; Smelting Furn	62
	Steel Foundries; Heat Treating	13
	Surf Coat Oper; Coating Oven Htr; Nat Gas	30
LNB + FGR	Fluid Cat Cracking Units	3,600
	Fuel Fired Equip; Process Htrs; Process Gas	700
	In-Process; Process Gas; Coke Oven Gas	880
	Iron & Steel Mills—Galvanizing	35
	Iron & Steel Mills—Reheating	1,100
	Iron Prod; Blast Furn; Blast Htg Stoves	1,000
	Sand/Gravel; Dryer	11
	Steel Prod; Soaking Pits	100
LNB + SCR	Iron & Steel Mills—Annealing	270
	Process Heaters—Distillate Oil	2,300
	Process Heaters—Natural Gas	27,000
	Process Heaters—Other Fuel	14
	Process Heaters—Process Gas	4,200
	Process Heaters—Residual Oil	37
NSCR	Rich Burn IC Engines—Gas	22,000
	Rich Burn IC Engines—Gas, Diesel, LPG	3,700
	Rich Burn Internal Combustion Engines—Oil	11,000
OXY-Firing	Glass Manufacturing—Containers	7,600
	Glass Manufacturing—Flat	18,000
	Glass Manufacturing—Pressed	3,900
SCR	Ammonia—NG-Fired Reformers	5,800
	Cement Manufacturing—Dry	25,000
	Cement Manufacturing—Wet	22,000
	IC Engines—Gas	54,000
	ICI Boilers—Coal/Cyclone	2,200
	ICI Boilers—Coal/Wall	22,000
	ICI Boilers—Coke	490
	ICI Boilers—Distillate Oil	4,800

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
	ICI Boilers—Liquid Waste	730
	ICI Boilers—LPG	280
	ICI Boilers—Natural Gas	36,000
	ICI Boilers—Process Gas	8,600
	ICI Boilers—Residual Oil	17,000
	Natural Gas Prod; Compressors	810
	Space Heaters—Distillate Oil	22
	Space Heaters—Natural Gas	640
	Sulfate Pulping—Recovery Furnaces	9,900
SCR + Steam Injection	Combustion Turbines—Natural Gas	18,000
SCR + Water Injection	Combustion Turbines—Jet Fuel	—
	Combustion Turbines—Natural Gas	—
	Combustion Turbines—Oil	210
SNCR	By-Product Coke Mfg; Oven Underfiring	4,300
	Comm./Inst. Incinerators	1,400
	ICI Boilers—Coal/Stoker	7,000
	Indust. Incinerators	250
	Medical Waste Incinerators	—
	In-Process Fuel Use; Bituminous Coal	32
	Municipal Waste Combustors	4,400
	Nitric Acid Manufacturing	3,100
	Solid Waste Disp; Gov; Other Inc	95
SNCR—Urea	ICI Boilers—MSW/Stoker	120
SNCR—Urea Based	ICI Boilers—Coal/FBC	100
	ICI Boilers—Wood/Bark/Stoker—Large	5,500
	In-Process; Bituminous Coal; Cement Kilns	300
	In-Process; Bituminous Coal; Lime Kilns	31

3a.1.3 VOC Control Measures for NonEGU Point Sources.

VOC controls were applied to a variety of nonEGU point sources as defined in the emissions inventory in this RIA. The first control is: permanent total enclosure (PTE) applied to paper and web coating operations and fabric operations, and incinerators or thermal oxidizers applied to wood products and marine surface coating operations. A PTE confines VOC emissions to a particular area where can be destroyed or used in a way that limits emissions to the outside atmosphere, and an incinerator or thermal oxidizer destroys VOC emissions through exposure to high temperatures (2,000 degrees Fahrenheit or higher). The second control applied is petroleum and solvent evaporation applied to printing and publishing sources as well as to surface coating operations. Table 3a.2 contains the emissions reductions for these measures in the modeled control strategy for the alternate primary standard. For more information on these measures, refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.2: VOC NonEGU Point Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
Permanent Total Enclosure (PTE)	Fabric Printing, Coating and Dyeing	43
	Paper and Other Web Coating	490
Petroleum and Solvent Evaporation	Printing and Publishing	3,600
	Surface Coating	400

3a.1.4 NOx Control Measures for Area Sources

There were three control measures applied for NOx emissions from area sources. The first is RACT (reasonably available control technology) to 25 tpy (LNB). This control is the addition of a low NOx burner to reduce NOx emissions. This control is applied to industrial oil, natural gas, and coal combustion sources. The second control is water heaters plus LNB space heaters. This control is based on the installation of low-NOx space heaters and water heaters in commercial and institutional sources for the reduction of NOx emissions. The third control was switching to low sulfur fuel for residential home heating. This control is primarily designed to reduce sulfur dioxide, but has a co-benefit of reducing NOx. Table 3a.3 contains the listing of control measures and associated reductions for the modeled control strategy. For additional information regarding these controls please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.3: NOx Area Source Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
RACT to 25 tpy (LNB)	Industrial Coal Combustion	5,400
	Industrial NG Combustion	3,000
	Industrial Oil Combustion	570
Switch to Low Sulfur Fuel	Residential Home Heating	970
Water Heater + LNB Space Heaters	Commercial/Institutional—NG	4,300
	Residential NG	6,700

3a.1.5 VOC Control Measures for Area Source.

The most frequently applied control to reduce VOC emissions from area sources was CARB Long-Term Limits. This control, which represents controls available in VOC rules promulgated by the California Air Resources Board, applies to commercial solvents and commercial adhesives, and depends on future technological innovation and market incentive methods to achieve emission reductions. The next most frequently applied control was the use of low or no VOC materials for graphic art source categories. The South Coast Air District's SCAQMD Rule 1168 control applies to wood furniture and solvent source categories sets limits for adhesive and sealant VOC content. The OTC solvent cleaning rule control establishes hardware and operating requirements for specified vapor cleaning machines, as well as solvent volatility limits and operating practices for cold cleaners. The Low Pressure/Vacuum Relief Valve control measure is the addition of low pressure/vacuum (LP/V) relief valves to gasoline storage tanks at service stations with Stage II control systems. LP/V relief valves prevent breathing emissions from gasoline storage tank vent pipes. SCAQMD Limits control establishes VOC content limits for metal coatings along with application procedures and equipment requirements. Switch to Emulsified Asphalts control is a generic control measure replacing VOC-containing cutback asphalt with VOC-free emulsified asphalt. The equipment and maintenance control measure applies to oil and natural gas production. The Reformulation—FIP Rule control measure intends to reach the VOC limits by switching to and/or encouraging the use of low-VOC pesticides and better Integrated Pest Management (IPM) practices. Table 3a.4 contains the control measures and associated emission reductions described above for the modeled control strategy. For additional information regarding these controls please refer to the AirControlNET 4.1 control measures documentation report.

Table 3a.4: VOC Area Source Emission Reductions by Control Measure

Control Measure	Source Type	Modeled Control Strategy Reductions (annual tons/year)
CARB Long-Term Limits	Consumer Solvents	78,000
Catalytic Oxidizer	Conveyorized Charbroilers	250
Equipment and Maintenance	Oil and Natural Gas Production	450
Gas Collection (SCAQMD/BAAQMD)	Municipal Solid Waste Landfill	1,100
Incineration >100,000 lbs bread	Bakery Products	2,700
Low Pressure/Vacuum Relief Valve	Stage II Service Stations	9,900
	Stage II Service Stations—Underground Tanks	9,800
OTC Mobile Equipment Repair and Refinishing Rule	Aircraft Surface Coating	720
	Machn, Electric, Railroad Ctng	4,400
OTC Solvent Cleaning Rule	Cold Cleaning	10,000
SCAQMD—Low VOC	Rubber and Plastics Mfg	1,700
SCAQMD Limits	Metal Furniture, Appliances, Parts	6,300
SCAQMD Rule 1168	Adhesives—Industrial	22,000
Solvent Utilization	Large Appliances	8,200
	Metal Furniture	7,600
	Surface Coating	2,900
Switch to Emulsified Asphalts	Cutback Asphalt	3,300

3a.1.6 Supplemental Controls

Table 3a.5 below summarizes the supplemental control measures added to our control measures database by providing the pollutant it controls and its control efficiency (CE). These controls were applied not as part of the modeled control strategy, but as supplemental measures prior to extrapolating unknown control costs. However, these controls are not currently located in AirControlNET. These measures are primarily found in draft SIP technical documents and have not been fully assessed for inclusion in AirControlNET.

Table 3a.5: Supplemental Emissions Control Measures Added to the Control Measures Database

Poll	Control Technology	SCC	SCC Description	Percent Reduction (%)
NOx	LEC	20200252	Internal Comb. Engines/Industrial/ Natural Gas/2-cycle Lean Burn	87
		20200254	Internal Comb. Engines/Industrial/ Natural Gas/4-cycle Lean Burn	87
VOC	Enhanced LDAR	3018001-	Fugitive Leaks	50
		30600701 30600999 -	Flares	98
	LDAR	3018001 -	Fugitive Leaks	80
	Monitoring Program	30600702-	Cooling towers	No general estimate
	Inspection and Maintenance Program (Separators) Water Seals (Drains)	30600503-	Wastewater Drains and Separators	65
	Work Practices, Use of Low VOC Coatings (Area Sources)	2401025000 2401030000 2401060000 2425010000 2425030000 2425040000 2461050000	Solvent Utilization	90
	Work Practices, Use of Low VOC Coatings (NonEGU Point)	307001199 Surface Coating Operations within SCC 4020000000, Printing/Publishing processes within SCC 4050000000	Petroleum and Solvent Evaporation	90

Low Emission Combustion (LEC)

Overview: LEC technology is defined as the modification of a natural gas fueled, spark ignited, reciprocating internal combustion engine to reduce emissions of NOx by utilizing ultra-lean air-fuel ratios, high energy ignition systems and/or pre-combustion chambers, increased turbocharging or adding a turbocharger, and increased cooling and/or adding an intercooler or aftercooler, resulting in an engine that is designed to achieve a consistent NO_x emission rate of not more than 1.5-3.0 g/bhp-hr at full capacity (usually 100 percent speed and 100 percent load). This type of retrofit technology is fairly widely available for stationary internal combustion engines.

For CE, EPA estimates that it ranges from 82 to 91 percent for LEC technology applications. The EPA believes application of LEC would achieve average NO_x emission levels in the range of 1.5-3.0 g/bhp-hr. This is an 82-91 percent reduction from the average uncontrolled emission levels reported in the ACT document. An EPA memorandum summarizing 269 tests shows that

96 percent of IC engines with installed LEC technology achieved emission rates of less than 2.0 g/bhp-hr.[1] The 2000 EC/R report on IC engines summarizes 476 tests and shows that 97% of the IC engines with installed LEC technology achieve emission rates of 2.0 g/bhp-hr or less.[2]

Major Uncertainties: The EPA acknowledges that specific values will vary from engine to engine. The amount of control desired and number of operating hours will make a difference in terms of the impact had from a LEC retrofit. Also, the use of LEC may yield improved fuel economy and power output, both of which may affect the emissions generated by the device.

Leak Detection and Repair (LDAR) for Fugitive Leaks

Overview: This control measure is a program to reduce leaks of fugitive VOC emissions from chemical plants and refineries. The program includes special "sniffer" equipment to detect leaks, and maintenance schedules that affected facilities are to adhere to. This program is one that is contained within the Houston-Galveston-Brazoria 8-hour Ozone SIP.

Major Uncertainties: The degree of leakage from pipes and processes at chemical plants is always difficult to quantify given the large number of such leaks at a typical chemical manufacturing plant. There are also growing indications based on tests conducted by TCEQ and others in Harris County, Texas that fugitive leaks have been underestimated from chemical plants by a factor of 6 to 20 or greater. [3]

Enhanced LDAR for Fugitive Leaks

Overview: This control measure is a more stringent program to reduce leaks of fugitive VOC emissions from chemical plants and refineries that presumes that an existing LDAR program already is in operation.

Major Uncertainties: The calculations of CE and cost presume use of LDAR at a chemical plant. This should not be an unreasonable assumption, however, given that most chemical plants are under some type of requirement to have an LDAR program. However, as mentioned earlier, there is growing evidence that fugitive leak emissions are underestimated from chemical plants by a factor of 6 to 20 or greater.[4]

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[1] "Stationary Reciprocating Internal Combustion Engines Technical Support Document for NOx SIP Call Proposal," U.S. Environmental Protection Agency. September 5, 2000. Available on the Internet at http://www.epa.gov/ttn/naaqs/ozone/rto/sip/data/tsd9-00.pdf.

[2] "Stationary Internal Combustion Engines: Updated Information on NOx Emissions and Control Techniques," Ec/R Incorporated, Chapel Hill, NC. September 1, 2000. Available on the Internet at http://www.epa.gov/ttn/naaqs/ozone/ozonetech/ic_engine_nox_update_09012000.pdf.

[3] VOC Fugitive Losses: New Monitors, Emissions Losses, and Potential Policy Gaps. 2006 International Workshop. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Solid Waste and Emergency Response. October 25-27, 2006.

[4] VOC Fugitive Losses: New Monitors, Emissions Losses, and Potential Policy Gaps. 2006 International Workshop. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Solid Waste and Emergency Response. October 25-27, 2006.

Flare Gas Recovery

Overview: This control measure is a condenser that can recover 98 percent of the VOC emitted by flares that emit 20 tons per year or more of the pollutant.

Major Uncertainties: Flare gas recovery is just gaining commercial acceptance in the US and is only in use at a small number of refineries.

Cooling Towers

Overview: The control measure is continuous monitoring of VOC from the cooling water return to a level of 10 ppb. This monitoring is accomplished by using a continuous flow monitor at the inlet to each cooling tower.

There is not a general estimate of CE for this measure; one is to apply a continuous flow monitor until VOC emissions have reached a level of 1.7 tons/year for a given cooling tower.[5]

Major Uncertainties: The amount of VOC leakage from each cooling tower can greatly affect the overall cost-effectiveness of this control measure.

Wastewater Drains and Separators

Overview: This control measure includes an inspection and maintenance program to reduce VOC emissions from wastewater drains and water seals on drains. This measure is a more stringent version of measures that underlie existing NESHAP requirements for such sources.

Major Uncertainties: The reference for this control measures notes that the VOC emissions inventories for the five San Francisco Bay Area refineries whose data was a centerpiece of this report are incomplete. In addition, not all VOC species from these sources were included in the VOC data that is a basis for these calculations.[6]

Work Practices or Use of Low VOC Coatings

Overview: The control measure is either application of work practices (e.g., storing VOC-containing cleaning materials in closed containers, minimizing spills) or using coatings that have much lower VOC content. These measures, which are of relatively low cost compared to other VOC area source controls, can apply to a variety of processes, both for non-EGU point and area sources, in different industries and is defined in the proposed control techniques guidelines (CTG) for paper, film and foil coatings, metal furniture coatings, and large appliance coatings published by the US EPA in July 2007.[7]

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[5] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.
[6] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.
[7] U.S. Environmental Protection Agency. Consumer and Commercial Products: Control Techniques Guidelines in Lieu of Regulations for Paper, Film, and Foil Coatings; Metal

The estimated CE expected to be achieved by either of these control measures is 90 percent.

Major Uncertainties: The greatest uncertainty is in how many potentially affected processes are implementing or already implemented these control measures. This may be particularly true in California. Also, there are nine States that have many of the above work practices in effect for paper, film and foil coatings processes, but the work practices are not meant to achieve a specific emissions limit.[8] Hence, it is uncertain how much VOC reduction is occurring from this control measure in this case.

In addition to the new supplemental controls presented above, there were a number of changes made to existing AirControlNET controls. These changes were made based upon an internal review performed by EPA engineers to examine the controls applied by AirControlNET and determine if these controls were sufficient or could be more aggressive in their application, given the 2020 analysis year. This review was performed for nonEGU point NOx control measures. The result of this review was an increase in control efficiencies applied for many control measures, and more aggressive control measures for over 70 SCCs. The changes apply to the control strategies performed for the Eastern US only. These changes are listed in Table 3a.6.

Table 3a.6: Supplemental Emission Control Measures—Changes to Control Technologies Currently in our Control Measures Database For Application in 2020

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	10200104 10200204 10200205 10300207 10300209 10200217 10300216	ICI Boilers—Coal-Stoker	SNCR	SCR	90	40
NOX	10200901 10200902 10200903 10200907 10300902 10300903	ICI Boilers—Wood/Bark/ Waste	SNCR	SCR	90	55
NOX	10200401 10200402 10200404 10200405 10300401	ICI Boilers—Residual Oil	SCR	SCR	90	80

Furniture Coatings; and Large Appliance Coatings. 40 CFR 59. July 10, 2007. Available on the Intenet at http://www.epa.gov/ttncaaa1/t1/fr_notices/ctg_ccp092807.pdf. It should be noted that this CTG became final in October 2007.

[8] U.S. Environmental Protection Agency. Consumer and Commercial Products: Control Techniques Guidelines in Lieu of Regulations for Paper, Film, and Foil Coatings; Metal Furniture Coatings; and Large Appliance Coatings. 40 CFR 59. July 10, 2007, p. 37597. Available on the Intenet at http://www.epa.gov/ttncaaa1/t1/fr_notices/ctg_ccp092807.pdf.

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	10200501 10200502 10200504	ICI Boilers—Distillate Oil	SCR	SCR	90	80
NOX	10200601 10200602 10200603 10200604 10300601 10300602 10300603 10500106 10500206	ICI Boilers—Natural Gas	SCR	SCR	90	80
NOX	30500606	Cement Manufacturing—Dry	SCR	SCR	90	80
NOX	30500706	Cement Manufacturing—Wet	SCR	SCR	90	80
NOX	30300934	Iron & Steel Mills—Annealing	SCR	SCR	90	85
NOX	10200701 10200704 10200707 10200710 10200799 10201402 10300701 10300799	ICI Boilers—Process Gas	SCR	SCR	90	80
NOX	10200802 10200804	ICI Boilers—Coke	SCR	SCR	90	70
NOX	10201002	ICI Boilers—LPG	SCR	SCR	90	80
NOX	10201301 10201302	ICI Boilers—Liquid Waste	SCR	SCR	90	80
NOX	30700110	Sulfate Pulping—Recovery Furnaces	SCR	SCR	90	80
NOX	30100306	Ammonia Production—Pri. Reformer, Nat. Gas	SCR	SCR	90	80
	30500622 30500623	Cement Kilns	Biosolid Injection	Biosolid Injection	40	23
NOX	30590013 30190013 30190014 39990013	Industrial and Manufacturing Incinerators	SNCR	SCR	90	45
NOX	30101301 30101302	Nitric Acid Manufacturing	SNCR	SCR	90	60 to 98
NOX	30600201	Fluid Cat. Cracking Units	LNB + FGR	SCR	90	55
NOX	30590003	Process Heaters—Process Gas	LNB + SCR	LNB + SCR	90	88
NOX	30600101 30600103 30600111	Process Heaters—Distillate Oil	LNB + SCR	LNB + SCR	90	90
NOX	30600106 30600199	Process Heaters—Residual Oil	LNB + SCR	LNB + SCR	90	80
NOX	30600102 30600105	Process Heaters—Natural Gas	LNB + SCR	LNB + SCR	90	80

Poll	SCC	AirControlNET Source Description	AirControlNET Control Technology	New Control Technology	New CE (%)	Old CE (%)
NOX	30700104	Sulfate Pulping—Recovery Furnaces	SCR	SCR	90	80
NOX	30790013	Pulp and Paper—Natural Gas—Incinerators	SNCR	SCR	90	45
NOX	39000201	In-Process; Bituminous Coal; Cement Kiln	SNCR—urea based	SCR	90	50
NOX	39000203	In-Process; Bituminous Coal; Lime Kiln	SNCR—urea based	SCR	90	50
NOX	39000289	In-Process Fuel Use; Bituminous Coal; Gen	SNCR	SCR	90	40
NOX	39000489	In-Process Fuel Use; Residual Oil; Gen	LNB	SCR	90	37
NOX	39000689	In-Process Fuel Use; Natural Gas; Gen	LNB	SCR	90	50
NOX	39000701	In-Proc; Process Gas; Coke Oven/Blast Furn	LNB + FGR	SCR	90	55
NOX	39000789	In-Process; Process Gas; Coke Oven Gas	LNB	SCR	90	50
NOX	50100101 50100506 50200506 50300101 50300102 50300104 50300506 50100102	Solid Waste Disp; Gov; Other Incin; Sludge	SNCR	SCR	90	45

The last category of supplemental controls is control technologies currently in our control measures database being applied to SCCs not controlled currently in AirControlNET.

Table 3a.7: Supplemental Emission Control Technologies Currently in our Control Measures Database Applied to New Source Types

Pollutant	SCC	SCC Description	Control Technology	CE
NOX	39000602	Cement Manufacturing—Dry	SCR	90
NOX	30501401	Glass Manufacturing—General	OXY-Firing	85
NOX	30302351 30302352 30302359	Taconite Iron Ore Processing—Induration—Coal or Gas	SCR	90
NOX	10100101	External Combustion Boilers; Electric Generation; Anthracite Coal; Pulverized Coal	SNCR	40
NOX	10100202	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Bituminous Coal)	SNCR	40
NOX	10100204	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Spreader Stoker (Bituminous Coal)	SNCR	40
NOX	10100212	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Tangential) (Bituminous Coal)	SNCR	40

Pollutant	SCC	SCC Description	Control Technology	CE
NOX	10100401	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Normal Firing	SNCR	50
NOX	10100404	External Combustion Boilers; Electric Generation; Residual Oil; Grade 6 Oil: Tangential Firing	SNCR	50
NOX	10100501	External Combustion Boilers; Electric Generation; Distillate Oil; Grades 1 and 2 Oil	SNCR	50
NOX	10100601	External Combustion Boilers; Electric Generation; Natural Gas; Boilers > 100 Million Btu/hr except Tangential	NGR	50
NOX	10100602	External Combustion Boilers; Electric Generation; Natural Gas; Boilers < 100 Million Btu/hr except Tangential	NGR	50
NOX	10100604	External Combustion Boilers; Electric Generation; Natural Gas; Tangentially Fired Units	NGR	50
NOX	10101202	External Combustion Boilers; Electric Generation; Solid Waste; Refuse Derived Fuel	SNCR	50
NOX	20200253	Internal Comb. Engines/Industrial/Natural Gas/4-cycle Rich Burn	NSCR	90

3a.2 Mobile Control Measures Used in Control Scenarios

Tables 3a.8 and 3a.9 summarize the emission reductions for the mobile source control measures discussed in this section.

Table 3a.8: NOx Mobile Emission Reductions by Control Measure

Sector	Control Measure	Modeled Control Strategy Reductions (annual tons/year)
Onroad	Eliminate Long Duration Truck Idling	5,800
	Reduce Gasoline RVP	880
	Diesel Retrofits	91,000
	Continuous Inspection and Maintenance	20,000
	Commuter Programs	4,100
Nonroad	Diesel Retrofits and Engine Rebuilds	35,000

Table 3a.9: VOC Mobile Emission Reductions by Control Measure

Sector	Control Measure	Modeled Control Strategy Reductions (annual tons/year)
Onroad	Reduce Gasoline RVP	17,000
	Diesel Retrofits	8,400
	Continuous Inspection and Maintenance	28,000
	Commuter Programs	7,000
Nonroad	Reduce Gasoline RVP	6,300
	Diesel Retrofits and Engine Rebuilds	5,200

3a.2.1 Diesel Retrofits and Engine Rebuilds

Retrofitting heavy-duty diesel vehicles and equipment manufactured before stricter standards are in place—in 2007–2010 for highway engines and in 2011–2014 for most nonroad equipment—can provide NO_X and HC benefits. The retrofit strategies included in the RIA retrofit measure are:

- Installation of emissions after-treatment devices called selective catalytic reduction ("SCRs")

- Rebuilding nonroad engines ("rebuild/upgrade kit")

We chose to focus on these strategies due to their high NOx emissions reduction potential and widespread application. Additional retrofit strategies include, but are not limited to, lean NOx catalyst systems—which are another type of after-treatment device—and alternative fuels. Additionally, SCRs are currently the most likely type of control technology to be used to meet EPA's NOx 2007–2010 requirements for HD diesel trucks and 2008–2011 requirements for nonroad equipment. Actual emissions reductions may vary significantly by strategy and by the type and age of the engine and its application.

To estimate the potential emissions reductions from this measure, we applied a mix of two retrofit strategies (SCRs and rebuild/upgrade kits) for the 2020 inventory of:

- Heavy-duty highway trucks class 6 & above, Model Year 1995–2009

- All diesel nonroad engines, Model Year 1991–2007, except for locomotive, marine, pleasure craft, & aircraft engines

Class 6 and above trucks comprise the bulk of the NOx emissions inventory from heavy-duty highway vehicles, so we did not include trucks below class 6. We chose not to include locomotive and marine engines in our analysis since EPA has proposed regulations to address these engines, which will significantly impact the emissions inventory and emission reduction potential from retrofits in 2020. There was also not enough data available to assess retrofit strategies for existing aircraft and pleasure craft engines, so we did not include them in this analysis. In addition, EPA is in the process of negotiating standards for new aircraft engines.

The lower bound in the model year range—1995 for highway vehicles and 1991 for nonroad engines—reflects the first model year in which emissions after-treatment devices can be reliably applied to the engines. Due to a variety of factors, devices are at a higher risk of failure for earlier model years. We expect the engines manufactured before the lower bound year that are still in existence in 2020 to be retired quickly due to natural turnover, therefore, we have not included strategies for pre-1995/1991 engines because of the strategies' relatively small impact on emissions. The upper bound in the model year range reflects the last year before more stringent emissions standards will be fully phased-in.

We chose the type of strategy to apply to each model year of highway vehicles and nonroad equipment based on our technical assessment of which strategies would achieve reliable results at the lowest cost. After-treatment devices can be more cost-effective than rebuild and vice versa depending on the emissions rate, application, usage rates, and expected life of the engine. The performance of after-treatment devices, for example, depends heavily upon the model year of the engine; some older engines may not be suitable for after-treatment devices and would be better candidates for rebuild/upgrade kit. In certain cases, nonroad engines may not be suitable for either after-treatment devices or rebuild, which is why we estimate that retrofits are not suitable for 5% of the nonroad fleet. The mix of strategies employed in this RIA for highway vehicles and nonroad engines are presented in Table 3a.10 and Table 3a.11, respectively. The groupings of model years for highway vehicles reflect changes in EPA's published emissions standards for new engines.

Table 3a.10: Application of Retrofit Strategy for Highway Vehicles by Percentage of Fleet

Model Year	SCR
<1995	0%
1995–2006	100%
2007–2009	50%
>2009	0%

Table 3a.11: Application of Retrofit Strategy for Nonroad Equipment by Percentage of Fleet

Model Year	Rebuild/Upgrade kit	SCR
1991–2007	50%	50%

The expected emissions reductions from SCR's are based on data derived from EPA regulations (Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-duty Highway Engines and Vehicles published October 2000), interviews with component manufacturers, and EPA's Summary of Potential Retrofit Technologies. This information is available at www.epa.gov/otaq/retrofit/retropotentialtech.htm. The estimates for highway vehicles and nonroad engines are presented in Table 3a.12 and Table 3a.13, respectively.

Table 3a.12: Percentage Emissions Reduction by Highway Vehicle Retrofit Strategy

	PM	CO	HC	NOx
SCR (+DPF)	90%	90%	90%	70%

Table 3a.13: Percentage Emissions Reduction by Nonroad Equipment Retrofit Strategy

Strategy	PM	CO	HC	NOx
SCR (+DPF)	90%	90%	90%	70%
Rebuild/Upgrade Kit	30%	15%	70%	40%

It is important to note that there is a great deal of variability among types of engines (especially nonroad), the applicability of retrofit strategies, and the associated emissions reductions. We applied the retrofit emissions reduction estimates to engines across the board (e.g., retrofits for bulldozers are estimated to produce the same percentage reduction in emissions as for agricultural mowers). We did this in order to simplify model runs, and, in some cases, where we did not have enough data to differentiate emissions reductions for different types of highway vehicles and nonroad equipment. We believe the estimates used in the RIA, however, reflect the best available estimates of emissions reductions that can be expected from retrofitting the heavy-duty diesel fleet.

Using the retrofit module in EPA's National Mobile Inventory Model (NMIM) available at http://www.epa.gov/otaq/nmim.htm, we calculated the total percentage reduction in emissions (PM, NOx, HC, and CO) from the retrofit measure for each relevant engine category (source category code, or SCC) for each county in 2020. To evaluate this change in the emissions inventory, we conducted both a baseline and control analysis. Both analyses were based on NMIM 2005 (version NMIM20060310), NONROAD2005 (February 2006), and MOBILE6.2.03 which included the updated diesel PM file PMDZML.csv dated March 17, 2006.

For the control analysis, we applied the retrofit measure corresponding to the percent reductions of the specified pollutants in Tables 3a.12 and 3a.13 to the specified model years in Tables 3a.10 and 3a.11 of the relevant SCCs. Fleet turnover rates are modeled in the NMIM, so we applied the retrofit measure to the 2007 fleet inventory, and then evaluated the resulting emissions inventory in 2020. The timing of the application of the retrofit measure is not a factor; retrofits only need to take place prior to the attainment date target (2020 for this RIA). For example, if retrofit devices are installed on 1995 model year bulldozers in 2007, the only impact on emissions in 2020 will be from the expected inventory of 1995 model year bulldozer emissions in 2020.

We then compared the baseline and control analyses to determine the percent reduction in emissions we estimate from this measure for the relevant SCC codes in the targeted nonattainment areas.

3a.2.2 Implement Continuous Inspection and Maintenance Using Remote Onboard Diagnostics (OBD)

Continuous Inspection and Maintenance (I/M) is a new way to check the status of OBD systems on light-duty OBD-equipped vehicles. It involves equipping subject vehicles with some type of transmitter that attaches to the OBD port. The device transmits the status of the OBD system to receivers distributed around the I/M area. Transmission may be through radio-frequency, cellular or wi-fi means. Radio frequency and cellular technologies are currently being used in the states of Oregon, California and Maryland.

Current I/M programs test light-duty vehicles on a periodic basis—either annually or biennially. Emission reduction credit is assigned based on test frequency. Using Continuous I/M, vehicles are continuously monitored as they are operated throughout the non-attainment area. When a vehicle experiences an OBD failure, the motorist is notified and is required to get repairs within the normal grace period—typically about a month. Thus, Continuous I/M will result in repairs happening essentially whenever a malfunction occurs that would cause the check engine light to illuminate. The continuous I/M program is applied to the same fleet of vehicles as the current periodic I/M programs. Currently, MOBILE6 provides an increment of benefit when going from a biennial program to an annual program. The same increment of credit applies going from an annual program to a continuous program.

Source Categories Affected by Measure:

- All 1996 and newer light-duty gasoline vehicles and trucks:
- All 1996 and newer (SCC 2201001000) Light Duty Gasoline Vehicles (LDGV), Total: All Road Types
- All 1996 and newer (SCC 2201020000) Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
- All 1996 and newer (SCC 2201040000) Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types

OBD systems on light duty vehicles are required to illuminate the malfunction indicator lamp whenever emissions of HC, CO or NOx would exceed 1.5 times the vehicle's certification standard. Thus, the benefits of this measure will affect all three criteria pollutants. MOBILE6 was used to estimate the emission reduction benefits of Continuous I/M, using the methodology discussed above.

3a.2.3 Eliminating Long Duration Truck Idling

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

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

TSE can eliminate idling when trucks are resting at truck stops or public rest areas and while trucks are waiting to perform a task at private distribution terminals. When truck spaces are electrified, truck drivers can shut down their engines and use electricity to power equipment which supplies air conditioning, heat, and electrical power for on-board appliances.

MIRTs can eliminate long duration idling from trucks that are stopped away from these central sites. For a more complete list of MIRTs see EPA's Idle Reduction Technology page at http://www.epa.gov/otaq/smartway/idlingtechnologies.htm.

This measure demonstrates the potential emissions reductions if every class 8a and 8b truck is equipped with a MIRT or has dependable access to sites with TSE in 2020.

To estimate the potential emissions reduction from this measure, we applied a reduction equal to the full amount of the emissions attributed to long duration idling in the MOBILE model, which is estimated to be 3.4% of the total NOx emissions from class 8a and 8b heavy duty diesel trucks. Since the MOBILE model does not distinguish between idling and operating emissions, EPA estimates idling emissions in the inventory based on fuel conversion factors. The inventory in the MOBILE model, however, does not fully capture long duration idling emissions. There is evidence that idling may represent a much greater share than 3.4% of the real world inventory, based on engine control module data from long haul trucking companies. As such, we believe the emissions reductions demonstrated from this measure in the RIA represent ambitious but realistic targets. For more information on determining baseline idling activity see EPA's "Guidance for Quantifying and Using Long-Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity" available at http://www.epa.gov/smartway/idle-guid.htm.

Pollutants and Source Categories Affected by Measure: NO_x

Table 3a.14: Class 8a and 8b Heavy Duty Diesel Trucks (decrease NOx for all SCCs)

SCC	Note: All SCC Descriptions below begin with "Mobile Sources; Highway Vehicles—Diesel"
2230074110	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Interstate: Total
2230074130	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Other Principal Arterial: Total
2230074150	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Minor Arterial: Total
2230074170	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Major Collector: Total
2230074190	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Minor Collector: Total
2230074210	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Rural Local: Total
2230074230	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Interstate: Total
2230074250	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Other Freeways and Expressways: Total
2230074270	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Other Principal Arterial: Total
2230074290	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Minor Arterial: Total
2230074310	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Collector: Total
2230074330	Heavy Duty Diesel Vehicles (HDDV) Class 8A & 8B; Urban Local: Total

Estimated Emissions Reduction from Measure (%): 3.4 % decrease in NOx for all SCCs affected by measure

3a.2.4 Commuter Programs

Commuter programs recognize and support employers who provide incentives to employees to reduce light-duty vehicle emissions. Employers implement a wide range of incentives to affect change in employee commuting habits including transit subsidies, bike-friendly facilities, telecommuting policies, and preferred parking for vanpools and carpools. The commuter measure in this RIA reflects a mixed package of incentives.

This measure demonstrates the potential emissions reductions from providing commuter incentives to 10% and 25% of the commuter population in 2020.

We used the findings from a recent Best Workplaces for Commuters survey, which was an EPA sponsored employee trip reduction program, to estimate the potential emissions reductions from this measure.[9] The BWC survey found that, on average, employees at workplaces with comprehensive commuter programs emit 15% fewer emissions than employees at workplaces that do not offer a comprehensive commuter program.

[9] Herzog, E., Bricka, S., Audette, L., and Rockwell, J., 2005. *Do Employee Commuter Benefits Reduce Vehicle Emissions and Fuel Consumption? Results of the Fall 2004 Best Workplaces for Commuters Survey*, Transportation Research Record, Journal of the Transportation Research Board: Forthcoming.

We believe that getting 10%–25% of the workforce involved in commuter programs is realistic. For modeling purposes, we divided the commuter programs measure into two program penetration rates: 10% and 25%. This was meant to provide flexibility to model a lower penetration rate for areas that need only low levels of emissions reductions to achieve attainment.

According to the 2001 National Household Transportation Survey (NHTS) published by DOT, commute VMT represents 27% of total VMT. Based on this information, we calculated that BWC would reduce light-duty gasoline emissions by 0.4% and 1% with a 10% and 25% program penetration rate, respectively.

Pollutants and Source Categories Affected by Measure (SCC): NO_x, and VOC

Table 3a.15: All Light-Duty Gasoline Vehicles and Trucks

SCC	Note: All SCC Descriptions below begin with "Mobile Sources; Highway Vehicles—Gasoline"
2201001110	Light Duty Gasoline Vehicles (LDGV); Rural Interstate: Total
2201001130	Light Duty Gasoline Vehicles (LDGV); Rural Other Principal Arterial: Total
2201001150	Light Duty Gasoline Vehicles (LDGV); Rural Minor Arterial: Total
2201001170	Light Duty Gasoline Vehicles (LDGV); Rural Major Collector: Total
2201001190	Light Duty Gasoline Vehicles (LDGV); Rural Minor Collector: Total
2201001210	Light Duty Gasoline Vehicles (LDGV); Rural Local: Total
2201001230	Light Duty Gasoline Vehicles (LDGV); Urban Interstate: Total
2201001250	Light Duty Gasoline Vehicles (LDGV); Urban Other Freeways and Expressways: Total
2201001270	Light Duty Gasoline Vehicles (LDGV); Urban Other Principal Arterial: Total
2201001290	Light Duty Gasoline Vehicles (LDGV); Urban Minor Arterial: Total
2201001310	Light Duty Gasoline Vehicles (LDGV); Urban Collector: Total
2201001330	Light Duty Gasoline Vehicles (LDGV); Urban Local: Total
2201020110	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Interstate: Total
2201020130	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Other Principal Arterial: Total
2201020150	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Minor Arterial: Total
2201020170	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Major Collector: Total
2201020190	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Minor Collector: Total
2201020210	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Rural Local: Total
2201020230	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Interstate: Total
2201020250	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Other Freeways and Expressways: Total
2201020270	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Other Principal Arterial: Total
2201020290	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Minor Arterial: Total
2201020310	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Collector: Total
2201020330	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5); Urban Local: Total
2201040110	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Interstate: Total
2201040130	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Other Principal Arterial: Total
2201040150	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Minor Arterial: Total
2201040170	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Major Collector: Total
2201040190	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Minor Collector: Total
2201040210	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Rural Local: Total
2201040230	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Interstate: Total
2201040250	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Other Freeways and Expressways: Total
2201040270	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Other Principal Arterial: Total
2201040290	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Minor Arterial: Total
2201040310	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Collector: Total
2201040330	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5); Urban Local: Total

Estimated Emissions Reduction from Measure (%):
With a 10% program penetration rate: 0.4%
With a 25% program penetration rate: 1%

3a.2.5 Reduce Gasoline RVP from 7.8 to 7.0 in Remaining Nonattainment Areas

Volatility is the property of a liquid fuel that defines its evaporation characteristics. RVP is an abbreviation for "Reid vapor pressure," a common measure of gasoline volatility, as well as a generic term for gasoline volatility. EPA regulates the vapor pressure of all gasoline during the summer months (June 1 to September 15 at retail stations). Lower RVP helps to reduce VOCs, which are a precursor to ozone formation. This control measure represents the use of gasoline with a RVP limit of 7.0 psi from May through September in counties with an ozone season RVP value greater than 7.0 psi.

Under section 211(c)(4)(C) of the CAA, EPA may approve a non-identical state fuel control as a SIP provision, if the state demonstrates that the measure is necessary to achieve the national primary or secondary ambient air quality standard (NAAQS) that the plan implements. EPA can approve a state fuel requirement as necessary only if no other measures would bring about timely attainment, or if other measures exist but are unreasonable or impracticable.

Source Categories Affected by Measure:

- All light-duty gasoline vehicles and trucks: Affected SCC:
  - 2201001000 Light Duty Gasoline Vehicles (LDGV), Total: All Road Types
  - 2201020000 Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
  - 2201040000 Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types
  - 2201070000 Heavy Duty Gasoline Vehicles (HDGV), Total: All Road Types
  - 2201080000 Motorcycles (MC), Total: All Road Types

3a.3 EGU Controls Used in the Control Strategy

Table 3a.16 contains the ozone season emissions from all fossil EGU sources (greater than 25 megawatts) for the baseline and the control strategy.

Table 3a.16: NOx EGU Ozone Season Emissions (All Fossil Units >25MW) (1,000 Tons)[a]

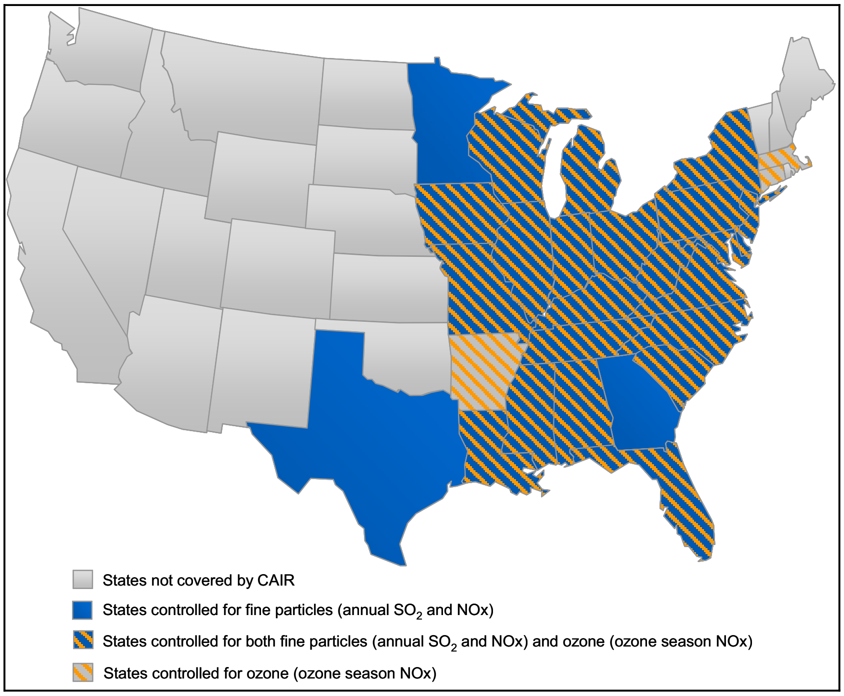
	OTC	MWRPO	East TX	National	CAIR Region	CAIR Cap
Baseline (CAIR/CAMR/CAVR)	73	154	43	828	463	485
Control Strategy	65 (−11%)	113 (−26%)	33 (−23%)	812 (−2%)	470	482

[a] Numbers in parentheses are the percentage change in emissions.

3a.3.1 CAIR

The data and projections presented in Section 3.2.2 cover the electric power sector, an industry that will achieve significant emission reductions under the Clean Air Interstate Rule (CAIR) over the next 10 to 15 years. Based on an assessment of the emissions contributing to interstate transport of air pollution and available control measures, EPA determined that achieving required reductions in the identified States by controlling emissions from power plants is highly cost effective. CAIR will permanently cap emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the eastern United States. CAIR achieves large reductions of SO_2 and/or NO_x emissions across 28 eastern states and the District of Columbia.

Figure 3a.1: CAIR Affected Region



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

Based on the final State rules that have been submitted and the proposed State rules that EPA has reviewed, EPA believes that all States intend to use the CAIR trading programs as their mechanism for meeting the emission reduction requirements of CAIR.

The analysis in this section reflects these realities and attempts to show, in an illustrative fashion, the costs and impacts of meeting a proposed 8-hr ozone standard of 0.070 ppm for the power sector.

3a.3.2 Integrated Planning Model and Background

CAIR was designed to achieve significant emissions reductions in a highly cost-effective manner to reduce the transport of fine particles that have been found to contribute to nonattainment. EPA analysis has found that the most efficient method to achieve the emissions reduction targets is through a cap-and-trade system on the power sector that States have the option of adopting. The modeling done with IPM assumes a region-wide cap and trade system on the power sector for the States covered.

It is important to note that the proposal RIA analysis used the Integrated Planning Model (IPM) v2.1.9 to ensure consistency with the analysis presented in 2006 PM NAAQS RIA and report incremental results. EPA's IPM v2.1.9 incorporated Federal and State rules and regulations adopted before March 2004 and various NSR settlements.

Final RIA analysis uses the latest version of IPM (v3.0) as part of the updated modeling platform. 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 NSR settlements. A detailed discussion of uncertainties associated with the EGU sector modeling can be found in 2006 PM NAAQS RIA (pg. 3-50)

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

3a.3.3 EGU NOx Emission Control Technologies

IPM v3.0 includes SO_2, NO_x, and mercury (Hg) emission control technology options for meeting existing and future federal, regional, and state, SO_2, NO_x and Hg emission limits. The NOx control technology options include Selective Catalytic Reduction (SCR) system and Selective Non-Catalytic Reduction (SNCR) systems. 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. Table 3a.17 summarizes retrofit NOx emission control performance assumptions.

Table 3a.17: Summary of Retrofit NOx Emission Control Performance Assumptions

	Selective Catalytic Reduction (SCR)		Selective Non-Catalytic Reduction (SNCR)	
Unit Type	**Coal**	**Oil/Gas[a]**	**Coal**	**Oil/Gas[a]**
Percent Removal	90% down to 0.06 lb/mmBtu	80%	35%	50%
Size Applicability	Units. 100 MW	Units. 25 MW	Units. 25 MW and Units < 200 MW	Units. 25 MW

[a] Controls to oil- or gas-fired EGUs are not applied as part of the EGU control strategy included in this RIA.

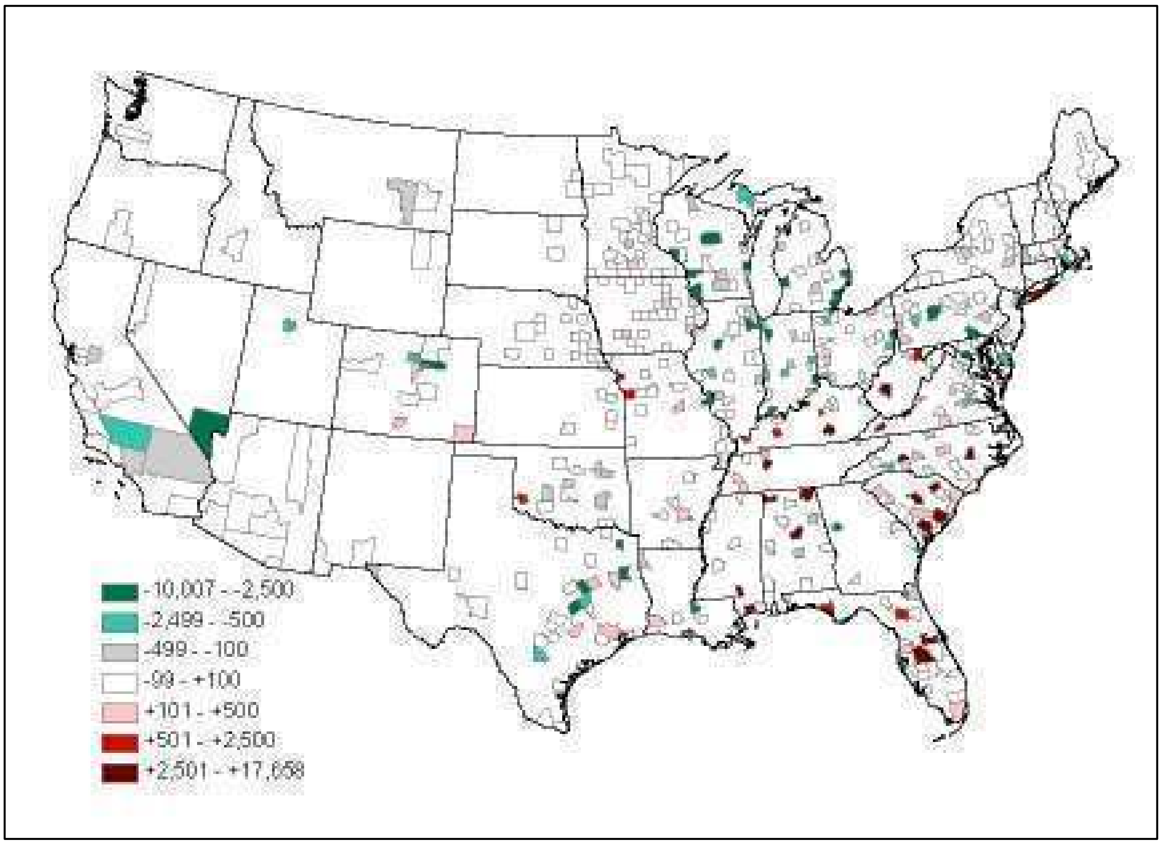
Existing coal-fired units that are retrofit with SCR have a NOx removal efficiency of 90%, with a minimum controlled NOx emission rate of 0.06 lb/mmBtu in IPM v2.1.9. Potential (new) coal-fired, combined cycle, and IGCC units are modeled to be constructed with SCR systems and designed to have emission rates ranging between 0.02 and 0.06 lb NOx/mmBtu.

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

3a.4 Emissions Reductions by Sector

Figures 3a.2–3a.6 show the NOx reductions for each sector and Figures 3a.7–3a.10 show the VOC reductions for each sector under the modeled control strategy.

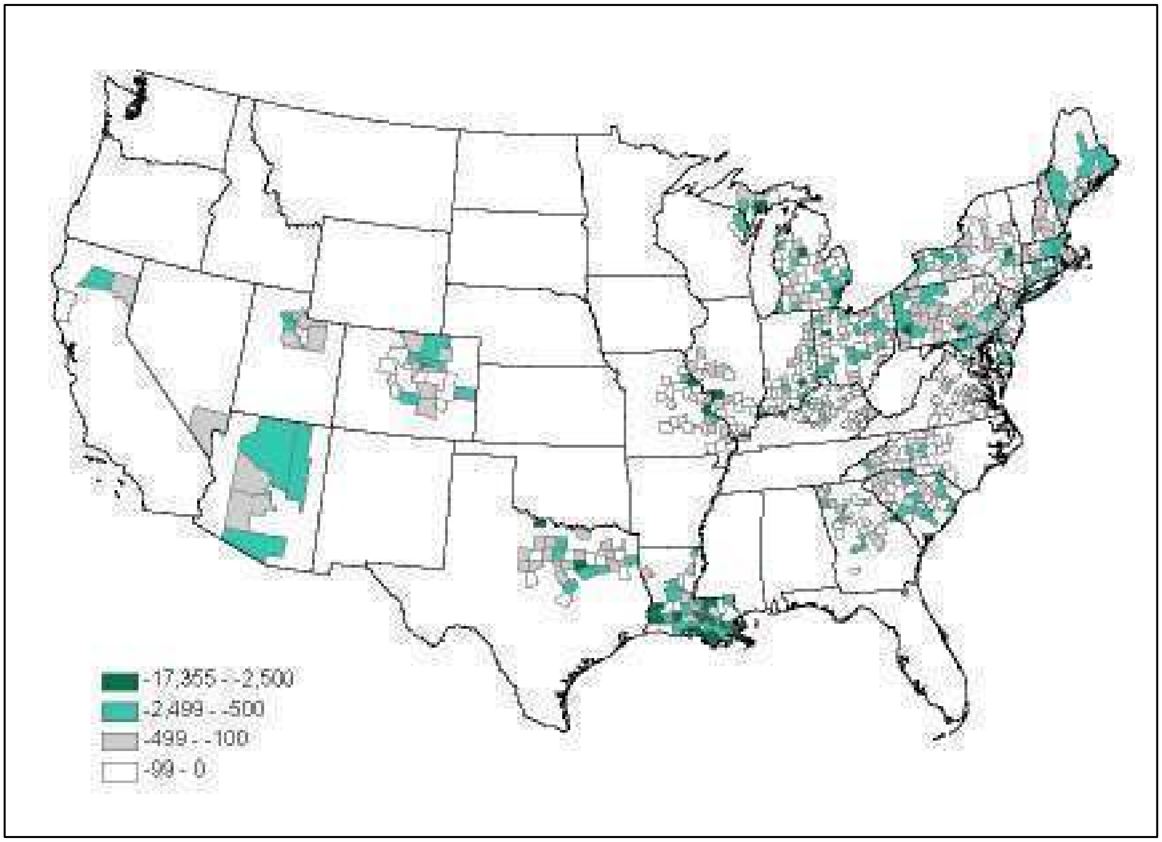
Figure 3a.2: Annual Tons of NOx Emissions Reduced from EGU Sources*



* Reductions are negative and increases are positive.

** The −99–+100 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

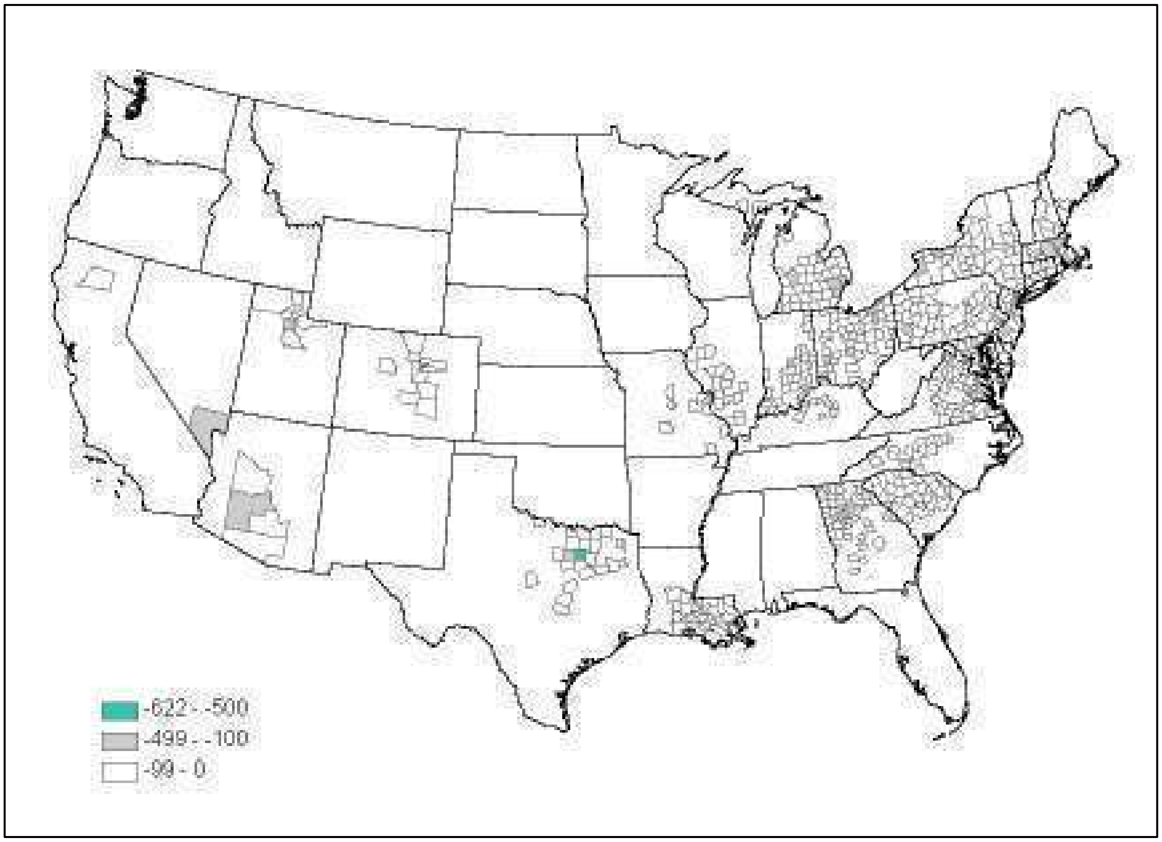
Figure 3a.3: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from NonEGU Point Sources*



* Reductions are negative and increases are positive.

** The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

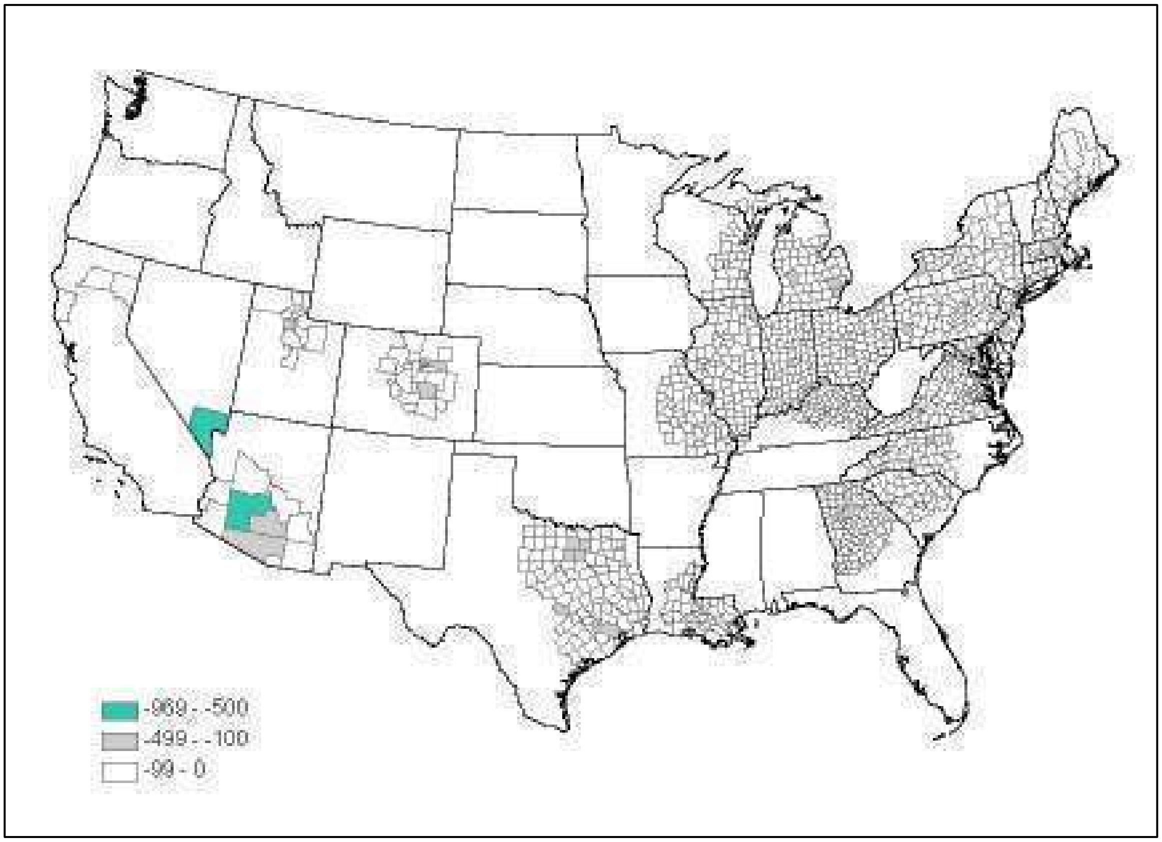
Figure 3a.4: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Area Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

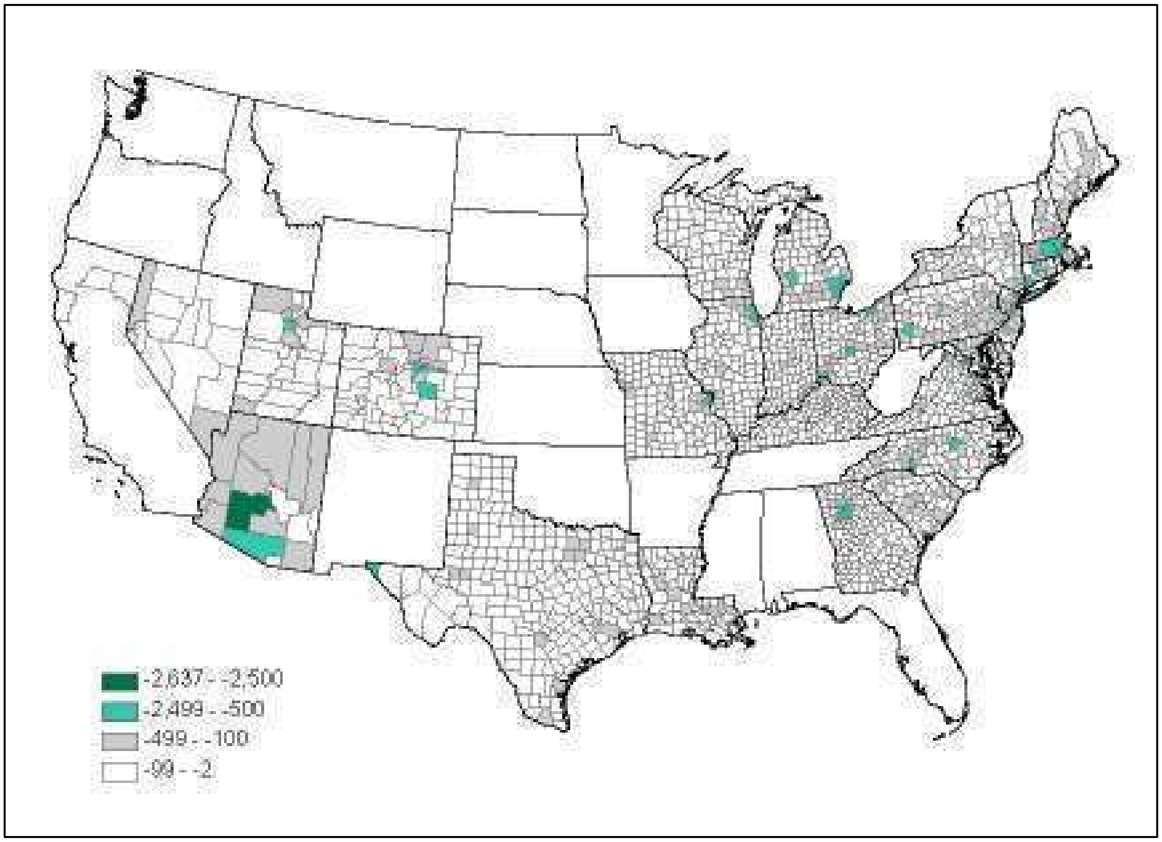
Figure 3a.5: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Nonroad Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

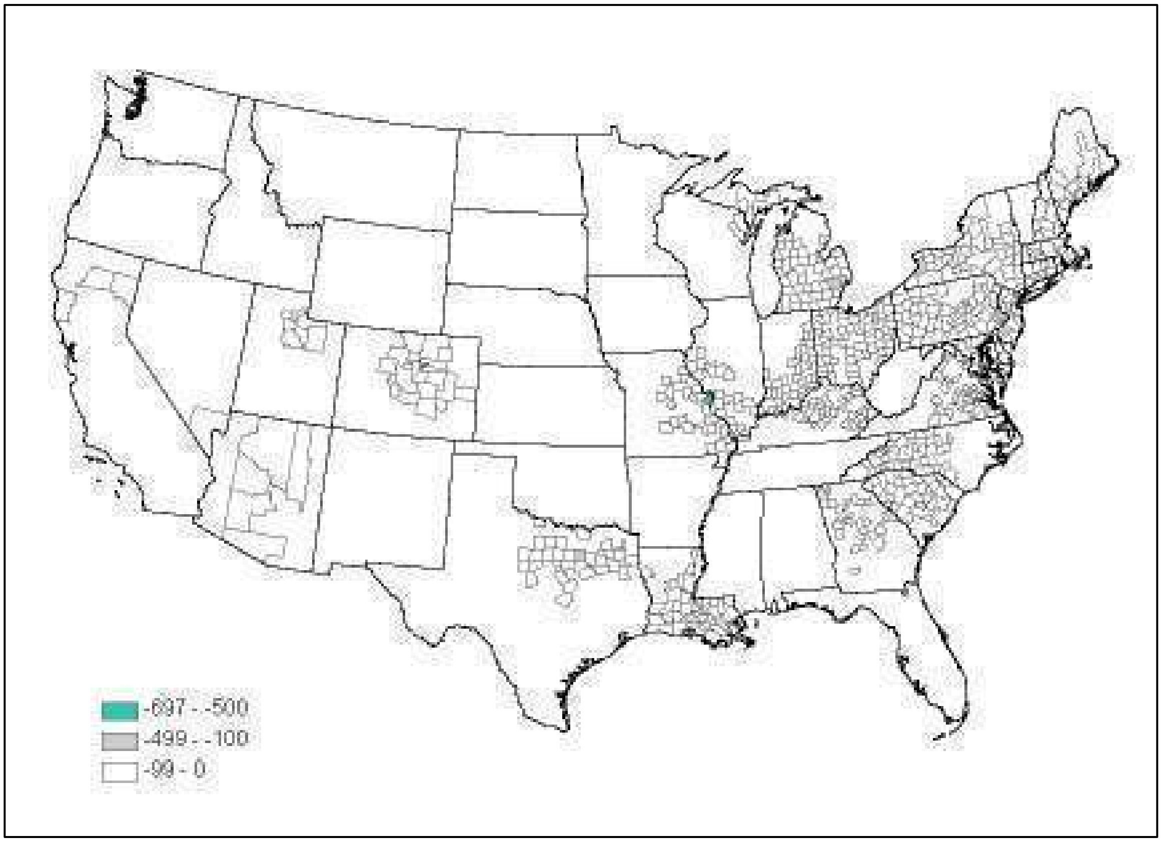
Figure 3a.6: Annual tons/year of Nitrogen Oxide (NOx) Emissions Reduced from Onroad Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level NOx reductions or increases that likely had little to no impact on ozone estimates. Most counties in this range had NOx differences of under 1 ton.

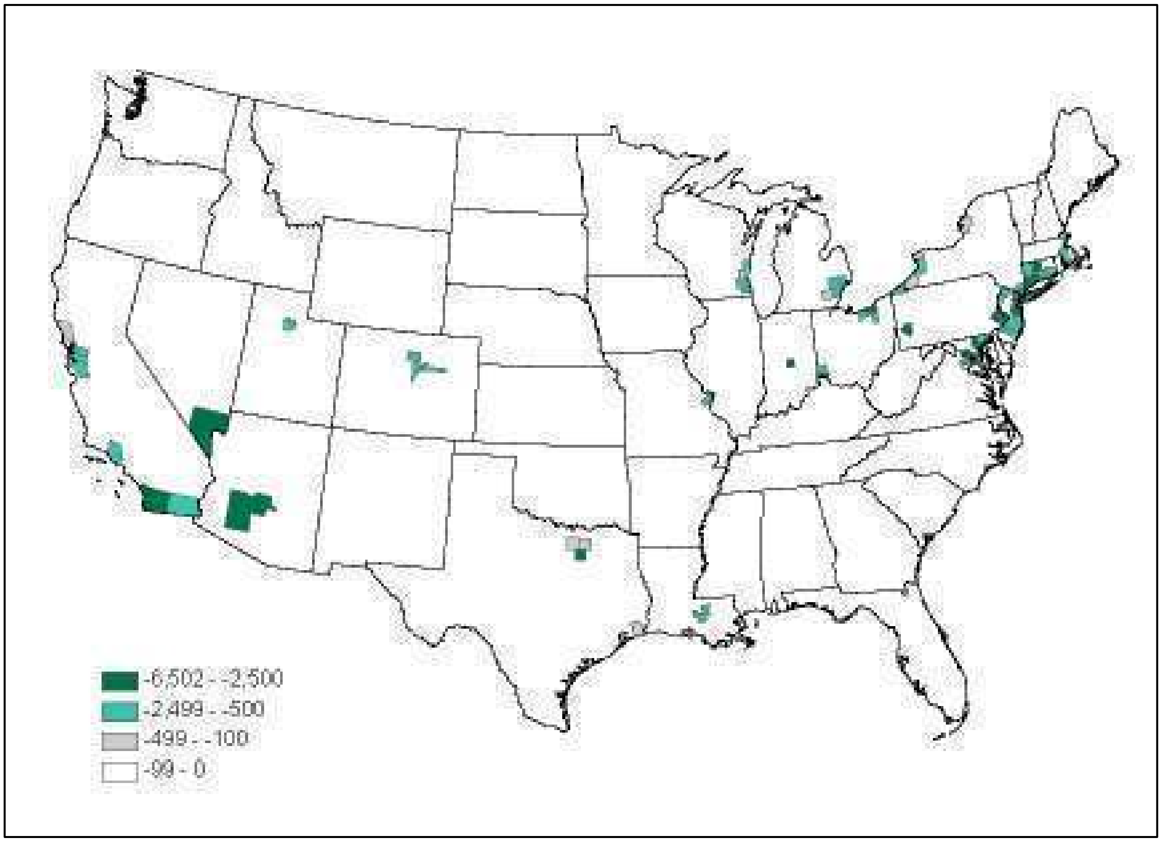
Figure 3a.7: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from NonEGU Point Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates

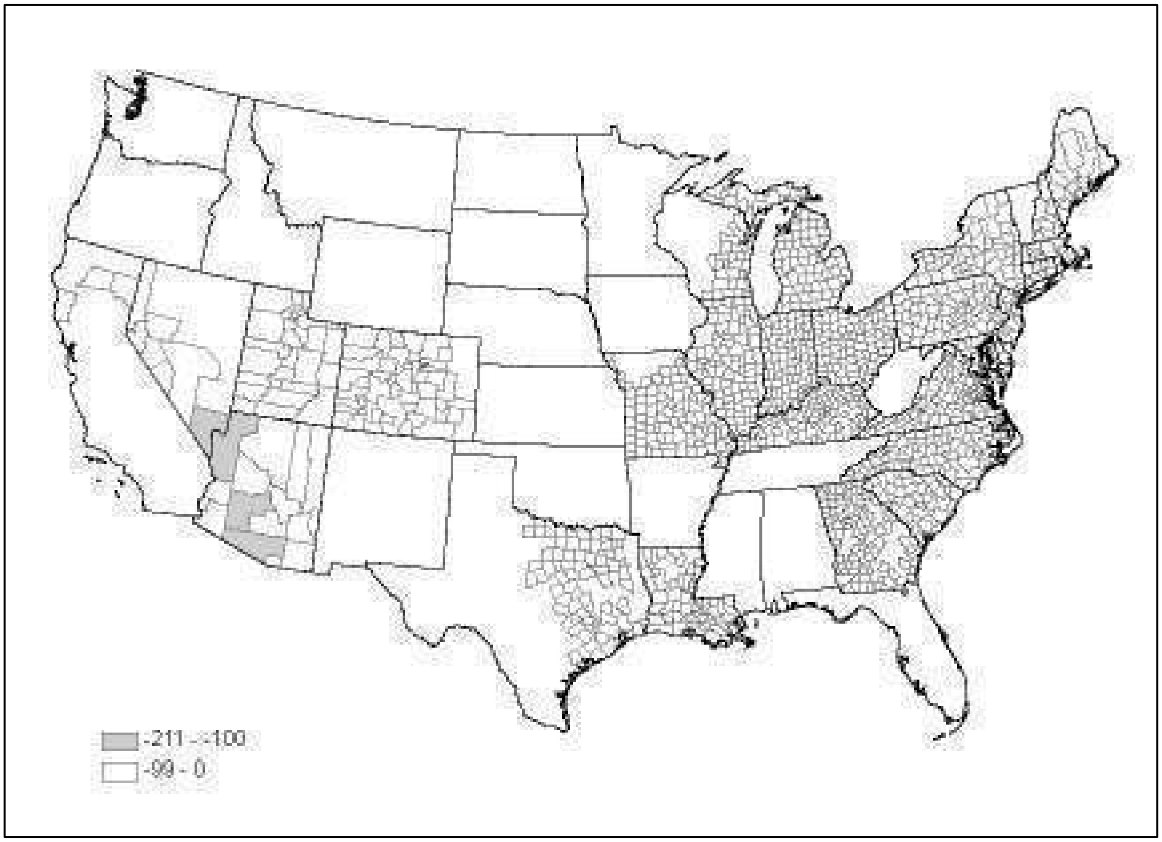
Figure 3a.8: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Area Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

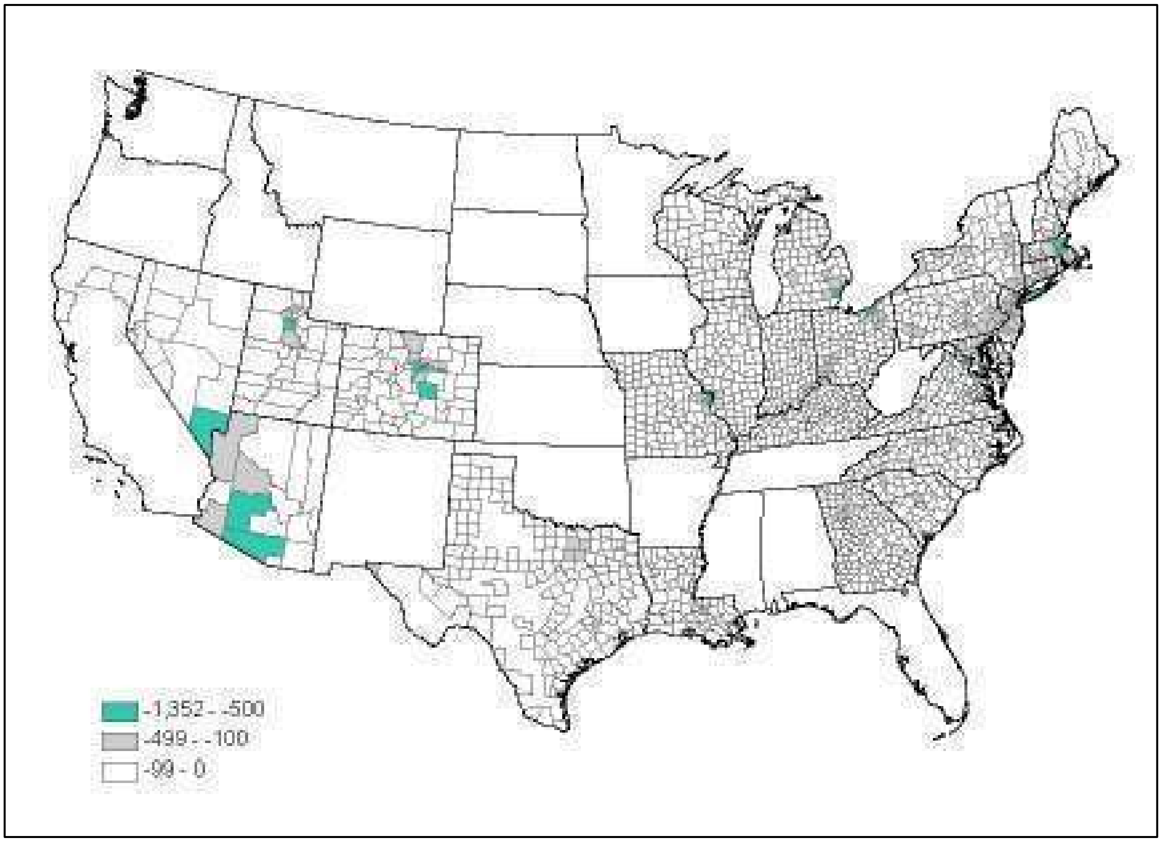
Figure 3a.9: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Nonroad Mobile Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

Figure 3a.10: Annual tons/year of Volatile Organic Compounds (VOC) Emissions Reduced from Onroad Mobile Sources*



*Reductions are negative and increases are positive

**The −99–0 range is not shown because these are small county-level VOC reductions or increases that likely had little to no impact on ozone estimates.

3a.5 Change in Ozone Concentrations Between Baseline and Modeled Control Strategy

Table 3a.18 provides the projected 8-hour ozone design values for the 2020 baseline and 2020 control strategy scenarios for each monitored county. The changes in ozone in 2020 between the baseline and the control strategy are also provided in this table.

Table 3a.18: Changes in Ozone Concentrations between Baseline and Modeled Control Strategy

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Alabama	Baldwin	0.063	0.063	0.000
Alabama	Clay	0.056	0.055	-0.001
Alabama	Elmore	0.054	0.055	0.001
Alabama	Etowah	0.054	0.052	-0.002
Alabama	Jefferson	0.059	0.060	0.001
Alabama	Lawrence	0.054	0.055	0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Alabama	Madison	0.057	0.057	0.000
Alabama	Mobile	0.063	0.064	0.001
Alabama	Montgomery	0.054	0.054	0.000
Alabama	Morgan	0.060	0.061	0.001
Alabama	Shelby	0.061	0.063	0.002
Alabama	Sumter	0.051	0.051	0.000
Alabama	Tuscaloosa	0.052	0.052	0.000
Arizona	Cochise	0.065	0.064	-0.001
Arizona	Coconino	0.067	0.067	0.000
Arizona	Maricopa	0.069	0.068	-0.001
Arizona	Navajo	0.058	0.057	-0.001
Arizona	Pima	0.063	0.062	-0.001
Arizona	Pinal	0.064	0.063	-0.001
Arizona	Yavapai	0.064	0.064	0.000
Arkansas	Crittenden	0.068	0.068	0.000
Arkansas	Montgomery	0.051	0.051	0.000
Arkansas	Newton	0.060	0.060	0.000
Arkansas	Pulaski	0.061	0.061	0.000
California	Alameda	0.068	0.068	0.000
California	Amador	0.067	0.067	0.000
California	Butte	0.068	0.068	0.000
California	Calaveras	0.071	0.071	0.000
California	Colusa	0.058	0.058	0.000
California	Contra Costa	0.069	0.069	0.000
California	El Dorado	0.080	0.080	0.000
California	Fresno	0.091	0.091	0.000
California	Glenn	0.057	0.057	0.000
California	Imperial	0.071	0.071	0.000
California	Inyo	0.068	0.068	0.000
California	Kern	0.096	0.096	0.000
California	Kings	0.076	0.076	0.000
California	Lake	0.054	0.054	0.000
California	Los Angeles	0.104	0.104	0.000
California	Madera	0.075	0.075	0.000
California	Marin	0.041	0.040	-0.001
California	Mariposa	0.071	0.071	0.000
California	Mendocino	0.045	0.045	0.000
California	Merced	0.079	0.079	0.000
California	Monterey	0.054	0.054	0.000
California	Napa	0.050	0.050	0.000
California	Nevada	0.075	0.075	0.000
California	Orange	0.080	0.080	0.000
California	Placer	0.075	0.075	0.000
California	Riverside	0.101	0.101	0.000
California	Sacramento	0.077	0.077	0.000
California	San Benito	0.066	0.066	0.000
California	San Bernardino	0.122	0.122	0.000
California	San Diego	0.077	0.076	-0.001
California	San Francisco	0.045	0.045	0.000
California	San Joaquin	0.067	0.066	-0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
California	San Luis Obispo	0.060	0.060	0.000
California	San Mateo	0.051	0.050	-0.001
California	Santa Barbara	0.068	0.068	0.000
California	Santa Clara	0.066	0.066	0.000
California	Santa Cruz	0.054	0.054	0.000
California	Shasta	0.057	0.057	0.000
California	Solano	0.057	0.057	0.000
California	Sonoma	0.048	0.048	0.000
California	Stanislaus	0.076	0.076	0.000
California	Sutter	0.067	0.067	0.000
California	Tehama	0.065	0.065	0.000
California	Tulare	0.083	0.083	0.000
California	Tuolumne	0.072	0.072	0.000
California	Ventura	0.077	0.077	0.000
California	Yolo	0.064	0.064	0.000
Colorado	Adams	0.056	0.053	-0.003
Colorado	Arapahoe	0.069	0.064	-0.005
Colorado	Boulder	0.062	0.058	-0.004
Colorado	Denver	0.064	0.060	-0.004
Colorado	Douglas	0.072	0.067	-0.005
Colorado	El Paso	0.062	0.059	-0.003
Colorado	Jefferson	0.072	0.067	-0.005
Colorado	La Plata	0.051	0.051	0.000
Colorado	Larimer	0.066	0.061	-0.005
Colorado	Montezuma	0.062	0.062	0.000
Colorado	Weld	0.063	0.059	-0.004
Connecticut	Fairfield	0.079	0.076	-0.003
Connecticut	Hartford	0.065	0.062	-0.003
Connecticut	Litchfield	0.064	0.061	-0.003
Connecticut	Middlesex	0.073	0.070	-0.003
Connecticut	New Haven	0.076	0.073	-0.003
Connecticut	New London	0.067	0.065	-0.002
Connecticut	Tolland	0.068	0.065	-0.003
Delaware	Kent	0.069	0.067	-0.002
Delaware	New Castle	0.070	0.067	-0.003
Delaware	Sussex	0.070	0.067	-0.003
D.C.	Washington	0.068	0.065	-0.003
Florida	Alachua	0.056	0.056	0.000
Florida	Baker	0.054	0.054	0.000
Florida	Bay	0.061	0.063	0.002
Florida	Brevard	0.050	0.051	0.001
Florida	Broward	0.054	0.054	0.000
Florida	Collier	0.056	0.056	0.000
Florida	Columbia	0.052	0.052	0.000
Florida	Duval	0.052	0.052	0.000
Florida	Escambia	0.064	0.064	0.000
Florida	Highlands	0.053	0.053	0.000
Florida	Hillsborough	0.065	0.065	0.000
Florida	Holmes	0.054	0.054	0.000
Florida	Lake	0.054	0.056	0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Florida	Lee	0.055	0.056	0.001
Florida	Leon	0.054	0.054	0.000
Florida	Manatee	0.060	0.060	0.000
Florida	Marion	0.058	0.058	0.000
Florida	Miami-Dade	0.052	0.052	0.000
Florida	Orange	0.055	0.057	0.002
Florida	Osceola	0.053	0.054	0.001
Florida	Palm Beach	0.054	0.054	0.000
Florida	Pasco	0.057	0.057	0.000
Florida	Pinellas	0.060	0.060	0.000
Florida	Polk	0.057	0.058	0.001
Florida	St Lucie	0.051	0.051	0.000
Florida	Santa Rosa	0.063	0.063	0.000
Florida	Sarasota	0.060	0.060	0.000
Florida	Seminole	0.056	0.058	0.002
Florida	Volusia	0.051	0.051	0.000
Florida	Wakulla	0.059	0.059	0.000
Georgia	Bibb	0.064	0.063	-0.001
Georgia	Chatham	0.052	0.052	0.000
Georgia	Cherokee	0.053	0.051	-0.002
Georgia	Clarke	0.053	0.051	-0.002
Georgia	Cobb	0.063	0.061	-0.002
Georgia	Coweta	0.065	0.059	-0.006
Georgia	Dawson	0.056	0.054	-0.002
Georgia	De Kalb	0.066	0.064	-0.002
Georgia	Douglas	0.063	0.061	-0.002
Georgia	Fayette	0.061	0.059	-0.002
Georgia	Fulton	0.070	0.068	-0.002
Georgia	Glynn	0.054	0.053	-0.001
Georgia	Gwinnett	0.061	0.059	-0.002
Georgia	Henry	0.064	0.062	-0.002
Georgia	Murray	0.059	0.058	-0.001
Georgia	Muscogee	0.053	0.052	-0.001
Georgia	Paulding	0.060	0.058	-0.002
Georgia	Richmond	0.064	0.059	-0.005
Georgia	Rockdale	0.063	0.061	-0.002
Georgia	Sumter	0.054	0.053	-0.001
Idaho	Ada	0.069	0.069	0.000
Idaho	Butte	0.065	0.065	0.000
Idaho	Canyon	0.059	0.059	0.000
Idaho	Elmore	0.060	0.060	0.000
Illinois	Adams	0.059	0.055	-0.004
Illinois	Champaign	0.057	0.056	-0.001
Illinois	Clark	0.053	0.052	-0.001
Illinois	Cook	0.073	0.072	-0.001
Illinois	Du Page	0.060	0.059	-0.001
Illinois	Effingham	0.057	0.056	-0.001
Illinois	Hamilton	0.058	0.057	-0.001
Illinois	Jersey	0.067	0.065	-0.002
Illinois	Kane	0.062	0.060	-0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Illinois	Lake	0.070	0.069	-0.001
Illinois	McHenry	0.066	0.065	-0.001
Illinois	McLean	0.057	0.055	-0.002
Illinois	Macon	0.055	0.054	-0.001
Illinois	Macoupin	0.057	0.055	-0.002
Illinois	Madison	0.066	0.063	-0.003
Illinois	Peoria	0.062	0.061	-0.001
Illinois	Randolph	0.059	0.058	-0.001
Illinois	Rock Island	0.054	0.053	-0.001
Illinois	St Clair	0.065	0.063	-0.002
Illinois	Sangamon	0.053	0.052	-0.001
Illinois	Will	0.061	0.060	-0.001
Illinois	Winnebago	0.058	0.056	-0.002
Indiana	Allen	0.066	0.065	-0.001
Indiana	Boone	0.067	0.065	-0.002
Indiana	Carroll	0.062	0.061	-0.001
Indiana	Clark	0.068	0.066	-0.002
Indiana	Delaware	0.064	0.062	-0.002
Indiana	Elkhart	0.065	0.064	-0.001
Indiana	Floyd	0.066	0.064	-0.002
Indiana	Gibson	0.051	0.050	-0.001
Indiana	Greene	0.062	0.061	-0.001
Indiana	Hamilton	0.069	0.068	-0.001
Indiana	Hancock	0.067	0.065	-0.002
Indiana	Hendricks	0.064	0.063	-0.001
Indiana	Huntington	0.063	0.062	-0.001
Indiana	Jackson	0.062	0.060	-0.002
Indiana	Johnson	0.064	0.062	-0.002
Indiana	Lake	0.077	0.077	0.000
Indiana	La Porte	0.074	0.072	-0.002
Indiana	Madison	0.067	0.065	-0.002
Indiana	Marion	0.068	0.066	-0.002
Indiana	Morgan	0.065	0.063	-0.002
Indiana	Porter	0.075	0.074	-0.001
Indiana	Posey	0.061	0.059	-0.002
Indiana	St Joseph	0.068	0.066	-0.002
Indiana	Shelby	0.068	0.067	-0.001
Indiana	Vanderburgh	0.060	0.058	-0.002
Indiana	Vigo	0.066	0.064	-0.002
Indiana	Warrick	0.064	0.061	-0.003
Iowa	Bremer	0.058	0.058	0.000
Iowa	Clinton	0.062	0.061	-0.001
Iowa	Harrison	0.062	0.062	0.000
Iowa	Linn	0.057	0.057	0.000
Iowa	Montgomery	0.056	0.056	0.000
Iowa	Palo Alto	0.054	0.053	-0.001
Iowa	Polk	0.046	0.046	0.000
Iowa	Scott	0.061	0.060	-0.001
Iowa	Story	0.048	0.048	0.000
Iowa	Van Buren	0.059	0.057	-0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Iowa	Warren	0.049	0.048	-0.001
Kansas	Linn	0.060	0.059	-0.001
Kansas	Sedgwick	0.063	0.063	0.000
Kansas	Sumner	0.062	0.062	0.000
Kansas	Trego	0.055	0.055	0.000
Kansas	Wyandotte	0.062	0.062	0.000
Kentucky	Bell	0.056	0.055	-0.001
Kentucky	Boone	0.063	0.060	-0.003
Kentucky	Boyd	0.070	0.069	-0.001
Kentucky	Bullitt	0.061	0.059	-0.002
Kentucky	Campbell	0.070	0.067	-0.003
Kentucky	Carter	0.057	0.056	-0.001
Kentucky	Christian	0.057	0.057	0.000
Kentucky	Daviess	0.058	0.058	0.000
Kentucky	Edmonson	0.059	0.057	-0.002
Kentucky	Fayette	0.057	0.055	-0.002
Kentucky	Graves	0.059	0.058	-0.001
Kentucky	Greenup	0.064	0.063	-0.001
Kentucky	Hancock	0.063	0.064	0.001
Kentucky	Hardin	0.057	0.056	-0.001
Kentucky	Henderson	0.060	0.057	-0.003
Kentucky	Jefferson	0.064	0.063	-0.001
Kentucky	Jessamine	0.057	0.056	-0.001
Kentucky	Kenton	0.065	0.062	-0.003
Kentucky	Livingston	0.061	0.060	-0.001
Kentucky	McCracken	0.063	0.062	-0.001
Kentucky	McLean	0.059	0.058	-0.001
Kentucky	Oldham	0.063	0.061	-0.002
Kentucky	Perry	0.055	0.054	-0.001
Kentucky	Pike	0.054	0.053	-0.001
Kentucky	Pulaski	0.058	0.060	0.002
Kentucky	Scott	0.050	0.049	-0.001
Kentucky	Simpson	0.056	0.056	0.000
Kentucky	Trigg	0.052	0.052	0.000
Kentucky	Warren	0.060	0.058	-0.002
Louisiana	Ascension	0.068	0.065	-0.003
Louisiana	Beauregard	0.061	0.058	-0.003
Louisiana	Bossier	0.060	0.060	0.000
Louisiana	Caddo	0.058	0.057	-0.001
Louisiana	Calcasieu	0.066	0.063	-0.003
Louisiana	East Baton Rouge	0.076	0.073	-0.003
Louisiana	Grant	0.060	0.058	-0.002
Louisiana	Iberville	0.072	0.068	-0.004
Louisiana	Jefferson	0.069	0.066	-0.003
Louisiana	Lafayette	0.065	0.061	-0.004
Louisiana	Lafourche	0.065	0.062	-0.003
Louisiana	Livingston	0.068	0.064	-0.004
Louisiana	Orleans	0.057	0.056	-0.001
Louisiana	Ouachita	0.061	0.060	-0.001
Louisiana	Pointe Coupee	0.063	0.057	-0.006

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Louisiana	St Bernard	0.063	0.061	-0.002
Louisiana	St Charles	0.066	0.063	-0.003
Louisiana	St James	0.064	0.061	-0.003
Louisiana	St John The Baptis	0.068	0.066	-0.002
Louisiana	St Mary	0.061	0.057	-0.004
Louisiana	West Baton Rouge	0.073	0.070	-0.003
Maine	Cumberland	0.063	0.061	-0.002
Maine	Hancock	0.071	0.068	-0.003
Maine	Kennebec	0.060	0.058	-0.002
Maine	Knox	0.063	0.061	-0.002
Maine	Oxford	0.050	0.048	-0.002
Maine	Penobscot	0.064	0.062	-0.002
Maine	Sagadahoc	0.059	0.057	-0.002
Maine	York	0.066	0.064	-0.002
Maryland	Anne Arundel	0.072	0.069	-0.003
Maryland	Baltimore	0.070	0.067	-0.003
Maryland	Carroll	0.065	0.061	-0.004
Maryland	Cecil	0.071	0.068	-0.003
Maryland	Charles	0.065	0.062	-0.003
Maryland	Frederick	0.065	0.061	-0.004
Maryland	Harford	0.076	0.073	-0.003
Maryland	Kent	0.069	0.067	-0.002
Maryland	Montgomery	0.064	0.061	-0.003
Maryland	Prince Georges	0.069	0.066	-0.003
Maryland	Washington	0.063	0.061	-0.002
Massachusetts	Barnstable	0.070	0.068	-0.002
Massachusetts	Berkshire	0.068	0.066	-0.002
Massachusetts	Bristol	0.069	0.066	-0.003
Massachusetts	Essex	0.070	0.068	-0.002
Massachusetts	Hampden	0.068	0.065	-0.003
Massachusetts	Hampshire	0.066	0.063	-0.003
Massachusetts	Middlesex	0.064	0.062	-0.002
Massachusetts	Norfolk	0.073	0.071	-0.002
Massachusetts	Suffolk	0.068	0.067	-0.001
Massachusetts	Worcester	0.065	0.062	-0.003
Michigan	Allegan	0.073	0.072	-0.001
Michigan	Benzie	0.066	0.065	-0.001
Michigan	Berrien	0.070	0.069	-0.001
Michigan	Cass	0.068	0.066	-0.002
Michigan	Clinton	0.064	0.062	-0.002
Michigan	Genesee	0.066	0.064	-0.002
Michigan	Huron	0.068	0.067	-0.001
Michigan	Ingham	0.063	0.062	-0.001
Michigan	Kalamazoo	0.062	0.061	-0.001
Michigan	Kent	0.065	0.063	-0.002
Michigan	Lenawee	0.067	0.065	-0.002
Michigan	Macomb	0.075	0.073	-0.002
Michigan	Mason	0.065	0.064	-0.001
Michigan	Missaukee	0.061	0.060	-0.001
Michigan	Muskegon	0.069	0.068	-0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Michigan	Oakland	0.072	0.071	-0.001
Michigan	Ottawa	0.066	0.064	-0.002
Michigan	St Clair	0.070	0.067	-0.003
Michigan	Schoolcraft	0.062	0.061	-0.001
Michigan	Washtenaw	0.069	0.067	-0.002
Michigan	Wayne	0.071	0.069	-0.002
Minnesota	St Louis	0.059	0.059	0.000
Mississippi	Adams	0.060	0.059	-0.001
Mississippi	Bolivar	0.057	0.057	0.000
Mississippi	De Soto	0.062	0.062	0.000
Mississippi	Hancock	0.063	0.062	-0.001
Mississippi	Harrison	0.062	0.065	0.003
Mississippi	Hinds	0.050	0.050	0.000
Mississippi	Jackson	0.067	0.067	0.000
Mississippi	Lauderdale	0.051	0.050	-0.001
Mississippi	Lee	0.056	0.058	0.002
Mississippi	Madison	0.053	0.053	0.000
Mississippi	Warren	0.052	0.052	0.000
Missouri	Cass	0.060	0.060	0.000
Missouri	Cedar	0.063	0.062	-0.001
Missouri	Clay	0.064	0.064	0.000
Missouri	Greene	0.058	0.057	-0.001
Missouri	Jefferson	0.066	0.064	-0.002
Missouri	Monroe	0.060	0.058	-0.002
Missouri	Platte	0.063	0.062	-0.001
Missouri	St Charles	0.071	0.068	-0.003
Missouri	Ste Genevieve	0.065	0.062	-0.003
Missouri	St Louis	0.070	0.067	-0.003
Missouri	St Louis City	0.070	0.068	-0.002
Montana	Flathead	0.052	0.052	0.000
Nebraska	Douglas	0.056	0.056	0.000
Nebraska	Lancaster	0.045	0.045	0.000
Nevada	Clark	0.072	0.071	-0.001
Nevada	Douglas	0.059	0.059	0.000
Nevada	Washoe	0.063	0.063	0.000
Nevada	White Pine	0.065	0.065	0.000
Nevada	Carson City	0.062	0.062	0.000
New Hampshire	Belknap	0.059	0.058	-0.001
New Hampshire	Carroll	0.055	0.054	-0.001
New Hampshire	Cheshire	0.056	0.054	-0.002
New Hampshire	Grafton	0.057	0.056	-0.001
New Hampshire	Hillsborough	0.065	0.063	-0.002
New Hampshire	Merrimack	0.057	0.056	-0.001
New Hampshire	Rockingham	0.063	0.061	-0.002
New Hampshire	Strafford	0.059	0.057	-0.002
New Hampshire	Sullivan	0.061	0.059	-0.002
New Jersey	Atlantic	0.067	0.065	-0.002
New Jersey	Bergen	0.074	0.071	-0.003
New Jersey	Camden	0.077	0.074	-0.003
New Jersey	Cumberland	0.071	0.068	-0.003

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
New Jersey	Essex	0.052	0.051	-0.001
New Jersey	Gloucester	0.075	0.073	-0.002
New Jersey	Hudson	0.066	0.064	-0.002
New Jersey	Hunterdon	0.071	0.068	-0.003
New Jersey	Mercer	0.075	0.073	-0.002
New Jersey	Middlesex	0.073	0.070	-0.003
New Jersey	Monmouth	0.073	0.070	-0.003
New Jersey	Morris	0.071	0.068	-0.003
New Jersey	Ocean	0.079	0.076	-0.003
New Jersey	Passaic	0.067	0.064	-0.003
New Mexico	Bernalillo	0.065	0.064	-0.001
New Mexico	Dona Ana	0.069	0.068	-0.001
New Mexico	Eddy	0.063	0.063	0.000
New Mexico	Sandoval	0.063	0.063	0.000
New Mexico	San Juan	0.069	0.069	0.000
New Mexico	Valencia	0.056	0.056	0.000
New York	Albany	0.064	0.061	-0.003
New York	Bronx	0.069	0.067	-0.002
New York	Chautauqua	0.072	0.069	-0.003
New York	Chemung	0.061	0.059	-0.002
New York	Dutchess	0.068	0.065	-0.003
New York	Erie	0.075	0.072	-0.003
New York	Essex	0.069	0.067	-0.002
New York	Hamilton	0.063	0.062	-0.001
New York	Herkimer	0.059	0.057	-0.002
New York	Jefferson	0.073	0.071	-0.002
New York	Madison	0.062	0.060	-0.002
New York	Monroe	0.067	0.064	-0.003
New York	Niagara	0.075	0.073	-0.002
New York	Oneida	0.063	0.061	-0.002
New York	Onondaga	0.067	0.065	-0.002
New York	Orange	0.063	0.061	-0.002
New York	Oswego	0.053	0.052	-0.001
New York	Putnam	0.070	0.068	-0.002
New York	Queens	0.069	0.067	-0.002
New York	Rensselaer	0.066	0.063	-0.003
New York	Richmond	0.073	0.071	-0.002
New York	Saratoga	0.067	0.063	-0.004
New York	Schenectady	0.061	0.059	-0.002
New York	Suffolk	0.080	0.077	-0.003
New York	Ulster	0.063	0.061	-0.002
New York	Wayne	0.065	0.063	-0.002
New York	Westchester	0.074	0.071	-0.003
North Carolina	Alexander	0.062	0.061	-0.001
North Carolina	Avery	0.059	0.057	-0.002
North Carolina	Buncombe	0.060	0.059	-0.001
North Carolina	Caldwell	0.060	0.060	0.000
North Carolina	Caswell	0.060	0.059	-0.001
North Carolina	Chatham	0.058	0.057	-0.001
North Carolina	Cumberland	0.061	0.060	-0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
North Carolina	Davie	0.064	0.062	-0.002
North Carolina	Duplin	0.059	0.058	-0.001
North Carolina	Durham	0.061	0.060	-0.001
North Carolina	Edgecombe	0.063	0.062	-0.001
North Carolina	Forsyth	0.063	0.062	-0.001
North Carolina	Franklin	0.063	0.062	-0.001
North Carolina	Granville	0.064	0.063	-0.001
North Carolina	Guilford	0.060	0.058	-0.002
North Carolina	Haywood	0.064	0.064	0.000
North Carolina	Jackson	0.063	0.062	-0.001
North Carolina	Johnston	0.060	0.059	-0.001
North Carolina	Lenoir	0.060	0.059	-0.001
North Carolina	Lincoln	0.064	0.065	0.001
North Carolina	Martin	0.060	0.059	-0.001
North Carolina	Mecklenburg	0.071	0.070	-0.001
North Carolina	New Hanover	0.056	0.057	0.001
North Carolina	Northampton	0.062	0.060	-0.002
North Carolina	Person	0.063	0.061	-0.002
North Carolina	Pitt	0.059	0.058	-0.001
North Carolina	Randolph	0.057	0.056	-0.001
North Carolina	Rockingham	0.062	0.061	-0.001
North Carolina	Rowan	0.068	0.067	-0.001
North Carolina	Swain	0.053	0.052	-0.001
North Carolina	Union	0.062	0.061	-0.001
North Carolina	Wake	0.064	0.063	-0.001
North Carolina	Yancey	0.063	0.061	-0.002
North Dakota	Billings	0.054	0.054	0.000
North Dakota	Cass	0.055	0.055	0.000
North Dakota	Dunn	0.054	0.054	0.000
North Dakota	McKenzie	0.058	0.058	0.000
North Dakota	Mercer	0.055	0.055	0.000
North Dakota	Oliver	0.051	0.050	-0.001
Ohio	Allen	0.068	0.065	-0.003
Ohio	Ashtabula	0.075	0.073	-0.002
Ohio	Butler	0.068	0.064	-0.004
Ohio	Clark	0.066	0.062	-0.004
Ohio	Clermont	0.068	0.066	-0.002
Ohio	Clinton	0.069	0.066	-0.003
Ohio	Cuyahoga	0.067	0.065	-0.002
Ohio	Delaware	0.066	0.064	-0.002
Ohio	Franklin	0.068	0.066	-0.002
Ohio	Geauga	0.076	0.074	-0.002
Ohio	Greene	0.066	0.062	-0.004
Ohio	Hamilton	0.069	0.066	-0.003
Ohio	Jefferson	0.063	0.061	-0.002
Ohio	Knox	0.064	0.062	-0.002
Ohio	Lake	0.072	0.070	-0.002
Ohio	Lawrence	0.065	0.063	-0.002
Ohio	Licking	0.065	0.062	-0.003
Ohio	Lorain	0.067	0.065	-0.002

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Ohio	Lucas	0.070	0.067	-0.003
Ohio	Madison	0.065	0.062	-0.003
Ohio	Mahoning	0.065	0.062	-0.003
Ohio	Medina	0.067	0.065	-0.002
Ohio	Miami	0.065	0.062	-0.003
Ohio	Montgomery	0.065	0.062	-0.003
Ohio	Portage	0.068	0.066	-0.002
Ohio	Preble	0.060	0.057	-0.003
Ohio	Stark	0.065	0.063	-0.002
Ohio	Summit	0.071	0.068	-0.003
Ohio	Trumbull	0.068	0.066	-0.002
Ohio	Warren	0.068	0.065	-0.003
Ohio	Washington	0.061	0.060	-0.001
Ohio	Wood	0.068	0.065	-0.003
Oklahoma	Canadian	0.056	0.056	0.000
Oklahoma	Cleveland	0.060	0.058	-0.002
Oklahoma	Comanche	0.061	0.059	-0.002
Oklahoma	Dewey	0.058	0.056	-0.002
Oklahoma	Kay	0.060	0.060	0.000
Oklahoma	Mc Clain	0.061	0.060	-0.001
Oklahoma	Oklahoma	0.061	0.060	-0.001
Oklahoma	Ottawa	0.062	0.062	0.000
Oklahoma	Pittsburg	0.060	0.060	0.000
Oklahoma	Tulsa	0.066	0.065	-0.001
Oregon	Clackamas	0.062	0.062	0.000
Oregon	Columbia	0.055	0.055	0.000
Oregon	Jackson	0.061	0.061	0.000
Oregon	Lane	0.059	0.059	0.000
Oregon	Marion	0.054	0.054	0.000
Pennsylvania	Adams	0.059	0.056	-0.003
Pennsylvania	Allegheny	0.072	0.069	-0.003
Pennsylvania	Armstrong	0.068	0.065	-0.003
Pennsylvania	Beaver	0.071	0.068	-0.003
Pennsylvania	Berks	0.066	0.063	-0.003
Pennsylvania	Blair	0.060	0.058	-0.002
Pennsylvania	Bucks	0.078	0.075	-0.003
Pennsylvania	Cambria	0.063	0.061	-0.002
Pennsylvania	Centre	0.062	0.059	-0.003
Pennsylvania	Chester	0.071	0.068	-0.003
Pennsylvania	Clearfield	0.065	0.062	-0.003
Pennsylvania	Dauphin	0.065	0.060	-0.005
Pennsylvania	Delaware	0.070	0.068	-0.002
Pennsylvania	Erie	0.070	0.067	-0.003
Pennsylvania	Franklin	0.067	0.064	-0.003
Pennsylvania	Greene	0.063	0.061	-0.002
Pennsylvania	Lackawanna	0.061	0.059	-0.002
Pennsylvania	Lancaster	0.067	0.062	-0.005
Pennsylvania	Lawrence	0.057	0.055	-0.002
Pennsylvania	Lehigh	0.067	0.063	-0.004
Pennsylvania	Luzerne	0.062	0.059	-0.003

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Pennsylvania	Lycoming	0.061	0.059	-0.002
Pennsylvania	Mercer	0.068	0.065	-0.003
Pennsylvania	Montgomery	0.071	0.068	-0.003
Pennsylvania	Northampton	0.066	0.062	-0.004
Pennsylvania	Perry	0.061	0.058	-0.003
Pennsylvania	Philadelphia	0.077	0.074	-0.003
Pennsylvania	Tioga	0.064	0.062	-0.002
Pennsylvania	Washington	0.066	0.063	-0.003
Pennsylvania	Westmoreland	0.068	0.065	-0.003
Pennsylvania	York	0.067	0.062	-0.005
Rhode Island	Kent	0.069	0.067	-0.002
Rhode Island	Providence	0.069	0.066	-0.003
Rhode Island	Washington	0.070	0.068	-0.002
South Carolina	Abbeville	0.060	0.058	-0.002
South Carolina	Aiken	0.061	0.058	-0.003
South Carolina	Anderson	0.063	0.062	-0.001
South Carolina	Barnwell	0.058	0.056	-0.002
South Carolina	Berkeley	0.052	0.052	0.000
South Carolina	Charleston	0.054	0.054	0.000
South Carolina	Cherokee	0.061	0.059	-0.002
South Carolina	Chester	0.059	0.058	-0.001
South Carolina	Chesterfield	0.058	0.058	0.000
South Carolina	Colleton	0.058	0.057	-0.001
South Carolina	Darlington	0.061	0.060	-0.001
South Carolina	Edgefield	0.059	0.056	-0.003
South Carolina	Oconee	0.060	0.059	-0.001
South Carolina	Pickens	0.059	0.058	-0.001
South Carolina	Richland	0.066	0.064	-0.002
South Carolina	Spartanburg	0.062	0.061	-0.001
South Carolina	Union	0.058	0.057	-0.001
South Carolina	Williamsburg	0.052	0.051	-0.001
South Carolina	York	0.059	0.058	-0.001
South Dakota	Pennington	0.062	0.061	-0.001
Tennessee	Anderson	0.058	0.058	0.000
Tennessee	Blount	0.064	0.064	0.000
Tennessee	Davidson	0.056	0.056	0.000
Tennessee	Hamilton	0.061	0.062	0.001
Tennessee	Haywood	0.060	0.062	0.002
Tennessee	Jefferson	0.061	0.061	0.000
Tennessee	Knox	0.061	0.061	0.000
Tennessee	Lawrence	0.056	0.058	0.002
Tennessee	Meigs	0.061	0.060	-0.001
Tennessee	Putnam	0.061	0.061	0.000
Tennessee	Rutherford	0.058	0.057	-0.001
Tennessee	Sevier	0.066	0.065	-0.001
Tennessee	Shelby	0.065	0.065	0.000
Tennessee	Sullivan	0.066	0.066	0.000
Tennessee	Sumner	0.061	0.061	0.000
Tennessee	Williamson	0.060	0.060	0.000
Tennessee	Wilson	0.060	0.060	0.000

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Texas	Bexar	0.068	0.067	-0.001
Texas	Brazoria	0.073	0.072	-0.001
Texas	Brewster	0.054	0.053	-0.001
Texas	Cameron	0.052	0.051	-0.001
Texas	Collin	0.069	0.067	-0.002
Texas	Dallas	0.068	0.066	-0.002
Texas	Denton	0.074	0.072	-0.002
Texas	Ellis	0.063	0.059	-0.004
Texas	El Paso	0.069	0.068	-0.001
Texas	Galveston	0.074	0.072	-0.002
Texas	Gregg	0.067	0.064	-0.003
Texas	Harris	0.089	0.087	-0.002
Texas	Harrison	0.061	0.058	-0.003
Texas	Hidalgo	0.062	0.061	-0.001
Texas	Hood	0.058	0.056	-0.002
Texas	Jefferson	0.074	0.071	-0.003
Texas	Johnson	0.065	0.062	-0.003
Texas	Kaufman	0.054	0.052	-0.002
Texas	Montgomery	0.073	0.072	-0.001
Texas	Nueces	0.065	0.063	-0.002
Texas	Orange	0.066	0.063	-0.003
Texas	Parker	0.063	0.061	-0.002
Texas	Rockwall	0.061	0.060	-0.001
Texas	Smith	0.064	0.061	-0.003
Texas	Tarrant	0.075	0.073	-0.002
Texas	Travis	0.063	0.062	-0.001
Texas	Victoria	0.060	0.059	-0.001
Texas	Webb	0.053	0.053	0.000
Utah	Box Elder	0.064	0.062	-0.002
Utah	Cache	0.056	0.054	-0.002
Utah	Davis	0.070	0.067	-0.003
Utah	Salt Lake	0.069	0.067	-0.002
Utah	San Juan	0.064	0.063	-0.001
Utah	Utah	0.067	0.065	-0.002
Utah	Weber	0.065	0.062	-0.003
Vermont	Bennington	0.061	0.058	-0.003
Vermont	Chittenden	0.063	0.062	-0.001
Virginia	Arlington	0.072	0.068	-0.004
Virginia	Caroline	0.059	0.057	-0.002
Virginia	Charles City	0.069	0.066	-0.003
Virginia	Chesterfield	0.066	0.064	-0.002
Virginia	Fairfax	0.071	0.067	-0.004
Virginia	Fauquier	0.058	0.056	-0.002
Virginia	Frederick	0.061	0.060	-0.001
Virginia	Hanover	0.069	0.067	-0.002
Virginia	Henrico	0.067	0.065	-0.002
Virginia	Loudoun	0.066	0.063	-0.003
Virginia	Madison	0.062	0.061	-0.001
Virginia	Page	0.058	0.056	-0.002
Virginia	Prince William	0.063	0.060	-0.003

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Virginia	Roanoke	0.061	0.060	-0.001
Virginia	Rockbridge	0.057	0.055	-0.002
Virginia	Stafford	0.062	0.060	-0.002
Virginia	Wythe	0.060	0.059	-0.001
Virginia	Alexandria City	0.066	0.063	-0.003
Virginia	Hampton City	0.071	0.070	-0.001
Virginia	Suffolk City	0.070	0.069	-0.001
Washington	Clallam	0.041	0.041	0.000
Washington	Clark	0.061	0.061	0.000
Washington	King	0.063	0.063	0.000
Washington	Klickitat	0.061	0.059	-0.002
Washington	Mason	0.049	0.049	0.000
Washington	Pierce	0.065	0.065	0.000
Washington	Skagit	0.044	0.044	0.000
Washington	Spokane	0.060	0.060	0.000
Washington	Thurston	0.059	0.059	0.000
Washington	Whatcom	0.051	0.051	0.000
West Virginia	Berkeley	0.062	0.060	-0.002
West Virginia	Cabell	0.068	0.067	-0.001
West Virginia	Greenbrier	0.060	0.059	-0.001
West Virginia	Hancock	0.064	0.061	-0.003
West Virginia	Kanawha	0.062	0.061	-0.001
West Virginia	Monongalia	0.055	0.054	-0.001
West Virginia	Ohio	0.063	0.061	-0.002
West Virginia	Wood	0.062	0.061	-0.001
Wisconsin	Brown	0.065	0.064	-0.001
Wisconsin	Columbia	0.059	0.058	-0.001
Wisconsin	Dane	0.060	0.059	-0.001
Wisconsin	Dodge	0.063	0.061	-0.002
Wisconsin	Door	0.071	0.070	-0.001
Wisconsin	Florence	0.058	0.057	-0.001
Wisconsin	Fond Du Lac	0.061	0.060	-0.001
Wisconsin	Green	0.059	0.058	-0.001
Wisconsin	Jefferson	0.062	0.061	-0.001
Wisconsin	Kenosha	0.081	0.080	-0.001
Wisconsin	Kewaunee	0.071	0.069	-0.002
Wisconsin	Manitowoc	0.068	0.067	-0.001
Wisconsin	Marathon	0.058	0.057	-0.001
Wisconsin	Milwaukee	0.074	0.072	-0.002
Wisconsin	Oneida	0.056	0.055	-0.001
Wisconsin	Outagamie	0.060	0.059	-0.001
Wisconsin	Ozaukee	0.074	0.073	-0.001
Wisconsin	Racine	0.074	0.073	-0.001
Wisconsin	Rock	0.063	0.062	-0.001
Wisconsin	St Croix	0.059	0.059	0.000
Wisconsin	Sauk	0.057	0.056	-0.001
Wisconsin	Sheboygan	0.077	0.076	-0.001
Wisconsin	Vernon	0.060	0.059	-0.001
Wisconsin	Vilas	0.057	0.055	-0.002
Wisconsin	Walworth	0.063	0.062	-0.001

State	County	Baseline 8-hour Ozone Design Value (ppm)	Control Strategy 8-hour Ozone Design Value (ppm)	Change (ppm)
Wisconsin	Washington	0.064	0.063	-0.001
Wisconsin	Waukesha	0.063	0.062	-0.001
Wisconsin	Winnebago	0.065	0.064	-0.001
Wyoming	Campbell	0.067	0.067	0.000
Wyoming	Teton	0.062	0.062	0.000

Chapter 4: Approach for Estimating Reductions for Full Attainment Scenario

Synopsis

After applying the hypothetical modeled control strategy described in Chapter 3, there were multiple counties that were still not projected to attain potential new ozone standards. Because it was impossible in some areas to meet a tighter ozone standard nationwide using only known controls, EPA conducted a second step in the analysis and estimated the amount of further emission reductions needed to attain an alternate primary ozone standard. The term "extrapolated tons" will be used to refer to these additionally needed emissions reductions. Sections 4.1 and 4.2 of this chapter present the methodology EPA developed to determine the emissions reductions needed for full attainment of the four alternate standards analyzed in the RIA (i.e., 0.065, 0.070, 0.075, and 0.079 ppm) and the results of that analysis. Additionally, in other areas, the known controls in the hypothetical strategy resulted in ozone levels lower than one or more of the four alternate standards. Sections 4.3 and 4.4 of this chapter discuss the methodology and present the results of the "overcontrolled" analyses.

4.1 Development of Full Attainment Targets for Estimate of Extrapolated Costs

As previewed in the draft RIA, we conducted additional supplemental air quality modeling analyses for the final RIA. This was intended to improve the estimates of extrapolated tons needed to meet various potential standards. These additional modeling scenarios were designed to provide more information about the response of ozone to emissions changes in terms of non-linearities, geographic variations, the impacts of local versus upwind emissions reductions, and the relationship between NOx and VOC emissions changes. As a result of this additional information, the methodology to estimate the emissions reduction targets in the "extrapolated cost areas" has been improved.

4.1.1 Design of Supplemental Modeling Scenarios

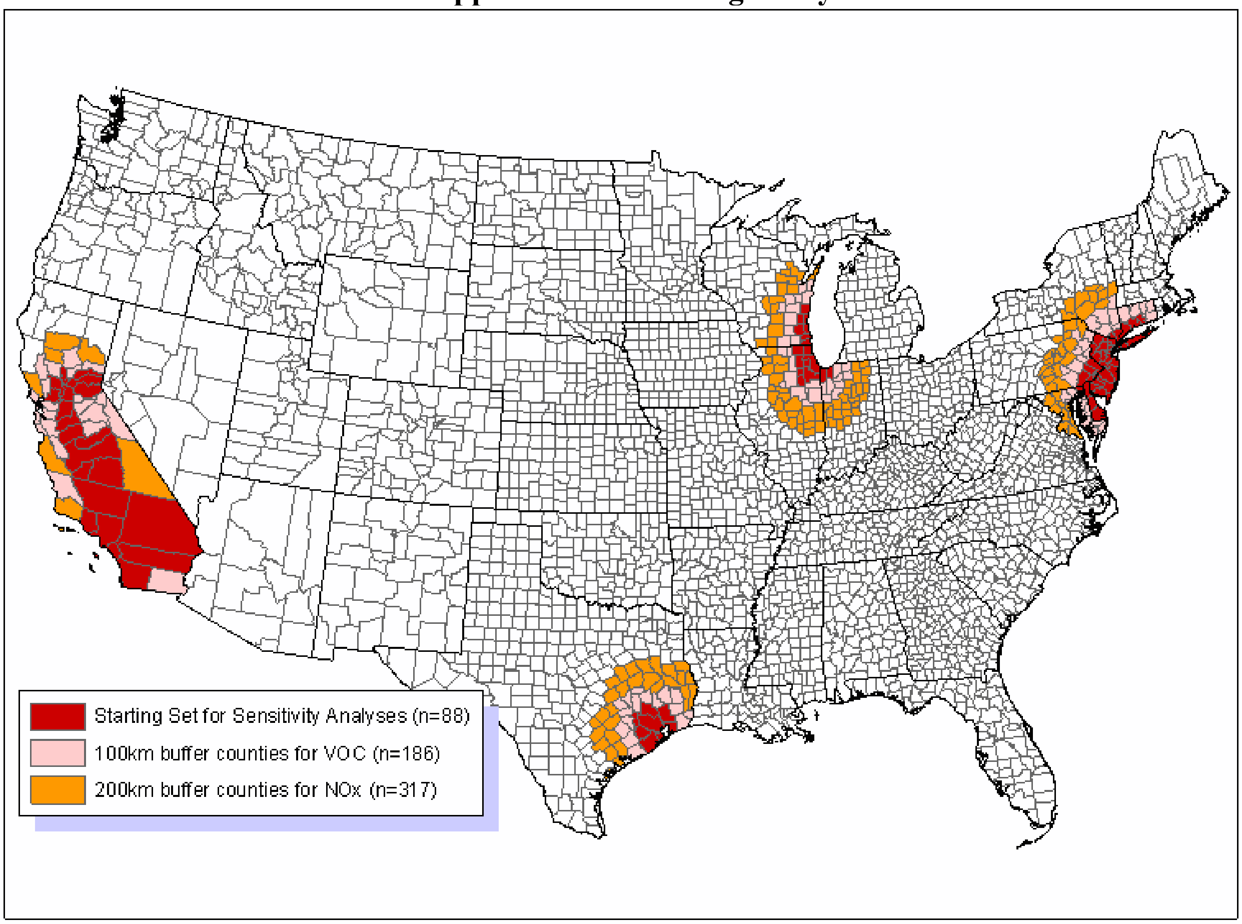
There were 61 counties that did not meet the 0.070 ppm standard even after application of the controls in the hypothetical RIA modeled control scenario. There were 21 counties that did not meet the 0.075 ppm standard.[1] All 21 of these counties are in four broad geographic regions: Houston, eastern Lake Michigan,[2] the Northeast Corridor,[3] and a large part of California. Because these four areas will require the largest emissions reductions beyond the RIA control

[1] 10 counties did not meet the 0.079 ppm standard. 166 counties did not meet the 0.065 ppm standard.
[2] This geographic area is an aggregate of five existing nonattainment or maintenance areas: a) Chicago-Gary-Lake County, IL-IN; b) Milwaukee-Racine, WI; c) Sheboygan WI; d) La Porte IN; and e) South Bend-Elkhart IN.
[3] This geographic area is an aggregate of six existing nonattainment or maintenance areas: a) Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE; b) New York-Northern New Jersey-Long Island, NY-NJ-CT; c) Greater Connecticut, CT; d) Baltimore MD; e) Kent and Queen Anne counties MD; and f) Poughkeepsie NY.

scenario, and therefore likely the largest extrapolated costs, we focused on these areas within the supplemental modeling analyses. We will refer to these four areas as "Phase 1" areas. Later, we will define a second and third set of areas that also require extrapolated emissions reductions which we will refer to as "Phase 2" and "Phase 3"areas. The primary distinction between these three sets of areas is that the supplemental modeling was done only for the Phase 1 areas.

A map of the four Phase 1 areas is shown in Figure 4.1. An approach similar to that used to define the geographic control areas for non-EGU point controls in the RIA control scenario (discussed in Chapter 3) was also used to define the supplemental modeling control zones for each of the four areas.

Figure 4.1: Counties within which Across-the-Board Emissions Reductions were Applied in the Supplemental Modeling Analyses



Six supplemental modeling runs were performed as part of this analysis. In the first three runs anthropogenic NOx emissions within the appropriate Phase 1 areas (i.e., the red, pink, and orange counties in Figure 4.1) were reduced across-the-board by 30, 60, and 90 percent. The second set of runs included 30, 60, and 90 percent across-the-board reductions to anthropogenic NOx and VOC emissions within the appropriate Phase 1 areas (i.e., the red, pink, and orange counties for NOx; only the red and pink counties for VOC). An estimate of the effects of VOC controls can be determined by comparing results from the NOx and VOC control run to the NOx only control run. In the two sets of across-the-board supplemental modeling runs the emissions reductions were applied on top of the controls in the hypothetical RIA control case. As in the modeled control strategy, NOx controls were applied to counties within a 200 km buffer and VOC controls were applied to counties within a 100 km buffer of the starting set of counties.

In the draft RIA, we used the concept of "impact ratios"[4] to calculate the additional tons needed to meet the air quality standard. The updated approach uses the supplemental modeling to determine what levels of ozone precursor reductions (NOx only or NOx plus VOC) are expected to be sufficient to bring an area into attainment of one of the various alternate ozone standards that were analyzed. After the development of emission targets for the 0.070 ppm alternative standard, we conducted a "verification" model run to assess whether our estimated emissions reductions actually resulted in attainment of 0.070 ppm in each area. The new estimates of extrapolated tons represent a considerable improvement from what was done for the draft RIA.

For purposes of this analysis, we assume attainment by 2020 for all areas except San Joaquin Valley and South Coast air basins in California. The state has submitted plans to EPA for implementing the current ozone standard which propose that these two areas of California meet that standard by 2024. We have assumed for analytical purposes that the San Joaquin Valley and South Coast air basin would attain a new standard in 2030. There are many uncertainties associated with the year 2030 analysis. Between 2020 and 2030 several federal air quality rules are likely to further reduce emissions of NOx and VOC, such as, but not limited to National rules for Diesel Locomotives, Diesel Marine Vessels, and Small Nonroad Gasoline Engines. These emission reductions should lower ambient levels of ozone in California between 2020 and 2030. Complete emissions inventories as well as air quality modeling were not available for this year 2030 analysis. Due to these limitations, it is not possible to adequately model 2030 air quality changes that are required to develop robust controls strategies with associated costs and benefits. In order to provide a rough approximation of the costs and benefits of attaining 0.075 ppm and the alternate standards in San Joaquin and South Coast air basins, we've relied on the available data. Available data includes emission inventories, which do not include any changes in stationary source emissions beyond 2020, and 2020 supplemental air quality modeling. This data was used to develop extrapolated costs and benefits of 2030 attainment. To view the complete analysis for the San Joaquin Valley and South Coast air basins see Appendix 7b.

4.1.2 Results of Supplemental Modeling for Phase 1 Areas

Figures 4.2a through 4.2d show the projected design values for individual counties within each of the Phase 1 areas for seven modeling cases (i.e., the RIA control scenario and each of the six supplemental modeling runs). These figures are instructive in describing how the extrapolated control targets were determined for these areas. For each area, the three counties that need the most extrapolated controls were chosen for the graphs.

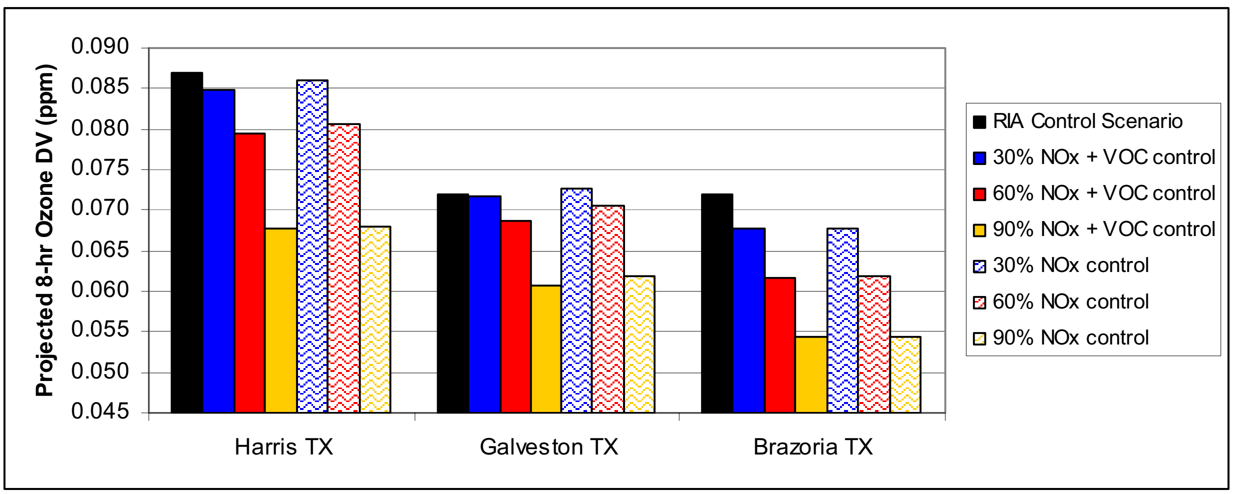
Figure 4.2a indicates that the highest ozone levels in the Houston area are projected to occur in Harris, Galveston, and Brazoria counties with Harris being the controlling county. After application of the RIA scenario controls, our modeling projects that the highest 2020 8-hour

[4] The units for impact ratios are ppb/kton. In the draft RIA we used a single, national impact ratio that assumed that 10,000 tons of NOx control would yield 0.001 ppm of ozone improvement.

ozone design value in this area will be 0.087 ppm. Thus, additional precursor reductions are needed to reach the current standard as well as all four of the alternate standards we are considering. Based on the NOx plus VOC control modeling scenarios, we can see that increasing the level of emissions reductions beyond the RIA case yields decreasing design values. At a 30% NOx + VOC reduction, the projected design value is 0.084 ppm. At a 60% NOx + VOC reduction, the projected design value is 0.079 ppm. Finally at a 90% NOx + VOC reduction, the projected design value is 0.067 ppm.

Based on these results, it is concluded that it is possible to meet the current ozone standard with additional NOx plus VOC emissions reductions between 0 and 30 percent. To meet an alternate NAAQS of 0.079 ppm, the Houston area will require additional NOx plus VOC emissions of approximately 60 percent. The 0.075 and 0.070 ppm standards will require between an additional 60-90% NOx plus VOC reduction beyond the RIA control case. The supplemental modeling indicates that it will take more than 90% NOx plus VOC control (above and beyond the RIA control case) to meet a 0.065 ppm standard. Based on these figures, one can also estimate the levels of NOx-only controls needed to meet a particular standard. We used linear interpolation to determine the specific percentage reduction in cases where attainment is expected to be achieved

Figure 4.2a: Projected 2020 8-hour Ozone Design Values in the RIA Control Scenario and Each of the Six Supplemental Modeling Scenarios for the Highest Three Counties within the Houston Area



between the supplemental scenarios of 0, 30, 60, and 90 percent.[5] The specific percentage reductions for Phase 1 areas are shown in Table 4.1.

Figure 4.2b shows two other aspects of the analysis. First, in some cases, the controlling county within an area can vary as the precursor emissions are reduced. In the eastern Lake Michigan area, the modeling indicates that an additional 60% NOx reduction will be sufficient to bring two

[5] To add precision to this process, we based these calculations on projected design values that contained data four places to the right of the decimal (e.g., 0.0755 ppm). In the last step of the process however, EPA truncates all decimal places beyond the third decimal. This is consistent with past policy on ozone design values.

counties with high design values (Kenosha and Sheboygan WI) into attainment of an 0.070 ppm standard. However, another county in that area does not reach 0.070 ppm with the 60% NOx reduction. Lake IN is still 0.077 ppm. The full attainment, extrapolated target analysis is done on a county by county basis, and the final area target is based on the county that requires the most additional reductions. Second, it should be noted that in this area the addition of VOC controls can have a significant impact on the projected design value. The 0.077 ppm value in Lake IN is reduced to 0.073 ppm when 60% VOC controls are added to the 60% NOx controls. Figure 4.2c is included for completeness sake and to show the supplemental modeling results in the Northeast Corridor.

Figure 4.2b: Projected 2020 8-hour Ozone Design Values in the RIA Control Scenario and Each of the Six Supplemental Modeling Scenarios for the Highest Counties within the Eastern Lake Michigan Area

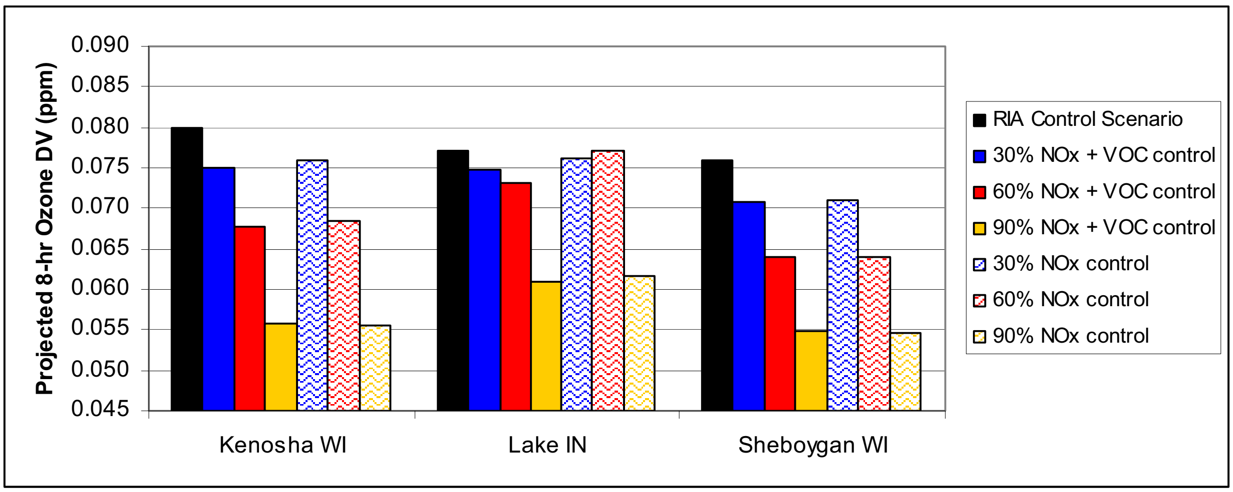
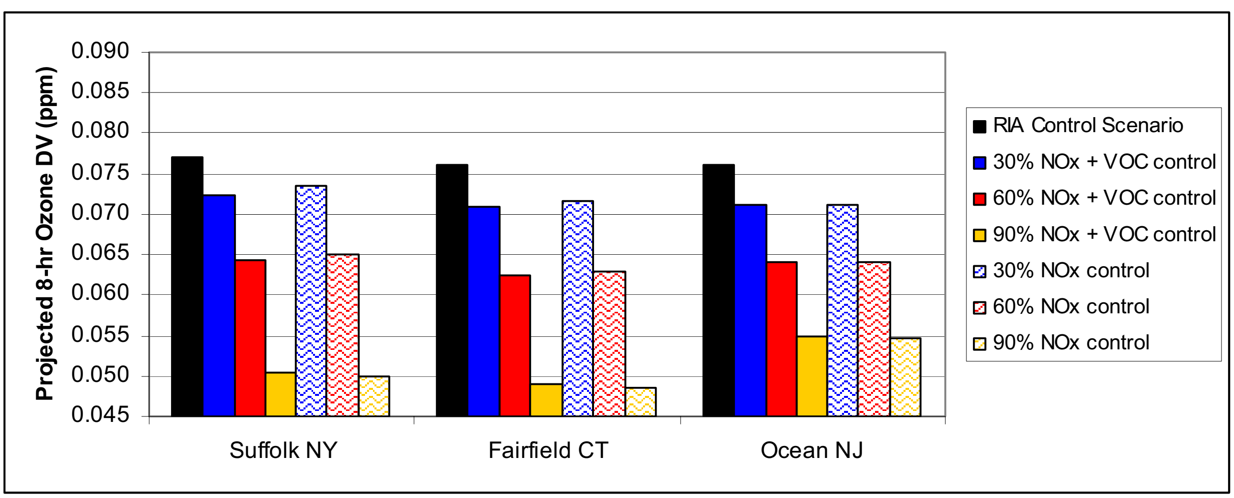
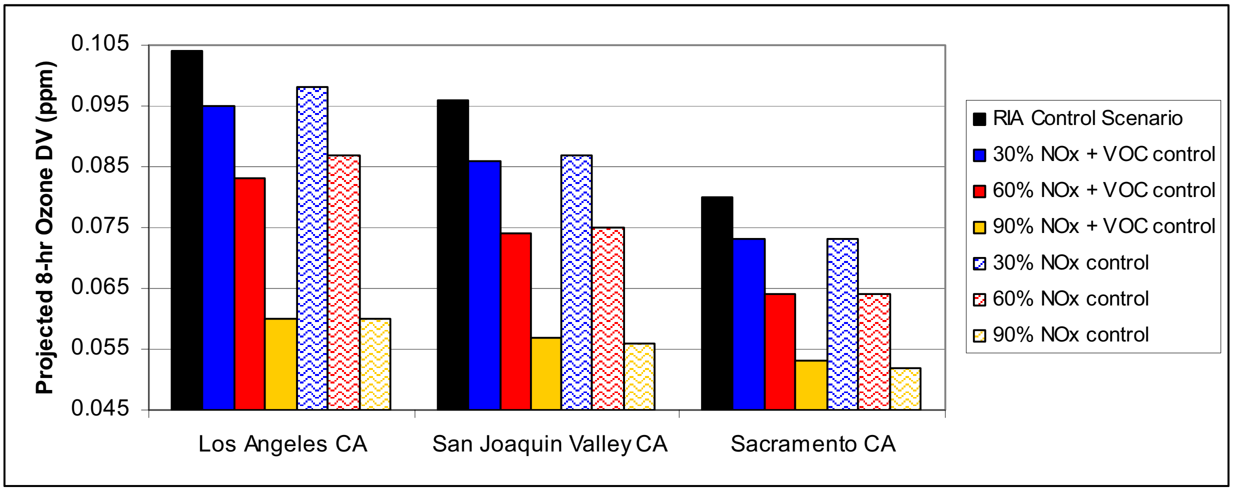


Figure 4.2c: Projected 2020 8-hour Ozone Design Values in the RIA Control Scenario and Each of the Six Supplemental Modeling Scenarios for the Highest Counties within the Northeast Corridor



As discussed in Chapter 3 and Chapter 5, there are two areas in Southern California that are not planning to meet the current standard by 2020 (i.e., the Los Angeles South Coast Air Basin and the San Joaquin Valley nonattainment areas). As a result, we have not estimated extrapolated targets that will be necessary to bring these two nonattainment areas into attainment of the alternate standards by 2020. However, due to the effects of ozone transport within California, we are assuming that some extrapolated controls (beyond the RIA control case) will be needed in these two areas to help other California nonattainment areas with earlier attainment dates meet the standards by 2020. These additional reductions in Los Angeles and San Joaquin Valley are considered to be part of the controls needed to meet the current NAAQS and are therefore not considered as part of the cost of any new alternate standard. Figure 4-2d shows the results of the supplemental modeling runs for three areas in California.

Figure 4.2d: Projected 2020 8-hour Ozone Design Values in the RIA Control Scenario and Each of the Six Supplemental Modeling Scenarios for Three Specific Areas in California



Extrapolated control targets were estimated for each Phase 1 area for: a) NOx only emissions reductions and b) NOx plus VOC emissions reductions. The results of the analysis to estimate emissions reductions for attainment in the Phase 1 areas are shown in Table 4.1 and Table 4.2. The amount of additional emissions reductions necessary for full attainment ranges from zero to over 90 percent depending upon the area and the standard.

Table 4.1: Estimated Percentage Reductions of NOx and VOC beyond the RIA Control Scenario Necessary to Meet Various Alternate Ozone Standards in the Phase I Areas

Phase 1 Area (NOx only)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet various standards				
		0.065	0.070	0.075	0.079	0.084
Amador and Calaveras Cos., CA	0.071	28%	4%			
Chico, CA	0.068	13%				
Imperial Co., CA	0.071	29%	1%			
Inyo Co., CA	0.068	18%				
Los Angeles South Coast Air Basin, CA	0.122	> 90%	88%	83%	79%	75%
Mariposa and Tuolumne Cos., CA	0.072	32%	8%			
Nevada Co., CA	0.075	39%	19%			
Sacramento Metro, CA	0.080	55%	38%	20%	3%	
San Benito Co., CA	0.066	1%				
San Diego, CA	0.076	52%	33%	6%		
San Francisco Bay Area, CA	0.069	21%				
San Joaquin Valley, CA	0.096	76%	67%	59%	49%	37%
Santa Barbara Co., CA	0.068	12%				
Sutter Co., CA	0.067	9%				
Ventura Co, CA	0.077	44%	28%	5%		
Northeast Corridor, CT-DE-MD-NJ-NY-PA	0.077	57%	39%	13%		
Eastern Lake Michigan, IL-IN-WI	0.080	82%	72%	62%	3%	
Houston, TX	0.087	> 90%	83%	71%	62%	36%

Table 4.2: Estimated Percentage Reductions of NOx beyond the RIA Control Scenario Necessary to Meet Various Alternate Ozone Standards in the Phase I Areas

Phase 1 Area (NOx + VOC)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet				
		0.065	0.070	0.075	0.079	0.084
Amador and Calaveras Cos., CA	0.071	28%	4%			
Chico, CA	0.068	13%				
Imperial Co., CA	0.071	28%	1%			
Inyo Co., CA	0.068	18%				
Los Angeles / South Coast Air Basin, CA	0.122	> 90%	89%	83%	79%	74%
Mariposa and Tuolumne Cos., CA	0.072	32%	8%			
Nevada Co., CA	0.075	40%	19%			
Sacramento Metro, CA	0.080	55%	38%	20%	3%	
San Benito Co., CA	0.066	1%				
San Diego, CA	0.076	49%	30%	5%		
San Francisco Bay Area, CA	0.069	20%				
San Joaquin Valley, CA	0.096	76%	67%	58%	48%	36%
Santa Barbara Co., CA	0.068	12%				
Sutter Co., CA	0.067	9%				
Ventura Co, CA	0.077	42%	26%	5%		
Northeast Corridor, CT-DE-MD-NJ-NY-PA	0.077	54%	35%	10%		
Eastern Lake Michigan, IL-IN-WI	0.080	78%	66%	25%	2%	
Houston, TX	0.087	> 90%	82%	69%	57%	29%

4.1.3 Estimating Attainment of the 0.070 and 0.065 ppm Standards in Phase 2 Areas

As discussed above, there were 61 counties that did not reach attainment of the 0.070 ppm standard with the controls in the hypothetical RIA scenario. The majority of these counties are in one of the Phase 1 areas. However, there were 12 counties (9 areas) outside of the Phase 1 areas that were also not projected to meet the 0.070 NAAQS. (All counties outside the Phase 1 areas met the 0.075 and 0.079 ppm air quality standards.) For convenience, these nine areas will be referred to Phase 2 areas. A two-step process was used to estimate the additional emissions reductions necessary for full attainment in the Phase 2 areas. Based on the Phase 1 modeling results, targets for these areas were only generated for NOx-only control given the preponderance of cases where the additional VOC emissions reductions did not reduce ozone enough to consider from a cost perspective.

For the Phase 2 areas, the first step in estimating attainment was to consider whether the emissions reductions needed to bring the Phase 1 areas into attainment of 0.070 ppm would also reduce ozone transport enough to bring these additional areas into attainment as well. For an example of how this determination was made consider two counties: Norfolk County, MA (Boston area) and Geauga County, OH (Cleveland area).

In Norfolk MA, the projected design value after the RIA control scenario is 0.071 ppm. This county is downwind of the Northeast Corridor. The supplemental modeling showed that if the Phase 1 areas reduced NOx emissions by at least 30% the 2020 design value in Norfolk MA would be reduced to 0.069 ppm (i.e., does not exceed the 0.070 standard). As part of the Phase I analysis, we estimated that the Northeast Corridor region would need an additional 39% NOx reduction to meet the 0.070 ppm standard within this area. The supplemental modeling shows that the same 39% NOx reduction would enable this standard to be met in Norfolk County as well, without any additional local controls in the Boston area.

In Geauga OH, the projected design value after the RIA control scenario is 0.074 ppm. Thus, Cleveland will need additional local emissions reductions to meet a revised ozone standard of 0.070 ppm. However, in the supplemental modeling, which did not include emissions reductions in Cleveland, the Geauga design value declined by 0.001, 0.002, and 0.003 ppm, in the 30, 60, and 90% NOx reduction runs, respectively. Given that the Lake Michigan region is the nearest upwind Phase 1 area to Geauga County, we believe these ozone reductions in Geauga County are associated with the emissions reductions modeled in the Lake Michigan region. The Lake Michigan region is estimated to need 72% additional NOx control. Considering the projected design values with an additional digit of precision, it is estimated that a 72% reduction in the eastern Lake Michigan area will yield a Geauga OH design value of 0.0718 ppm.[6]

In the second step of the process, we estimate what level of local control is required to reach 0.070 ppm after consideration of the impact of Phase 1 emissions reductions. For each of the Phase 2 areas that is still nonattainment after step 1 above, we developed a site-specific relationship between the ozone improvement in the RIA control case and the percent reduction in local NOx emissions in the RIA control case as compared to the baseline. This site-specific relationship was then used to determine how much additional NOx reduction was needed to meet the 0.070 ppm goal. Continuing with the Geauga County example helps illustrate this calculation. In this county there was a 0.0023 ppm reduction due to the hypothetical RIA controls. The RIA scenario represented a 17% reduction in NOx emissions within the 200 km buffer around the Cleveland area. With the existing information it is not possible to distinguish

[6] The full step 1 calculation for the Geauga OH example is as follows. A 60 percent reduction yields a design value of 0.0722 ppm. A 90 percent reduction yields a design value of 0.0710 ppm. The estimated Phase 1 target for eastern Lake Michigan is 72%, or four-tenths of the "distance" between 60 and 90% control. Forty percent of the 0.0012 ppm difference between the two runs is 0.00048 ppm. Subtracting that from 0.0722 ppm, yields the transport-considered design value of 0.0717 ppm which would be truncated to 0.071 ppm.

how much of the ozone improvement is due to local controls (i.e., within 200 km) versus upwind controls, so we made a simplifying assumption that all local air quality improvement for such areas can be attributed to the controls within 200 km. Converting to units of ppb for simplicity, dividing 2.3 ppb improvement by a 17% NOx emissions reduction yields a Geauga-specific relationship of 0.135 ppb / percent NOx controlled. This ratio is applied to the 71.8 ppb value from step 1 and it is determined that an additional 7 % reduction (0.9 ppb) would be sufficient to lower the 2020 design value in Geauga County to 70.9 ppb or 0.070 ppm, thereby attaining the standard.

The same two step methodology described above was used to estimate the extrapolated targets for the 0.065 ppm standard in the Phase 2 areas. Table 4.3 shows the full set of results for each of the nine Phase 2 areas. The amount of additional NOx control needed to meet the 0.070 ppm standard in Phase 2 areas ranges from zero to 25 percent. The amount of additional NOx control needed to meet the 0.065 ppm standard in Phase 2 areas ranges from zero to 74 percent.

Table 4.3: Estimated Percentage Reductions of NOx beyond the RIA Control Scenario Necessary to Meet the 0.070 ppm Ozone Standard in Phase 2 Areas[7]

Phase 2 Area (NOx only)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet various standards	
		0.065	0.070
Allegan Co, MI	0.072	will attain	will attain
Baton Rouge, LA	0.073	74%	25%
Boston-Lawrence-Worcester, MA	0.071	14%	will attain
Buffalo-Niagara Falls, NY	0.073	34%	8%
Cleveland-Akron-Lorain, OH	0.074	40%	7%
Dallas-Fort Worth, TX	0.073	34%	2%
Detroit-Ann Arbor, MI	0.073	57%	6%
Jefferson Co, NY	0.071	23%	will attain
Las Vegas, NV	0.071	14%	will attain

4.1.4 Estimating Attainment of the 0.065 ppm Standard outside of Phase 1 and 2 Areas

The last set of reduction targets generated are for those areas that require additional ozone precursor controls to meet the 0.065 ppm standard but are outside Phase 1 and 2 areas. There were 166 counties that did not reach attainment of the 0.065 ppm standard with the emissions reductions in the hypothetical RIA scenario. The majority of these counties are in one of the Phase 1 or Phase 2 areas. However, there were 46 counties (36 areas) outside of the Phase 1 and Phase 2 areas that were not projected to meet the 0.065 NAAQS. For convenience, these areas will be referred to Phase 3 areas.

A similar methodology as described in Section 4.1.3 was used to estimate the additional emissions reductions needed for the 0.065 ppm standard for the Phase 3 areas, but two simplifying assumptions were made to expedite the analysis. First, instead of explicitly accounting for the impacts of the Phase 1 and Phase 2 upwind emissions reductions on Phase 3 areas, we assumed that the design values from the 60% NOx reduction run were the appropriate starting point for estimating the additional emissions reductions in the Phase 3 areas. Since the

[7] The entry "will attain" in Tables 4.3 and 4.4 signifies that this area will come into attainment of the standard due to reduced ozone transport resulting from upwind controls.

targets for the Phase 1 areas are generally greater than 60% and since we have not accounted for the Phase 2 reductions, these estimates should provide a conservative estimate of the percentage emissions reductions needed for full attainment. Secondly, we did not develop site-specific impact ratios for the 36 Phase 3 areas. Instead, we used a standard relationship of 0.150 ppb / 1% NOx reduction for calculating the emissions reductions needed to attain 0.065 ppm in these areas. This value was the average site-specific relationship calculated for the Phase 2 areas, as described above. These assumptions are reasonable given the available data and the relatively small role that Phase 3 areas will play in determining the full costs of meeting a 0.065 ozone standard. However, the estimated emissions reductions needed to attain 0.065 in the Phase 3 areas are considered to be more uncertain than the emissions reductions calculated for attaining 0.070, 0.075, and/or 0.079. The results of the Phase 3 analysis are shown in Table 4.4. The amount of additional NOx control needed to meet the 0.065 ppm standard in Phase 3 areas ranges from zero to 29 percent.

Table 4.4: Estimated Percentage Reductions of NOx beyond the RIA Control Case Necessary to Meet the 0.065 ppm Ozone Standard in Phase 3 Areas

Phase 3 Area (NOx only)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet various standards
		0.065
Ada Co., ID	0.069	21%
Atlanta, GA	0.068	12%
Benton Harbor, MI	0.069	will attain
Campbell Co., WY	0.067	9%
Cass Co, MI	0.066	will attain
Charlotte-Gastonia-Rock Hill, NC-SC	0.070	29%
Cincinnati-Hamilton, OH-KY-IN	0.067	5%
Coconino Co., AZ	0.067	will attain
Columbus, OH	0.066	will attain
Denver-Boulder-Greeley-Ft Collins-Love.,	0.067	11%
Dona Ana Co., NM	0.068	13%
El Paso Co., TX	0.068	14%
Erie, PA	0.067	3%
Essex Co (Whiteface Mtn), NY	0.067	will attain
Hancock, Knox, Lincoln & Waldo Cos, ME	0.068	will attain
Huntington-Ashland, WV-KY	0.069	15%
Huron Co, MI	0.067	will attain
Indianapolis, IN	0.068	will attain
Jackson Co., MS	0.067	10%
Jamestown, NY	0.069	16%
Johnson City-Kingsport-Bristol, TN	0.066	will attain
Louisville, KY-IN	0.066	will attain
Memphis, TN-AR	0.068	15%
Muskegon, MI	0.068	will attain
Norfolk-Virginia Beach-Newport News, VA	0.070	20%
Phoenix-Mesa, AZ	0.068	7%
Pittsburgh-Beaver Valley, PA	0.069	18%
Providence (All RI), RI	0.068	will attain
Richmond-Petersburg, VA	0.067	1%
Salt Lake City, UT	0.067	10%
San Antonio, TX	0.067	will attain
San Juan Co., NM	0.069	20%
Springfield (Western MA), MA	0.066	will attain
St Louis, MO-IL	0.068	16%
Toledo, OH	0.067	3%
Washington, DC-MD-VA	0.068	will attain

4.1.5 Aggregate Results / Verification Modeling of Extrapolated Targets

The complete set of NOx targets are provided in Table 4.5a. As noted earlier, a single 2020 target was determined for all of California. This target was based on the Sacramento area which had the highest 2020 design values outside the Los Angeles and San Joaquin Valley areas. The assumption is that if all of California reduces at that level then all areas aside from Los Angeles and the San Joaquin Valley air basins will attain by 2020. Areas from which reductions would be required include the Los Angeles and San Joaquin Valley air basins, but would not necessarily bring them into attainment. Additional reductions may be required. Because of their later attainment date, the costs and benefits of additional reductions for Los Angeles and San Joaquin air basins are shown in Appendix 7b.

Table 4.5a: Complete Set of Estimated Percentage Reductions of NOx beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in 2020

All 2020 Extrapolated Cost Areas (NOx only)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet				
		0.065	0.070	0.075	0.079	0.084
Ada Co., ID	0.069	21%				
Atlanta, GA	0.068	12%				
Baton Rouge, LA	0.073	74%	25%			
Boston-Lawrence-Worcester, MA	0.071	14%				
Buffalo-Niagara Falls, NY	0.073	34%	8%			
Campbell Co., WY	0.067	9%				
Charlotte-Gastonia-Rock Hill, NC-SC	0.070	29%				
Cincinnati-Hamilton, OH-KY-IN	0.067	5%				
Cleveland-Akron-Lorain, OH	0.074	40%	7%			
Dallas-Fort Worth, TX	0.073	34%	2%			
Denver-Boulder-Greeley-Ft Collins, CO	0.067	11%				
Detroit-Ann Arbor, MI	0.073	57%	6%			
Dona Ana Co., NM	0.068	13%				
Eastern Lake Michigan, IL-IN-WI	0.080	82%	72%	62%	3%	
El Paso Co., TX	0.068	14%				
Erie, PA	0.067	3%				
Houston, TX	0.087	> 90%	83%	71%	62%	36%
Huntington-Ashland, WV-KY	0.069	15%				
Jackson Co., MS	0.067	10%				
Jamestown, NY	0.069	16%				
Jefferson Co, NY	0.071	23%				
Las Vegas, NV	0.071	14%				
Memphis, TN-AR	0.068	15%				
Norfolk-Virginia Beach-Newport News, VA	0.070	20%				
Northeast Corridor, CT-DE-MD-NJ-NY-PA	0.077	57%	39%	13%		
Phoenix-Mesa, AZ	0.068	7%				
Pittsburgh-Beaver Valley, PA	0.069	18%				
Richmond-Petersburg, VA	0.067	1%				
Sacramento / CA	0.080	55%	38%	20%	3%	
Salt Lake City, UT	0.067	10%				
San Juan Co., NM	0.069	20%				
St Louis, MO-IL	0.068	16%				
Toledo, OH	0.067	3%				

In total, 33 areas were determined to need additional emissions reductions for one or more of the alternate standards. The eastern Lake Michigan region was the only one in which NOx plus VOC control targets could be substantially lower than NOx only control targets. Table 4.5b shows the NOx + VOC targets for that area.

Table 4.5b: Estimated Percentage Reductions of NOx + VOC beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in 2020

All 2020 Extrapolated Cost Areas (NOx + VOC)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet various standards				
		0.065	0.070	0.075	0.079	0.084
Eastern Lake Michigan, IL-IN-WI	0.080	78%	66%	25%	2%	

Figures 4.3a through 4.3d show: 1) which counties are part of the 33 extrapolated cost areas and 2) the estimated percent reduction needed beyond the RIA control case to meet each of the four alternate standards within each of those areas. The conversion of these additional percentage reductions to actual extrapolated tons is described in Chapter 4.2. The calculation of the costs of these extrapolated tons is described in Chapter 5.

Figure 4.3a: Map of Extrapolated Cost Counties for the 0.065 ppm Alternate Standard and the Estimated Percent NOx Controls Needed to Meet that Standard

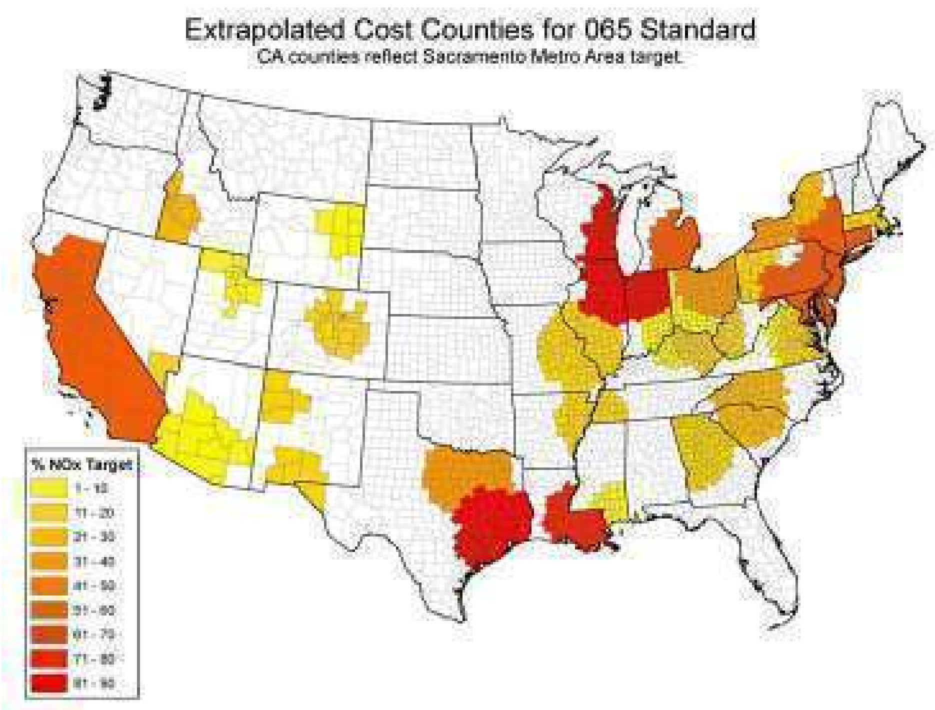


Figure 4.3b: Map of Extrapolated Cost Counties for the 0.070 ppm Alternate Standard and the Estimated Percent NOx Controls Needed to Meet that Standard

Figure 4.3c: Map of Extrapolated Cost Counties for the 0.075 ppm Alternate Standard and the Estimated Percent NOx Controls Needed to Meet that Standard

Figure 4.3d: Map of Extrapolated Cost Counties for the 0.079 ppm Alternate Standard and the Estimated Percent NOx Controls Needed to Meet that Standard

As noted earlier in this section, an additional CMAQ air quality simulation, called a “verification run,” was completed after the extrapolated percent emissions reductions were estimated. The purpose of this run was to determine the ozone design values that would be expected from the additional extrapolated reductions shown in Table 4.5a and Table 4.5b. These are the reductions that were estimated to be needed for full attainment of the 0.070 ppm standard for areas outside of Los Angeles and San Joaquin Valley. The results of the verification modeling were encouraging and confirmed our approach for estimating the extrapolated reductions. For the four areas where we projected that no additional local controls were needed and that the additional upwind reductions would be sufficient for attainment of 0.070 (see Table 4.3), the verification modeling indicated that all four areas had ozone design values less than 0.070 ppm after the extrapolated reductions were applied. Of the remaining nine areas that did not reach the 0.070 ppm standard in the RIA control case, eight of the nine were within plus or minus 0.002 ppm after application of the extrapolated emissions reductions. The proximity of the verification design values to the 0.070 ppm target provides confidence that the estimates of extrapolated tons are reasonable. Table 4.6 shows the results of the verification modeling for the 13 areas that were included in the (0.070 ppm) extrapolated cost analysis.

Table 4.6: Summary of the Verification Modeling Results

Extrapolated Control Area	2020 Design Value after RIA Control Scenario (ppm)	% reduction estimated for full attainment	2020 Design Value after Verification Scenario (ppm)
Boston, MA	0.071	attain due to upwind controls	0.069
Holland, MI	0.072	attain due to upwind controls	0.060
Las Vegas, NV	0.071	attain due to upwind controls	0.069
Watertown, NY	0.071	attain due to upwind controls	0.070
Dallas-Fort Worth, TX	0.073	2% NOx	0.071
Detroit, MI	0.073	6% NOx	0.071
Cleveland, OH	0.074	7% NOx	0.071
Buffalo, NY	0.073	8% NOx	0.072
Baton Rouge, LA	0.073	25% NOx	0.069
Northeast Corridor, CT-DE-MD-NJ-NY-PA	0.077	37% NOx	0.071
Sacramento, CA	0.071	38% NOx	0.070
Eastern Lake Michigan, IL-IN-WI	0.080	66% NOX + VOC	0.073
Houston, TX	0.087	83% NOx	0.069

4.2 Conversion of Full Attainment Percentage Targets into Extrapolated Tons

Table 4.7a provides the complete set of extrapolated tons of NOx emissions reduction needed to satisfy the various ozone standards. These extrapolated tons are obtained by multiplying the NOx targets in Table 4.5a by the remaining emissions for each area after the RIA control scenario. It is important to note that the extrapolated cost areas are potentially standard-specific because the location of counties in an extrapolated area depends on whether the particular standard is being violated. For example, as seen in Figures 4.3a and 4.3b, the Eastern Lake Michigan area extends further north into Wisconsin for the 0.065 ppm standard where areas like Green Bay attained the 0.070 standard but not 0.065 ppm standard.

Table 4.7a: Complete Set of Estimated Extrapolated Emissions Reductions of NOx Beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in 2020

All 2020 Extrapolated Cost Areas (NOx only)	Additional local emissions reductions [annual tons/year] needed to meet various standards (ppm)				
	0.065	0.070	0.075	0.079	0.084
Ada Co., ID	5,300				
Atlanta, GA	21,000				
Baton Rouge, LA	170,000	57,000			
Boston-Lawrence-Worcester, MA	14,000				
Buffalo-Niagara Falls-Jamestown, NY[A]	19,000	3,900			
Campbell Co., WY	2,600				
Charlotte-Gastonia-Rock Hill, NC-SC	62,000				
Cincinnati-Hamilton, OH-KY-IN	9,400				
Cleveland-Akron-Lorain, OH	83,000	13,000			
Dallas-Fort Worth, TX	53,000	3,100			
Denver-Boulder-Greeley-Ft Collins-Love, CO	8,600				
Detroit-Ann Arbor, MI	100,000	11,000			
Dona Ana CO., NM	980				
El Paso Co., TX	1,700				
Houston, TX	290,000	270,000	220,000	190,000	110,000
Huntington-Ashland, WV-KY	22,000				
Jackson Co., MS	7,600				
Jefferson Co, NY	7,300				
Las Vegas, NV	5,000				
Memphis, TN-AR	15,000				
Norfolk-Virginia Beach-Newport News, VA	30,000				
Northeast Corridor, CT-DE-MD-NJ-NY-PA	350,000	230,000	73,000		
Phoenix-Mesa, AZ	4,900				
Pittsburgh-Beaver Valley-Erie, PA[B]	17,000				
Richmond-Petersburg, VA	270				
Sacramento Metro, CA	310,000	210,000	110,000	17,000	
Salt Lake City, UT	4,000				
San Juan Co., NM	17,000				
St Louis, MO-IL	35,000				
Toledo, OH	85				

[a] Jamestown is included in the Buffalo-Niagara Falls, NY cost area because it falls within the 200km Buffalo-Niagara Falls buffer and has a lower design value.

[b] Erie is included in the Pittsburgh-Beaver Valley, PA cost area because it falls within the 200km Pittsburgh-Beaver Valley buffer and has a lower design value.

In total, additional emissions reductions are provided for 31 areas. As footnoted, Jamestown NY is included in the Buffalo-Niagara Falls NY area. There are three reasons for this: 1) Jamestown is within the 200km buffer for Buffalo-Niagara Falls, 2) as seen in Table 4-5a, the NOx target is greater in Buffalo-Niagara than Jamestown for each standard, and 3) Jamestown is in the same state. Erie is included in the Pittsburgh-Beaver Valley PA area for the same three reasons.

As noted in Table 4.5b in Section 4.1.5, the eastern Lake Michigan area was the only one in which NOx plus VOC additional emission reductions could be substantially lower than NOx-only emissions reductions. Table 4.7b shows the additional NOx + VOC emission reductions for this area.

Table 4.7b: Estimated Extrapolated Emissions Reductions of NOx + VOC Beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in 2020

All 2020 Extrapolated Cost Areas (NOx + VOC)	Additional local emissions reductions [annual tons/year] needed to meet various standards (ppm)							
	0.065		0.070		0.075		0.079	
	NOx	VOC	NOx	VOC	NOx	VOC	NOx	VOC
Eastern Lake Michigan, IL-IN-WI	350,000	400,000	280,000	330,000	100,000	120,000	8,100	9,800

4.3 Methodology Used to Estimate the Amount of "Overcontrolled" Emissions in the Modeled Control Strategy

The corollary to extrapolated tons (needed tons above and beyond the modeled control strategy) is "overcontrolled" tons. These are emissions reductions within the hypothetical control case that were subsequently determined not to be needed to meet particular alternate standards. That is, once we modeled the baseline and control strategy scenarios we found that we had reduced ozone beyond the particular alternate standard. In order to better estimate the costs and benefits of full attainment of the standards, EPA has estimated the "overcontrolled" emissions percentages within the modeled control strategy for the four alternate standards: 079, 075, 070 & 065. These percentages are to be applied to the tons reduced between the baseline and the control case.

The methodology for calculating the "overcontrol" percentages is based on simple linear interpolation between the baseline scenario and the model control strategy. These two model runs were used to estimate what level of control was just needed to bring an area into attainment of a standard. A caveat to this approach is that it assumes that all air quality impacts are due to local controls; there is no consideration of the potential impacts of ozone transport.

The details of the methodology are as follows. The first step was to identify all counties with ozone concentrations greater than 0.070 ppm in the base case. These 142 counties were the starting point for designing the modeled control strategy described in Chapter 3. Because the majority of the California controls are in the baseline and because several CA areas continue to be nonattainment of all four alternate standards in 2020 and beyond, we did not assess "overcontrol" in California. The remaining counties were aggregated into 32 distinct areas for an assessment of whether that area overcontrolled to meet an alternate standard. Each area included the original nonattainment county or counties, plus all counties within 200 km of that county or counties. The "overcontrolled" analysis was done for the county with the highest ozone levels in the control case modeling. These 32 areas comprised 1,199 counties. These are the same 1,199 non-California counties over which NonEGU point and Area sources were controlled in the hypothetical strategy.

A simple three-step process was used to determine the amount of overcontrol in the hypothetical control case for each of the 32 areas. The results are summarized in Table 4.8.

Table 4.8: Estimated Percentages of Modeled Control Strategy Emissions Reductions not needed to Meet the Various Ozone Standards in 2020

	Model projected 8-hour ozone design values (ppm)			Percent of control emissions not needed for alternate standards			
Area controlled within the Modeled Control Strategy	2020 Base Case	2020 Base Line	2020 Control Case	0.079	0.075	0.070	0.065
Houston, TX	0.0924	0.0890	0.0877	NONE	NONE	NONE	NONE
Eastern Lake Michigan, IL-IN-WI	0.0850	0.0814	0.0803	NONE	NONE	NONE	NONE
Northeast Corridor	0.0821	0.0796	0.0767	ALL	NONE	NONE	NONE
Baton Rouge, LA	0.0781	0.0768	0.0737	ALL	71%	NONE	NONE
Cleveland-Akron-Lorain, OH	0.0795	0.0765	0.0742	ALL	74%	NONE	NONE
Detroit-Ann Arbor, MI	0.0766	0.0752	0.0734	ALL	ALL	NONE	NONE
Dallas-Fort Worth, TX	0.0770	0.0754	0.0732	ALL	ALL	NONE	NONE
Buffalo-Niagara Falls, NY	0.0777	0.0754	0.0722	ALL	ALL	NONE	NONE
Allegan Co, MI	0.0772	0.0734	0.0721	ALL	ALL	NONE	NONE
Boston-Lawrence-Worcester, MA	0.0762	0.0737	0.0719	ALL	ALL	NONE	NONE
Jefferson Co, NY	0.0749	0.0734	0.0715	ALL	ALL	NONE	NONE
Las Vegas, NV	0.0749	0.0724	0.0710	ALL	ALL	NONE	NONE
Jamestown, NY	0.0754	0.0728	0.0697	ALL	ALL	39%	NONE
Denver-Boulder-Greeley-Ft Collins-Love.,	0.0742	0.0728	0.0677	ALL	ALL	63%	NONE
Pittsburgh-Beaver Valley, PA	0.0739	0.0721	0.0693	ALL	ALL	57%	NONE
Charlotte-Gastonia-Rock Hill, NC-SC	0.0730	0.0716	0.0707	ALL	ALL	22%	NONE
Hancock, Knox, Lincoln & Waldo Cos, ME	0.0731	0.0713	0.0688	ALL	ALL	84%	NONE
Norfolk-Virginia Beach-Newport News (HR)	0.0729	0.0712	0.0703	ALL	ALL	67%	NONE
St Louis, MO-IL	0.0730	0.0710	0.0686	ALL	ALL	96%	NONE
Providence (All RI), RI	0.0737	0.0708	0.0683	ALL	ALL	ALL	NONE
Huntington-Ashland, WV-KY	0.0731	0.0707	0.0690	ALL	ALL	ALL	NONE
Benton Harbor, MI	0.0740	0.0705	0.0692	ALL	ALL	ALL	NONE
Erie, PA	0.0732	0.0704	0.0675	ALL	ALL	ALL	NONE
Cincinnati-Hamilton, OH-KY-IN	0.0723	0.0703	0.0676	ALL	ALL	ALL	NONE
Atlanta, GA	0.0718	0.0701	0.0680	ALL	ALL	ALL	NONE
Toledo, OH	0.0728	0.0701	0.0677	ALL	ALL	ALL	NONE
Salt Lake City, UT	0.0728	0.0701	0.0676	ALL	ALL	ALL	NONE
Muskegon, MI	0.0734	0.0699	0.0685	ALL	ALL	ALL	NONE
Phoenix-Mesa, AZ	0.0718	0.0699	0.0682	ALL	ALL	ALL	NONE
Richmond-Petersburg, VA	0.0712	0.0699	0.0677	ALL	ALL	ALL	NONE
Indianapolis, IN	0.0720	0.0697	0.0681	ALL	ALL	ALL	NONE
Cass Co, MI	0.0717	0.0683	0.0666	ALL	ALL	ALL	NONE

a) For each standard, we first determined if the area was below that standard in the baseline modeled scenario. If so, then all of the hypothetical controls should be returned from the control scenario. For example, the highest projected design value in the Cincinnati area was 0.072 ppm in the basecase and 0.070 ppm in the baseline. Thus, that area did not actually need any of the hypothetical controls above and beyond the baseline to meet the 0.079, 0.075, or 0.070 standards locally. Therefore, all of the controls in that area should be returned for those standards.

b) For each standard, we then determined if the area was above that standard in the modeled control case. If so, then none of the hypothetical controls should be given back. As an example, the Houston area had a projected design value of 0.087 ppm in the control case. Therefore, all of the emissions in the modeled control strategy (and some extrapolated tons) are needed in that area.

c) For each standard, and for all other areas that were above the standard in the baseline and below in the control case, we used linear interpolation to estimate what percentage of the emissions reductions in the modeled control strategy could be returned and still allow the standard to be met. For example, the maximum projected design value in the Cleveland area was 0.0795 ppm in the basecase, 0.0765 ppm in the baseline, and 0.0742 ppm in the control case. Linear interpolation[8] between the baseline and the control case indicates that 74% of the controls in the Cleveland area, including counties within a 200km buffer, could be given back and still just meet the 0.075 ppm target. All of the control strategy reductions would be given back for the less-stringent 0.079 ppm standard and none of the reductions would be given back for the more-stringent 0.070 ppm standard.

4.4 Conversion of Estimated Percentages of Unnecessary Emission Reductions into "Overcontrolled" Tons

The percentages of modeled control strategy emissions reductions not needed to meet the various ozone standards in 2020 shown in Table 4.8 were applied to the control case reductions in Table 4.9. In areas and targets where the percentages in Table 4.8 were "ALL," the unnecessary emissions reductions in Table 4.9 are equal to the baseline minus control case emissions seen in the same table. Similarly, in areas and targets where there was no "over-control" ("NONE" in Table 4.8), emission reductions not needed for alternative standards in Table 4.9 are zero; that is, the control scenario did not "over-control" emissions for that area and target. As seen in Table 4.8, ozone concentration estimates are greater than 0.0795 ppm in both Houston and Eastern Lake Michigan; therefore there was no over-control and no unnecessary emission reductions.

[8] The calculation used to determine the 74% target for the 0.075 ppm targets is as follows: 1.0-[(0.0765-0.0759)/(0.0765-0.0742)], where 0.0759 ppm represents the highest ozone level that still attains a 0.075 ppm standard, due to the usual truncation of the fourth decimal place.

Table 4.9: Estimated 2020 Control Case Emission Reductions not needed to Meet the Various Ozone Standards in 2020

	Annual Emissions [tons/year]				2020 Control Case Emission Reductions not needed for alternate standards			
Area controlled within the modeled control Strategy	2020 Base Case	2020 Baseline	2020 Control Case	Baseline minus Control Case	0.079	0.075	0.070	0.065
Eastern Lake Michigan, IL-IN-WI-MI	600,000	500,000	460,000	36,000	0	0	0	0
Houston-Galveston-Brazoria, TX	460,000	340,000	320,000	12,000	0	0	0	0
Northeast Corridor, CT-DE-DC-NY-NJ-PA-VA	910,000	840,000	750,000	98,000	98,000	0	0	0
Jefferson Co., NY	36,000	34,000	32,000	2,000	2,000	2,000	0	0
Allegan Co., MI	20,000	18,000	15,000	3,100	3,100	3,100	0	0
Buffalo-Niagara Falls, NY	66,000	62,000	55,000	7,000	7,000	7,000	0	0
Las Vegas, NV	45,000	43,000	36,000	7,800	7,800	7,800	0	0
Boston-Lawrence-Worcester-Portsmouth, MA-NH	150,000	140,000	130,000	14,000	14,000	14,000	0	0
Cleveland-Akron-Lorain, OH	270,000	250,000	210,000	44,000	44,000	32,000	0	0
Dallas-Fort Worth, TX	210,000	200,000	160,000	43,000	43,000	43,000	0	0
Detroit-Ann Arbor, MI	260,000	240,000	190,000	50,000	50,000	50,000	0	0
Baton Rouge, LA	400,000	350,000	230,000	110,000	110,000	81,000	0	0
Richmond-Petersburg, VA	12,000	11,000	11,000	310	310	310	310	0
Muskegon Co., MI	5,100	4,400	4,000	420	420	420	420	0
Norfolk-Virginia Beach-Newport News, VA	9,600	9,100	8,300	780	780	780	520	0
Huntington-Ashland, WV-KY	5,800	5,400	4,200	1,200	1,200	1,200	1,200	0
Providence (All RI), RI	13,000	12,000	10,000	1,500	1,500	1,500	1,500	0
Toledo, OH	4,700	4,400	2,800	1,600	1,600	1,600	1,600	0
Charlotte-Gastonia-Rock Hill, NC-SC	240,000	230,000	220,000	14,000	14,000	14,000	3,200	0
Indianapolis, IN	44,000	43,000	36,000	6,600	6,600	6,600	6,600	0
Salt Lake City, UT	53,000	49,000	42,000	7,400	7,400	7,400	7,400	0
Phoenix, AZ	89,000	83,000	75,000	7,500	7,500	7,500	7,500	0
Hancock, Knox, Lincoln & Waldo Cos, ME	41,000	39,000	30,000	9,300	9,300	9,300	7,800	0
Denver, CO	110,000	110,000	81,000	25,000	25,000	25,000	16,000	0
Pittsburgh-Beaver Valley, PA	160,000	150,000	120,000	30,000	30,000	30,000	17,000	0
St Louis, MO-IL	290,000	270,000	240,000	30,000	30,000	30,000	29,000	0
Atlanta, GA	220,000	210,000	180,000	31,000	31,000	31,000	31,000	0
Cincinnati-Hamilton, OH-KY-IN	320,000	290,000	250,000	41,000	41,000	41,000	41,000	0

Chapter 5: Engineering Cost Estimates

Synopsis

This chapter summarizes the data sources and methodology used to estimate the engineering costs of attaining the alternative more stringent levels for the ozone primary standard analyzed in this RIA. This chapter estimates the engineering costs of 0.065 ppm, 0.070 ppm, 0.075 ppm, and 0.079 ppm. The chapter presents engineering cost estimates for the illustrative modeled control strategy outlined in Chapter 3 (which uses currently available known controls). The modeled control strategy discussion is followed by a presentation of estimates for the engineering costs of the additional tons of emissions that are needed to move to full attainment of the alternate standards analyzed, referred to as Extrapolated Costs (methodology and numbers discussed in Chapter 4).

As noted in Chapter 3, EPA first modeled an illustrative control strategy aimed at attaining a tighter standard of 0.070 ppm in 2020. EPA modeled the lower end of the proposed range to capture a larger number of geographic areas that may be affected by a new ozone standard. These known controls were insufficient to bring all areas into attainment with 0.070 ppm, and EPA then developed methodology to estimate additional tons of emissions needed to attain 0.079 ppm, 0.075 ppm, 0.070 ppm, and 0.065 ppm. This chapter presents the engineering costs associated with each portion of the control analysis, clearly identifying the relative engineering costs of modeled versus extrapolated emissions reductions as well as providing an estimate of the total engineering cost of attainment nationwide in 2020. Nationwide attainment refers to all areas of the nation that are required to attain the current ozone standard by the year 2020. It does not reflect full attainment for the two areas of California, which have attainment dates for the current standard post 2020. For a complete discussion attainment for these two areas of California see Appendix 7b. Section 5.1 summarizes the methodology and the engineering costs associated with applying known and supplemental controls to partially attain a 0.070 ppm alternative standard, incremental to reaching the current baseline (effectively 0.084 ppm) in 2020.

Section 5.2 describes the methodology used to estimate the engineering costs of extrapolated tons needed to reach attainment of the final 0.075 ppm standard as well as the three alternatives and provides estimates of how much additional engineering costs will be associated with moving from the modeled partial attainment scenario (i.e. modeled control strategy) to the nationwide attainment scenario (see Chapter 4 for discussion of extrapolated tons needed to attain 0.079, 0.075, 0.070, and 0.065 ppm).

The engineering costs described in this chapter generally include the costs of purchasing, installing, and operating the referenced technologies. For a variety of reasons, actual control costs may vary from the estimates EPA presents here. As discussed throughout this report, the technologies and control strategies selected for analysis are illustrative of one way in which nonattainment areas could meet a revised standard. There are numerous ways to construct and evaluate potential control programs that would bring areas into attainment with alternative standards, and EPA anticipates that state and local governments will consider programs that are best suited for local conditions. Furthermore, based on past experience, EPA believes that it is reasonable to anticipate that the marginal cost of control will decline over time due to technological improvements and more widespread adoption of previously niche control technologies. Also, EPA recognizes the extrapolated portion of the engineering cost estimates reflects substantial uncertainty about which sectors, and which technologies, might become available for cost-effective application in the future. This is explained in further detail in Section 5.3. Appendix 5a includes detailed cost and control efficiency information on different control measures applied as part of our modeled control strategy, and also includes summary results from applications of specific control measures.

It is also important to recognize that the engineering cost estimates are limited in their scope. Because we is not certain of the specific actions that states will take to design State Implementation Plans to meet the revised standards, we do not present estimated costs that government agencies may incur for managing the requirement and implementation of these control strategies or for offering incentives that may be necessary to encourage or motivate the implementation of the technologies, especially for technologies that are not necessarily market driven. This analysis does not assume specific control measures that would be required in order to implement these technologies on a regional or local level.

We use EMPAX-CGE to estimate the economic impacts and the social costs associated with the modeled control strategy. EMPAX uses as input the engineering costs estimated for the modeled control strategy to calculate its economic impacts and social costs. Economic impacts are estimates of changes in price and output for those industries and consumers of their output affected by the modeled control strategy. Social costs are costs from changes in household welfare due to impacts from the costs of the controls in the modeled control strategy. For more details on the economic impacts and social costs, please refer to Appendix 5b.

5.1 Modeled Controls

5.1.1 Sector Methodology

5.1.1.1 NonEGU Point and Area Sources: AirControlNET

After designing a national hypothetical control strategy using the methodology discussed in Chapter 3 (see sub-section 3.2.1), EPA used AirControlNET to estimate engineering control costs. 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 information regarding 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, in dollars per ton, using the capital recovery factor.[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. Capital costs are converted to annual costs, in dollars per ton, using the capital recovery factor (CRF). The capital recovery factor incorporates the interest rate and equipment life (in years) of the control equipment. Operating costs are calculated as a function of annual O&M and other variable costs. The resulting TACC equation is TACC = (CRF * CC) + O&M.

Engineering costs will differ based upon quantity of emissions reduced, plant capacity, or stack flow which can vary by emissions inventory year. Engineering costs will also differ by the year the costs are calculated for (i.e., 1999$ versus 2006$). 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 modeled control strategy. 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 (found at http://epa.gov/ttn/catc/products.html#cccinfo). Applied controls and their respective engineering costs are provided in the Ozone NAAQS RIA docket.

The modeled control 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 were calculated by examining the marginal cost curves for each pollutant for the geographic areas (approximately 1,300 counties for NOx controls, see Figure 3.5 and approximately 120 counties for VOC controls, see Figure 3.6) being analyzed for this analysis. For reductions of NOx emissions the cap (see Figure 5.1) was set at $23,000/ton (2006$). At this cap, ninety-eight percent of the possible reductions from known measures are achieved at eighty-two percent of the total annualized engineering cost. There were only two controls whose cost per ton were greater than this cap, and subsequently not included in this analysis, due to the large capital component of installing these controls. A similar process was followed for reductions from VOCs. The relative air quality effectiveness of reductions in VOC was considered, and the marginal cost curve (Figure 5.2) was analyzed. Subsequently, the cap was set at approximately $5,000/ton (2006$). At this cap, forty-six percent of the possible reductions are achieved at fifteen percent of the total engineering cost. It is important to note that as part of the extrapolated cost analysis the VOC cap was raised to $15,000/ton (for geographic areas where the supplemental air quality modeling showed VOC control to be beneficial). At this cap (2006$) ninety-eight percent of the possible reductions could be achieved.

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[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.

Figure 5.1: Marginal Cost Curve for Modeled Control Strategy Geographic Areas (NOX nonEGU Point and Area Source Controls Prior to Cut Points)

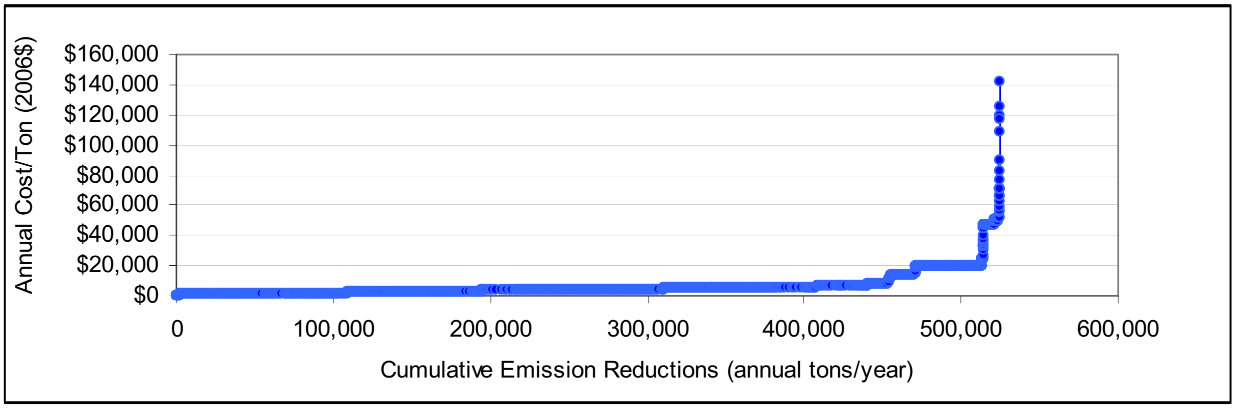
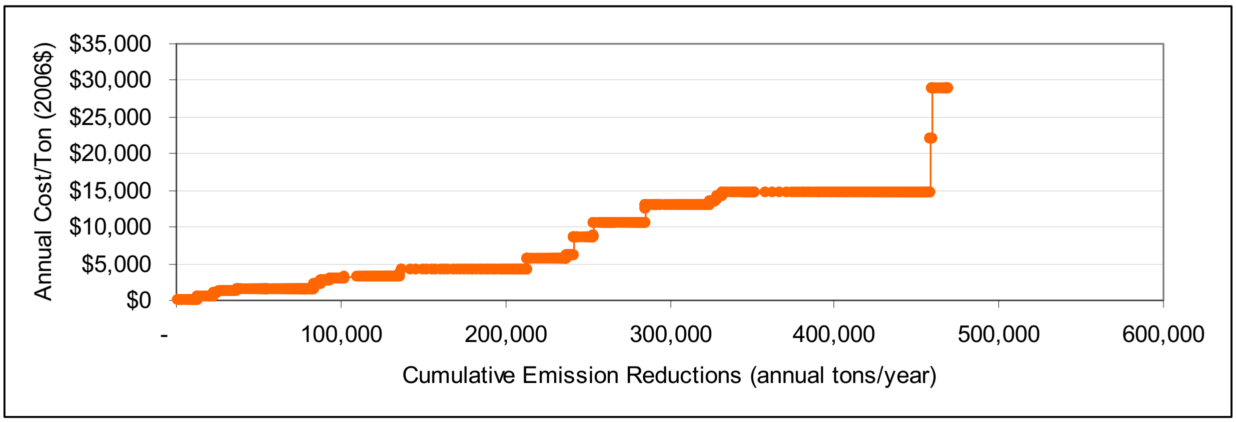


Figure 5.2: Marginal Cost Curve for Modeled Control Strategy Geographic Areas (VOC nonEGU Point and Area Source Controls Prior to Cut Points)



5.1.1.2 EGU Sources: the Integrated Planning Model

Engineering costs for the electric power sector are estimated using the Integrated Planning Model (IPM). 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.[2] Applied controls and their respective engineering costs are provided in the docket. IPM is described in further detail in Appendix 3.

5.1.1.3 Onroad and Nonroad Mobile Sources: National Mobile Inventory Model (NMIM) and Various Studies

Engineering cost information for mobile source controls was taken from studies conducted by EPA for previous rulemakings and studies conducted for development of voluntary and local measures that could be used by state or local programs to assist in improving air quality. Applied controls and their respective engineering costs are provided in the docket.[3]

Engineering costs, in terms of dollars per ton emissions reduced, were applied to emission reductions calculated for the onroad and nonroad mobile sectors that were generated using the NMIM. NMIM is an EPA model for estimating pollution from highway vehicles and nonroad mobile equipment. NMIM uses current versions of EPA's model for onroad mobile sources, MOBILE6, and nonroad mobile sources, NONROAD, to calculate emission inventories [4].

5.1.2 Modeled Controls—Engineering Cost by Sector

In this section, we provide engineering cost estimates of the control strategies identified in Chapter 3 that include control technologies on nonEGU stationary sources, area sources, EGUs, and onroad and nonroad mobile sources. Engineering costs generally refer to the capital equipment expense, the site preparation costs for the application, and annual operating and maintenance costs.

The total annualized cost of control in each sector in the control scenario is provided in Table 5.1. These numbers reflect the engineering costs across sectors annualized at a discount rate of 7% and 3%, consistent with the guidance provided in the Office of Management and Budget's (OMB) (2003) Circular A-4. However, it is important to note that it is not possible to estimate both 7% and 3% discount rates for each source (see section 5.1.3). In Table 5.1, an annualized control cost is provided to allow for comparison across sectors, and between costs and benefits. A 7% discount rate was used for control measures applied to nonEGU point, area,

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[2] The application of the 0.070 EGU control strategy results in annual NOx allowance price decreasing from $1618/ton in the baseline to $641/ton. See Technical Support Document on EGU Control Strategies for more details. Further detailed information on IPM is available in Section 6 of the 2006 PM RIA or at http://www.epa.gov/airmarkets/epa-ipm

[3] The expected emissions reductions from SCR retrofits are based on data derived from EPA regulations (Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-duty Highway Engines and Vehicles published October 2000), interviews with component manufacturers, and EPA's Summary of Potential Retrofit Technologies available at www.epa.gov/otaq/retrofit/retropotentialtech.htm.
For more information on mobile idle reduction technologies (MIRTs) see EPA's Idle Reduction Technology page at http://www.epa.gov/otaq/smartway/idlingtechnologies.htm.

[4] More information regarding the National Mobile Inventory Model (NMIM) can be found at http://www.epa.gov/otaq/nmim.htm

and mobile sources. Engineering costs from EGU sources, which are calculated using the IPM model and variable interest rates, are captured in this table at an annualized 7% discount rate.[5]

[5] A different plant-specific interest rate is applied in estimating control costs within IPM. See PM RIA for details.

Table 5.1: Annual Control Costs by Sector and Region, for the Modeled Control Strategy (2006$) [a, b, e]

	Modeled Control Strategy Engineering Cost by Region (M 2006$)			Total Cost (M 2006$)	Average Cost/Ton (2006$)
Source Category	**East**	**West**	**CA**		
Electric Generating Units (EGU) Sector					
Controls for NOx cap and trade program and local measures in projected nonattainment areas for coal units.	$170	$(70) [c]	$66	$160	$1,900 [f]
Total	$170	$(70)	$66	$160	
Mobile Source Sector					
Onroad Sources (Ex: automobiles, buses, trucks, and motorcycles traveling on roads and highways)	$360	$55	$45	$460	$2,100
Nonroad Sources (Ex: railroad locomotives; marine vessels, aircraft, and farm, construction, industrial and lawn/garden equipment)	$150	$21	$16	$190	$3,400
Total	$510	$75	$61	$650	
NonEGU Sector					
Point Sources (Ex: chemical manufacturing, cement manufacturing, petroleum refineries, and iron and steel mills)	$1,400	$57	$4.7	$1,500	$3,800
Area Sector					
Area Sources (Ex: residential woodstoves, agriculture)	$480	$44	$20	$550	$1,900
Total				$2,000	
Total Annualized Costs (using a 7% interest rate)	$2,600	$170	$160	$2,800	
Total Annualized Costs (using a 3% interest rate) [d]	$2,400	$160	$160	$2,600	

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns. The modeled control strategy is that strategy applied to reach attainment of the 0.070 alternate primary standard, and is described in detail in Chapter 3.

[b] All estimates provided reflect the engineering cost of the modeled control strategy, incremental to a 2020 baseline of compliance with the current standard of 0.084 ppm.

[c] The total cost is negative in the west for the modeled control strategy due to an electricity generation shift. The west generates less electricity and exports from the east.

[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 this modeled control strategy, data for calculating annualized costs at a 3% discount was only available for NonEGU 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.

[e] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[f] This average cost/ton estimate is based on ozone season NOx reductions from EGUs from controls that operate year-round as explained in Chapter 3. By counting NOx reductions in the ozone season while operation of NOx controls is modeled as year-round, our cost/ton estimate may spread out reductions and thus affect the average cost/ton estimate. It should be noted that the resulting cost/ton of the controls applied within EGU control strategy is practically the same as that in 2020 for the final CAIR rule ($1,900 in 2006 dollars).

Total annualized costs were calculated using a 3% discount rate for controls which had a capital component and where equipment life values were available. In this RIA, the nonEGU point source sector was 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 source and mobile controls to provide a reliable 3 percent discount rate estimate. As such, the 3% value in Table 5.1 is representative of the sum of the nonEGU Point Source sector at a 3% discount rate, and the EGU, mobile, and Area Source sector at a 7% discount rate. It is expected that the 3% discount rate value is overestimated due to the addition of cost sectors at a higher discount rate. With the exception of the 3 % Total Annualized Cost estimate on Table 5.1, engineering cost estimates presented throughout this and subsequent chapters are based on a 7% discount rate.

The total annualized engineering costs associated with the application of known and supplemental controls, incremental to the baseline, are approximately $2.8 billion using a 7% discount rate.

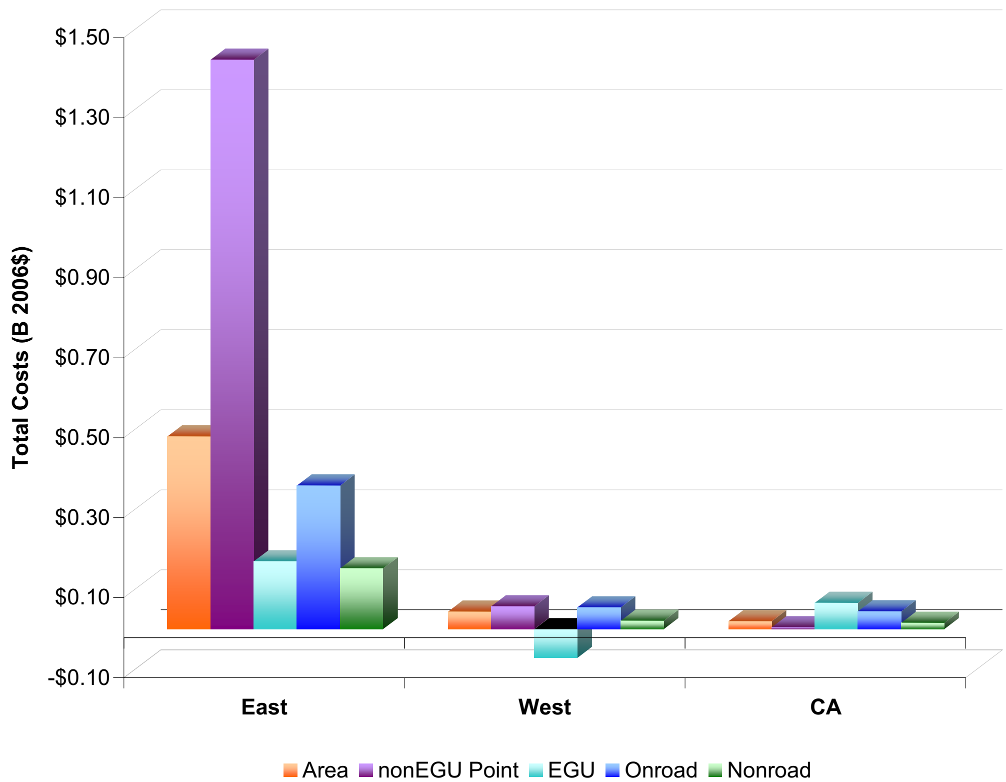
5.1.3 Limitations and Uncertainties Associated with Engineering Cost Estimates

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 these point source control measures as we have done for the proposed ozone RIA and the PM2.5 RIA last year.

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 our office (OAQPS) 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

Figure 5.3: Total Annualized Costs by Emissions Sector and Region for Modeled Control Strategy in 2020[a, b, c, d]



[a] Total costs presented above are for a seven percent discount rate.

[b] All estimates provided reflect the engineering cost of the modeled control strategy, incremental to a 2020 baseline of compliance with the current standard of 0.084 ppm.

[c] The total cost is negative in the west for the modeled control strategy due to an electricity generation shift. The west generates less electricity and exports from the east.

[d] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

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. Such area source controls can include reformulation of coatings to reduce VOC, as one example. 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 the PM2.5 and ozone RIAs.

For mobile source measures, the situation is very much like that for our area source measures. We do not have sufficient capital cost information from what our mobile source office (OTAQ) has sent us to compute annualized costs for different interest rates other than 7%. Finally, It should be noted that the annualized capital costs for EGUs are prepared at an interest rate other than 7%. Information on the annualization of EGU control costs is presented later in this chapter.

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.

The economic impacts of the cost of these modeled control strategy is included in Appendix 5b of this analysis. The illustrative analysis does quantify the potential for advancements in the capabilities of pollution control technologies as well as reductions in their engineering costs over time. This is discussed in Section 5.4.

For purposes of this analysis, we assume attainment by 2020 for all areas except San Joaquin Valley and South Coast air basins in California. The state has submitted plans to EPA for implementing the current ozone standard which propose that these two areas of California meet that standard by 2024. We have assumed for analytical purposes that the San Joaquin Valley and South Coast air basin would attain a new standard in 2030. There are many uncertainties associated with the year 2030 analysis. Between 2020 and 2030 several federal air quality rules are likely to further reduce emissions of NOx and VOC, such as, but not limited to National rules for Diesel Locomotives, Diesel Marine Vessels, and Small Nonroad Gasoline Engines. These emission reductions should lower ambient levels of ozone in California between 2020 and 2030. Complete emissions inventories as well as air quality modeling were not available for this year 2030 analysis. Due to these limitations, it is not possible to adequately model 2030 air quality changes that are required to develop robust controls strategies with associated costs and benefits. In order to provide a rough approximation of the costs and benefits of attaining 0.075 ppm and the alternate standards in San Joaquin and South Coast air basins, we've relied on the available data. Available data includes emission inventories, which do not include any changes in stationary source emissions beyond 2020, and 2020 supplemental air quality modeling. This data was used to develop extrapolated costs and benefits of 2030 attainment. To view the complete analysis for the San Joaquin Valley and South Coast air basins see Appendix 7b.3

5.2 Extrapolated Engineering Costs

5.2.1 Methodology

This section presents the methodology and results of the extrapolated engineering cost calculations of attainment of a new ozone standard of 0.075 ppm and analyses of three alternative standards, a less stringent 0.079 ppm and two more stringent options (.065 and 0.070 ppm).

As discussed in Chapter 3, the application of the modeled control strategy was not successful in reaching nationwide attainment of the alternate ozone standards. Many areas remained in nonattainment for all four alternate standard scenarios; therefore, the engineering costs detailed in Section 5.1 represent only the costs of partial attainment.

The estimation of engineering costs for unspecified emission reductions needed to reach attainment many years in the future is inherently a difficult issue. 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 emissions reductions that are unforeseen today, and to reduce costs of emerging technologies over time. But we cannot quantitatively predict the amount of technology advance in the future. For areas needing significant additional emission reductions, much of the control must be for sources that historically haven't been controlled. The relationship of the cost of such control to the cost of control options available today is not at all clear. Available, current known control measures increase in cost beyond the range of what has ever been implemented and would still not provide the needed additional control for full attainment in the analysis year 2020. In the absence of technological change, the needed control for full attainment in 2020 would not be available.

The degree to which unknown controls are needed to achieve attainment depends significantly upon variables in the analysis, such as attainment date assumptions. We will better understand the true scope of the issue in the future as states conduct detailed area-by-area analyses to determine available controls and attainment dates that are appropriate under the Clean Air Act. We do not attempt to determine specific attainment dates in this analysis. The Clean Air Act provides flexibility for a nonattainment area to receive an attainment date up to 20 years after designation if earlier attainment is not practical based on controls that are reasonably available considering cost. Although we assume attainment in 2020 (except for two California areas), areas that face difficulty attaining could qualify under the Clean Air Act for an attainment date as late as 2030 (assuming designations in 2010). This would give such areas additional time to take advantage for national standards to reduce emissions from onroad and nonroad mobile sources through fleet turnover, and to take advantage of technological innovation in cleaner technologies after 2020.

Prior to presenting the methodology for estimating costs for unspecified emission reductions, it is important to provide information from EPA's Science Advisory Board Council Advisory,[6] dated June 8, 2007, on the issue of estimating costs of unidentified control measures.

> *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*

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

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 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.

To generate estimates of the costs and benefits of meeting alternative standards, EPA has assumed the application of unspecified future controls that make possible the emissions reductions needed for attainment in 2020 (excluding two California areas). By definition, there is no cost data in existence for unidentified future technologies or innovative strategies.

EPA used two methodologies for estimating the costs of unspecified future controls: a new hybrid methodology and a fixed-cost methodology. Both approaches assume that innovative strategies and new control options make possible the emissions reductions needed for attainment by 2020. The fixed cost methodology was preferred by EPA's Science Advisory Board over two other options, including a marginal-cost-based approach. The hybrid approach has not yet been reviewed by the SAB.

The hybrid approach creates a marginal cost curve and an average cost curve representing the cost of unknown future controls needed for 2020 attainment. This approach explicitly estimates the average per-ton cost of unspecified emissions reductions assumed for each area, with a higher average cost-per-ton in areas needing a higher proportion of unknown controls relative to known modeled controls. This requires assumptions about the average cost of the least expensive unspecified future controls, and the rate at which the average cost of these controls rises as more extrapolated tons are needed for attainment (relative to the amount of reductions from known, modeled controls). These factors in turn depend on implicit assumptions about future technological progress and innovation in emission reduction strategies.

The fixed cost methodology utilizes a national average cost per ton of future unspecified controls needed for attainment, as well as two sensitivity values (presented in Appendix 5a.4.3). The range of estimates reflects different assumptions about the cost of additional emissions reductions beyond those in the modeled control strategy. The alternative estimates implicitly reflect different assumptions about the amount of technological progress and innovation in emission reduction strategies.

The hybrid methodology has the advantage of using the information about how significant the needed reductions from unspecified control technology are relative to the known control measures and matching that with expected increasing per unit cost for going beyond the modeled technology. Under this approach, the relative costs of unspecified controls in different geographic areas reflect the expectation that average per-ton control costs are likely to be higher in areas needing a higher ratio of emission reductions from unspecified and known controls.

The fixed cost methodology reflects a view that because no cost data exists for unspecified future strategies, it is unclear whether approaches using hypothetical cost curves will be more accurate or less accurate in forecasting total national costs of unspecified controls than a fixed-cost approach that uses a range of national cost per ton values.

Technological change will provide new control possibilities that can be employed to provide the additional unspecified control needed to reach attainment. These new technologies will make control possible where control has not been available for estimating our known control. An example might be the development of a new control technology for a type of emissions that have never been controlled. Technological change is also expected to reduce the cost of known controls that currently have prohibitive costs. For example, suppose a source that was not chosen for control because the estimated cost was $60,000 per ton but technological change reduces the cost to $16,000 per ton. Finally, control technologies may change so that higher control efficiencies may be obtained without a significant increase in per unit costs of control.

Both approaches (the hybrid and the fixed) estimate costs using national level parameters and local area information about needed emission reductions. Because cost changes due to technological change will be available on a national level, it makes sense to use national level estimates of these parameters. Local areas have different levels of needed emission reductions and different inventories of uncontrolled emissions and estimates of needed emission reductions are used in both models. The hybrid model also uses information about the amount of modeled control estimated for the local area.

The hybrid approach has yet to be peer reviewed and reflects a range of views about the likely cost of future techniques and strategies that reduce air pollutant emissions. Section 5.4 discusses historical experience which has shown numerous technological advances in emission reduction technologies, and provides a few examples of today's emerging technologies.

5.2.1.1 Initial Steps

The first step involved identifying supplemental known controls not included in the modeled control strategy. These controls include the controls discussed in Appendix 3a.1.6, as well as additional controls applied to select EGU sources, and VOC controls up to $15,000/ton for select geographic areas. For the more stringent alternative of 0.065 ppm additional geographic areas were included, and therefore additional known measures were available to be applied as well.

For the other three alternatives, there were geographic areas that were "over controlled" and controls were removed from the analysis. For a complete discussion of the supplemental and "over control" emission reductions and costs see Appendix 5a.4.1 and 5a4.2 respectively. After the supplemental controls are applied, any remaining emission reductions needed are classified as additional tons from unknown control measures.

Supplemental controls were applied in addition to the known controls in this illustrative analysis in order to achieve the highest possible known emission reduction from NonEGU point and Area sources. Supplemental control measures are those controls that are 1) applied in these analyses but are not found in AirControlNET, and 2) are in AirControlNET but whose data have been modified to better approximate their applicability to source categories in 2020. The controls and associated data such as control cost estimates not found in AirControlNET are taken from technical reports prepared to support preliminary 8-hour ozone State Implementation Plans (SIPs) prepared by States and from various reports prepared by the staffs of various local air quality regulatory agencies (e.g., Bay Area Air Quality Management District). The reports that are the sources of additional controls data are included within footnotes in the Chapter 3 Appendix. Modification of control data, including percent reduction levels and control cost data, in AirControlNET occurred as a result of a review of the nonEGU point and area NOx control measures by technical staff. The changes EPA supplied are provided later in the Chapter 3 Appendix.

Next. we classified the areas needing additional controls by attainment date. Because two areas in California require no incremental additional progress towards attainment by 2020 for a more stringent standard (their requirements to reach attainment of the current standard by 2024 will be the requirement that is binding) we separated the requirements to attain more stringent standards for those two areas from the analysis for the rest of the nation. A highly uncertain estimate of the extrapolated engineering cost in 2030 is provided in Appendix 5a.5.

5.2.1.2 Theoretical Model for Hybrid Approach

A simple model of how marginal costs increase with increasing control requirements was developed. The model relies on emission estimates of unspecified emissions (E_1) needed to reach attainment and the modeled control emission estimates. These unspecified emissions vary both with the area and standard being analyzed. The modeled emissions vary by area. The ratio (R) of unspecified emissions (E_1) to controlled emissions estimates (E_0) is thus unique to each area and standard being analyzed. The model of cost also includes two parameters developed for use that don't vary across analyses of areas and standards. One is a national projected dollar per ton cost for the last ton controlled for the controlled emissions (N or jumping off price). The other is a constant multiplier (M) to determine an average cost per ton that increases as size of the needed unknown controls (E_1) increase relative to the modeled controls (R). The following equations show how Average cost (AC), Total Cost (TC), and marginal (MC) are modeled in the hybrid approach. See the appendix for a more detailed explanation.

$$AC = N(1+RM)$$

$$TC = AC(E_1)$$

$MC = N(1+2RM)$

For the controlled emissions estimated in the modeled control, costs increase at an increasing rate as more control is applied. The shape of the control cost curve for 2020 after technological change is unknown but would also be expected to increase at an increasing rate. With all of the uncertainty and as part of the trade-off between simplicity/transparency and model richness we chose a proportional per unit cost increase. This model assumes per unit costs increase at a constant rate proportional to R.

5.2.1.3 Parameter Estimation for Hybrid Approach

The jumping off price (N) used is $15,000/ton (2006$). To determine this number we calculated the marginal costs for the last control applied in all geographic areas for nonEGU and Area known controls[7] and averaged them for both the modeled control strategy and an alternate primary standard of 0.065 ppm, this allowed for consistency with the modeled control strategy marginal costs. These calculations showed a range of $14,500 to $16,000 per ton (2006$), with $15,000 falling in the middle. The February 2007 report, "Direct Cost Estimates for the Clean Air Act Second Section 812," uses $10,000 (1999$) per ton. For simplicity and comparability we used the $15,000/ton. In addition the marginal cost curve for the modeled control strategy NOx nonEGU and Area, 90% of the controls applied are below $15,000/ton. The jumping off price (N) should be interpreted as the cost of the very first ton needed from the unknown control[8]. We chose the value $15,000/ton and not the $23,000/ton applied for NOx nonEGU point and Area source controls because the $23,000/ton was calculated as an extreme upper limit for NOx nonEGU controls and is not representative of the upper limit of controls applied across all emissions sectors. It is important to note that the cost/ton numbers calculated above are specific to this scenario. In an ideal world, we would have more complete information about the available control options in each area and we would be able to estimate what the next control to be employed (the "jumping off" control) would be for each area needing control beyond the modeled known control.

We have to estimate R and E information for each area and each standard. Figure 5.4 shows how for phase 1 supplemental air quality modeling areas how R varies based upon the level of the standard and the local geographic area emissions.

We have no way to econometrically estimate M. The constant multiplier (M) incorporates many different influences on the unit costs of control such as technological change in control technology, change in energy technology, learning by doing, relative price changes, and distribution of sources with uncontrolled emissions. Using a high value for marginal cost we can solve for M based on this value and our parameter estimate of $15,000 for N, and our highest

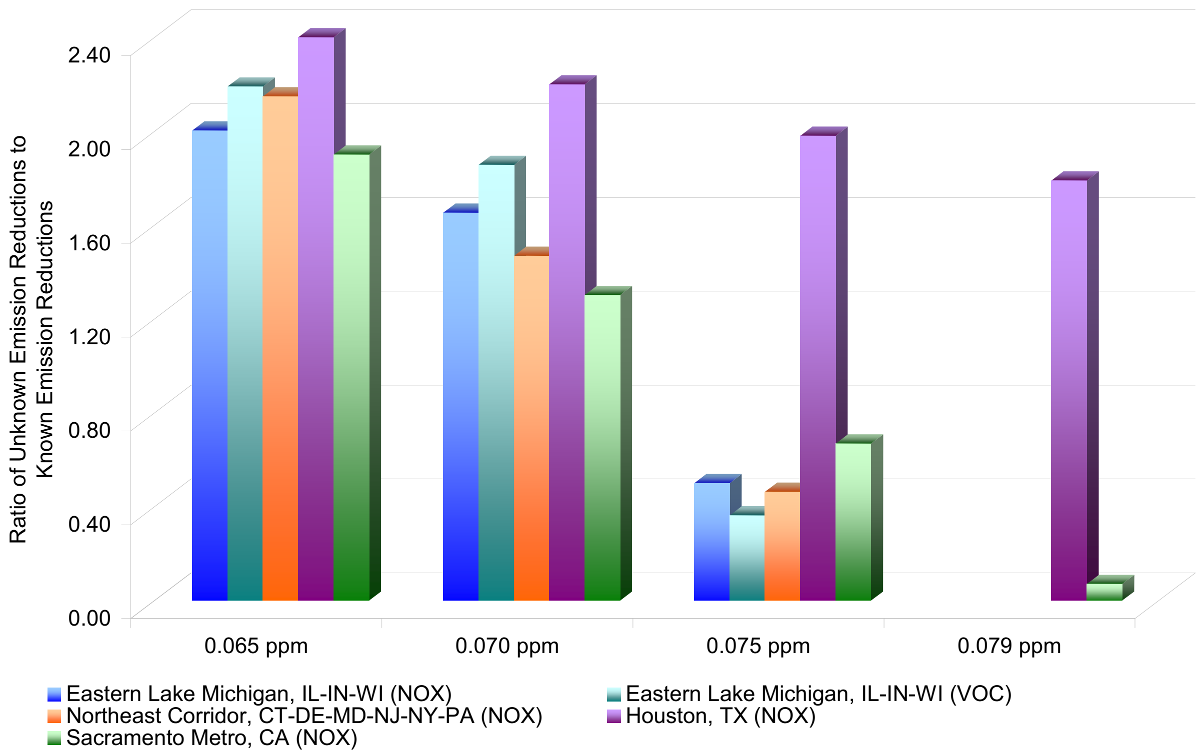
[7] NOx NonEGU point and Area controls were used for this calculation due to availability of detailed data across all emission sectors.

[8] Although $15,000/ton (2006$) represents the cost of the very first ton of unknown control needed, marginal costs for the last ton of unknown control are assumed to be no higher than $46,000/ton (2006$)

value of R[9] (2.19)for areas meeting the current standard in 2020. For the modeled control we used a maximum marginal cost of control of $23,000 dollars/ton. At this cost 98% of the possible reductions NOx from nonEGU point and area were applied. To arrive at a high value we doubled the maximum marginal cost value ($46,000). A number this high is rarely seen in either implemented controls or other RIAs (e.g. the 1997 Ozone RIA highest cost per ton was $10,000 (1990$) which is $14,000 (2006$)). This leads to our estimate of M of 0.47.   To arrive at a low value we used the maximum marginal cost from the modeled control strategy ($23,000). This leads to our estimate of M of 0.12. We calculated an M of 0.24 for the middle estimate based upon the higher and lower M values described above. The results reported in this chapter are for an M of 0.24, the estimates using the high and low value of M are reported in Appendix 5a.

[9] The R for Eastern Lake Michigan was 2.19 for the 0.065 ppm alternative standard. The R for Houston was higher, yet this value was not used when calculating the highest value of M because Houston is the only area in our analysis for 2020 that did not meet the current standard, and therefore not representative of the majority of areas needing to reach a new ozone standard.

Figure 5.4: Ratio of Unspecified Emission Reductions to Known Emission Reductions Across Various Standards for Phase 1 Areas[a, b, c]



[a] Phase 1 Areas are defined in Chapter 4 Section 4.1.1

[b] There are values of R for both NOx and VOC for the Eastern Lake Michigan, IL-IN-WI. This is the only geographic area where unknown control costs were calculated for VOC.

[c] Houston did not meet the current standard after the modeled control strategy.

The cost of the last ton needed for the unknown control is N(1+2RM). Thus, the per unit control cost for the unspecified tons in an area starts with N and linearly increases with R. The ratio of needed unknown control to modeled control (R) can be interpreted as a measure of "the degree of difficulty" (see Figure 5.4). For example, the per unit control costs would be expected to be higher if the unknown control needed is twice the modeled control than if it is half the modeled control. Table 5.2 shows how the cost of the last ton controlled for the highest R value would vary with different values of M. Figure 5.5 also depicts how the average cost per ton would vary.

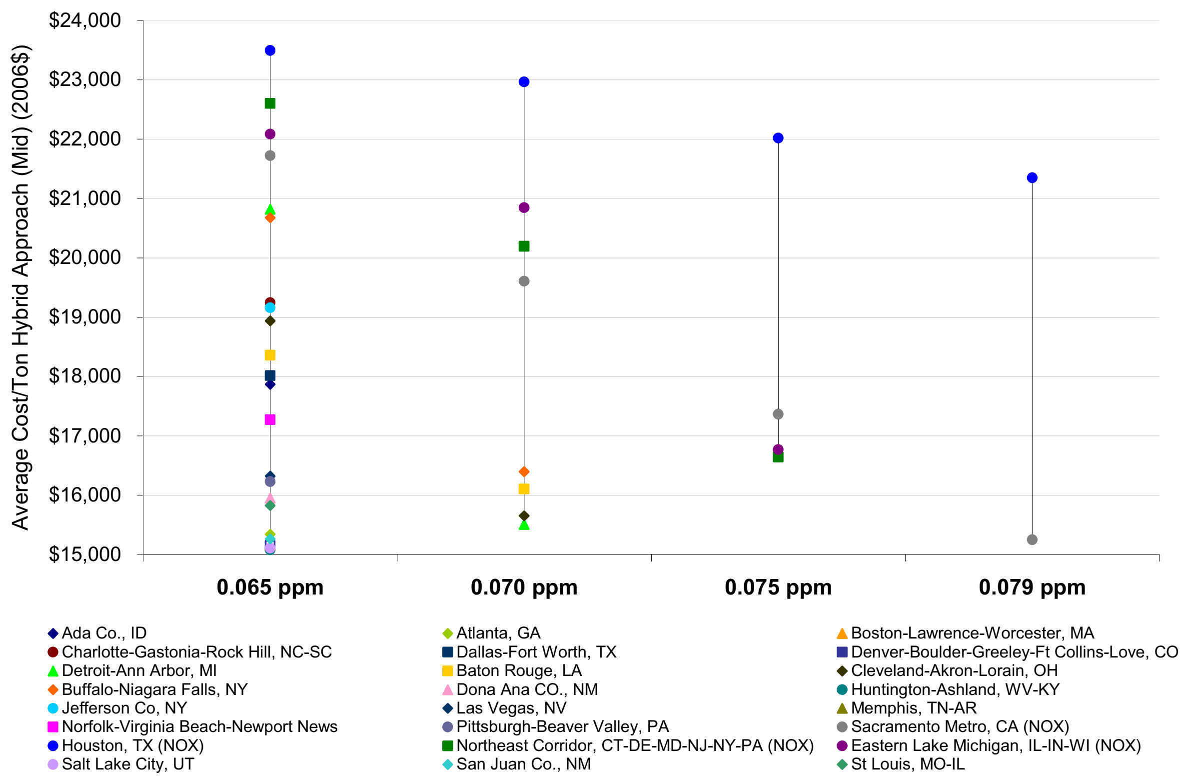
Table 5.2: Marginal Cost and Average Cost Values Used in Calculating M[a]

	Highest Annual Cost/Ton Values (2006$), Given R = 2.19		
	M = 0.12	**M = 0.24**	**M = 0.47**
Marginal Cost (MC)	$23,000	$31,000	$46,000
Average Cost (AC)	$19,000	$23,000	$30,000

[a] Marginal and average costs could be higher than the values presented above for tighter ozone standards.

Figure 5.5 shows the range of average cost/ton values across geographic areas and standards. This helps graphically illustrate the interplay of all the variables to create a geographically specific average cost/ton that is then multiplied by the amount of unspecified emissions reductions needed to attain. These average cost per ton values

Figure 5.5: Ranges of Hybrid (Mid) Average Cost/Ton Values across Geographic Areas and Standards



5.2.1.4 Fixed Cost Approach

As discussed above the Science Advisory Board advice favored a fixed cost per ton approach as the simplest and most straightforward. The extrapolated cost equation involves only unspecified emissions (E_1) and Fixed Cost per ton (F). Thus the total cost (TC) equation is:

$$TC = E_1 F$$

The primary estimate of F is $15,000. The $15,000 per ton amount is commensurate with that used in the 1997 RIA in using current dollars. It is also consistent with what an advisory committee to the Section 812 second prospective analysis on the Clean Air Act Amendments suggested.

Values of $10,000/ton and $20,000/ton are used for the sensitivity analyses found in Appendix 5a.4.3.

5.2.2 Results

5.2.2.1 Emission Reductions Needed to Attain Various Standards

Application of supplemental control measures (for a complete discussion see Chapter 5 Appendix section 5a.4) mentioned above resulted in some geographic areas no longer needing extrapolated tons to attain various alternate primary standards. Table 5.3 shows the emission reductions needed by geographic area, pollutant, and standard. Eastern Lake Michigan is the only area with both NOx and VOC emission reductions estimates. For the other areas additional control of NOx only is expected to be a less expensive approach than controlling both NOx and VOC. As expected, more areas need extrapolated emission reductions when the alternative standards are more stringent.

Table 5.3: Extrapolated Emission Reductions Needed (Post Application of Supplemental Controls) to Meet Various Alternate Standards in 2020

2020 Extrapolated Cost Area	Additional Emission Reductions Needed (annual tons/year)							
	0.065 ppm		0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC	NOX	VOC
Ada Co., ID	2,800							
Atlanta, GA	5,500							
Baton Rouge, LA	160,000		49,000					
Boston-Lawrence-Worcester, MA	8,500							
Buffalo-Niagara Falls, NY	18,000		3,700					
Campbell Co., WY	50							
Charlotte-Gastonia-Rock Hill, NC-SC	47,000							
Cincinnati-Hamilton, OH-KY-IN	(40)[a]							
Cleveland-Akron-Lorain, OH	78,000		11,000					
Dallas-Fort Worth, TX	48,000		(30)[a]					
Denver-Boulder-Greeley-Ft Collins-Love, CO	1,600							
Detroit-Ann Arbor, MI	100,000		8,700					
Dona Ana CO., NM	410							
Eastern Lake Michigan, IL-IN-WI	320,000	320,000	250,000	250,000	74,000	49,000	(60)[a]	(50)[a]
El Paso Co., TX	-[a]							
Houston, TX	180,000		160,000		110,000		81,000	
Huntington-Ashland, WV-KY	800							
Jackson Co., MS	(200)[a]							
Jefferson Co, NY	6,200							
Las Vegas, NV	3,900							
Memphis, TN-AR	1,100							

2020 Extrapolated Cost Area	Additional Emission Reductions Needed (annual tons/year)							
	0.065 ppm		0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC	NOX	VOC
Norfolk-Virginia Beach-Newport News	21,000							
Northeast Corridor, CT-DE-MD-NJ-NY-PA	340,000		220,000		65,000			
Phoenix-Mesa, AZ	(60) [a]							
Pittsburgh-Beaver Valley, PA	13,000							
Richmond-Petersburg, VA	(600) [a]							
Sacramento Metro, CA [b]	130,000		89,000		44,000		1,800	
Salt Lake City, UT	430							
San Juan Co., NM	1,300							
St Louis, MO-IL	17,000							
Toledo, OH	(90) [a]							

[a] negative or zero values indicate the supplemental measures applied yielded equal or greater emission reductions than were needed for the geographic area to attain the standard being analyzed.

[b] Sacramento Metro, CA geographic area also contains the South Coast and San Joaquin Valley Areas. These two areas will still be reducing emissions to meet the 0.08 ozone standard, and therefore the costs of these emission reductions are not incurred as part of meeting a new ozone standard. The difference between the emission reductions needed in Table 4.7a and this table are accounted for by the tons that South Coast and San Joaquin need to reduce to reach the current standard, and to help Sacramento attain a new ozone standard.

5.2.2.2 Fixed Cost Approach Extrapolated Costs

Figure 5.6 and Table 5.4 presents the extrapolated cost estimates regionally for the various alternative standards for a fixed cost approach of $15,000/ton. These costs are the values from Table 5.3 multiplied by $15,000. See the Appendix 5a.4.3 for sensitivity analyses of varying the fixed dollar per ton to values other than $15,000. When we evaluate the portion of costs for the extrapolated costs fixed approach by supplemental air quality modeling phase (as described in Chapter 4), 100% of the costs are allocated to phase 1 geographic areas for the 0.075 ppm and 0.079 ppm standard. For the 0.065 ppm and 0.070 ppm standards 73% to 94% are allocated to phase 1 areas, 22% to 6% in phase 2 areas, and only 5% to 0% for phase 3 areas. The sensitivity analysis for the fixed cost approach at $10,000/ton and $20,000/ton resulted in extrapolated costs of $3.4 to $6.8 billion dollars for the 0.075 ppm standard.

5.2.2.3 Hybrid Approach Extrapolated Cost Results

Table 5.5 presents the extrapolated cost estimates regionally for the various alternative standards for the hybrid approach (mid). See the Appendix 5a.4.4 for sensitivity analyses of values of M of 0.47 and 0.12. A value of 0.24 is used for M because R goes up with the stringency of the standard, the differences in costs between cost areas increase with the stringency of the

Figure 5.6: Extrapolated Cost by Region to Meet Various Alternate Standards Using Fixed Cost Approach ($15,000/ton)

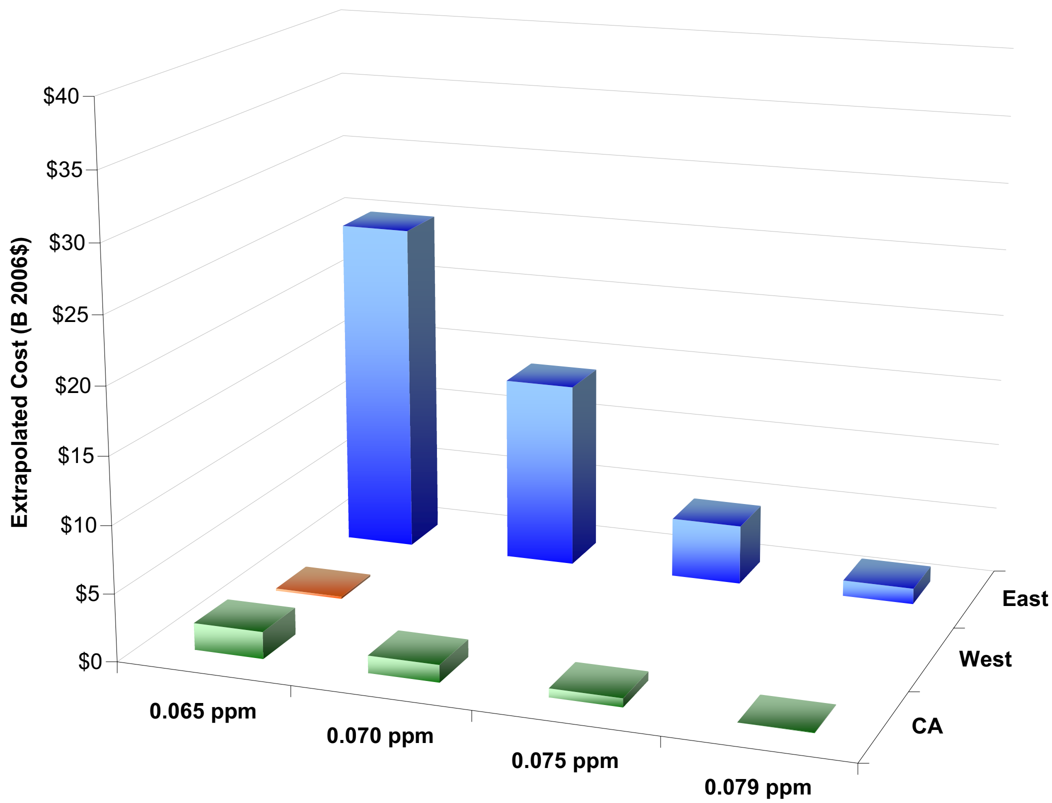


Table 5.4: Extrapolated Cost by Region to Meet Various Alternate Standards Using Fixed Cost Approach ($15,000/ton) [a, b]

2020 Extrapolated Cost by Region	Fixed Cost Approach Extrapolated Cost (M 2006$)			
	0.065 ppm	**0.070 ppm**	**0.075 ppm**	**0.079 ppm**
East	$25,000	$14,000	$4,500	$1,200
West	$160	-	-	-
California	$2,000	$1,300	$660	$28
Total Extrapolated Cost	**$27,000**	**$16,000**	**$5,100**	**$1,200**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

alternative being considered. When we evaluate the portion of costs for the extrapolated costs fixed approach by supplemental air quality modeling phase (as described in Chapter 4), 100% of the costs are allocated to phase 1 geographic areas for the 0.075 ppm and 0.079 ppm standard. For the 0.065 ppm and 0.070 ppm standards 74% to 95% are allocated to phase 1 areas, 21% to 5% in phase 2 areas, and only 5% to 0% for phase 3 areas.

Figure 5.7: Extrapolated Cost by Region to Meet Various Alternate Standards Using Hybrid Approach (Mid)

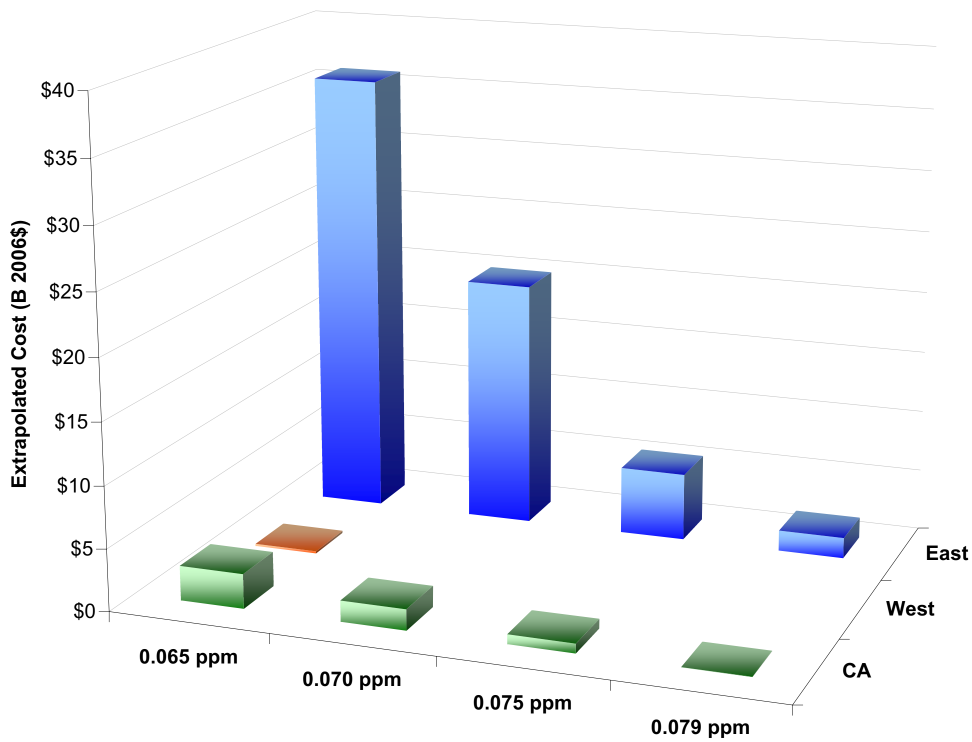


Table 5.5: Extrapolated Cost by Region to Meet Various Alternate Standards Using Hybrid Approach (Mid) [a, b]

2020 Extrapolated Cost by Region	Hybrid Approach Extrapolated Cost (M 2006$)			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
East	$36,000	$20,000	$5,500	$1,700
West	$170			
California	$2,800	$1,700	$770	$28
Total Extrapolated Cost	$39,000	$22,000	$6,300	$1,800

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

5.3 Summary of Costs

Table 5.6 presents a summary of the total national cost of attaining 0.079, 0.075, 0.070, and 0.065 ppm standards in 2020. This summary includes the engineering costs presented above from the modeled controls and the extrapolated costs. The range presented in the extrapolated costs and the total costs represent the upper and lower bound cost estimates. Consistent with OMB Circular A-4, costs are presented at a 7% discount rate. It is more consistent to present the extrapolated costs at the same discount rate as the modeled control costs, for which a 7% rate was determined to be more representative of actual costs (see section 5.1.3). Although the amount of reduction assumed to occur using unknown controls increases, the uncertainty of the associated costs and benefits calculations increases.

Table 5.6: Total Costs of Attainment in 2020 for Alternate Levels of the Ozone Standard [a, b, c]

Region		Annual Engineering Costs (M 2006$)							
		0.065 ppm		**0.070 ppm**		**0.075 ppm [d]**		**0.079 ppm [d]**	
Known Control Costs ($B)	East	$4,100		$3,100		$2,400		$960	
	West	$230		$14		-$4		-$5	
	California	$160		$160		$160		$160	
Known Control Costs[e]		$4,500		$3,300		$2,500		$1,100	
Extrapolated Costs ($B)		Fixed	Hybrid	Fixed	Hybrid	Fixed	Hybrid	Fixed	Hybrid
	East	$25,000	$36,000	$14,000	$20,000	$4,500	$5,500	$1,200	$1,700
	West	$160	$170	$0	$0	$0	$0	$0	$0
	California	$2,000	$2,800	$1,300	$1,700	$660	$770	$28	$28
Extrapolated Costs		$27,000	$39,000	$16,000	$22,000	$5,100	$6,300	$1,200	$1,800
Total Cost Range		**$32,000**	**$44,000**	**$19,000**	**$25,000**	**$7,600**	**$8,800**	**$2,400**	**$2,900**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for the analysis of these areas.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

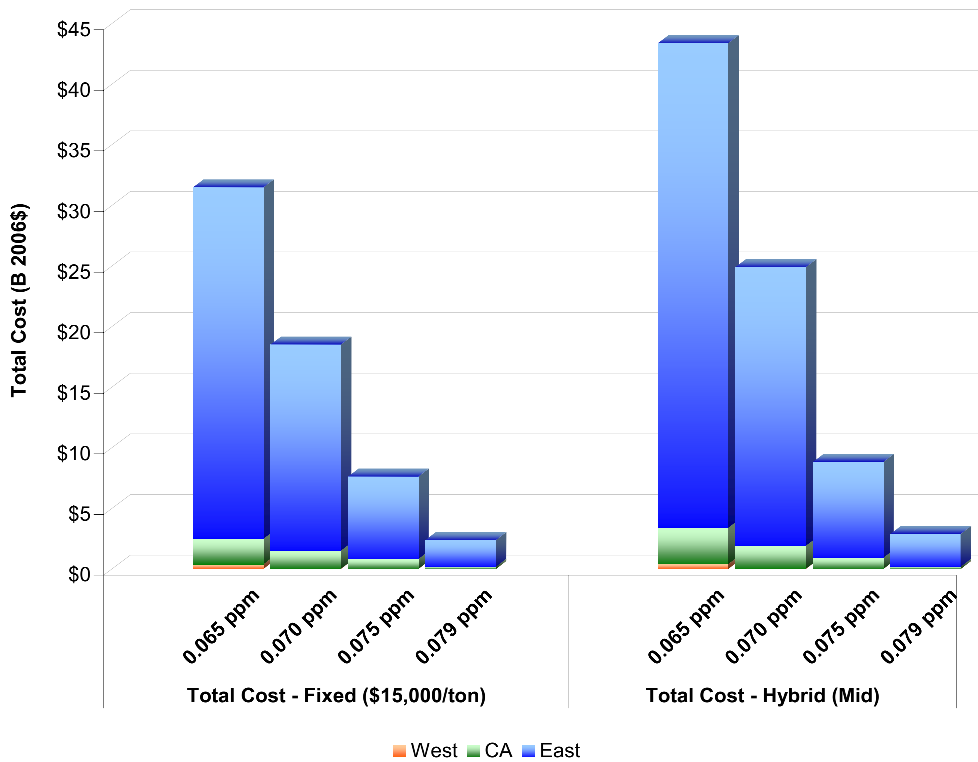
[d] Known control costs for 0.079 ppm and 0.075 ppm include the modeled EGU cap and trade strategy, and therefore contain greater emission reductions than are needed to attain for some geographic areas. Therefore these results represent an overestimate of the costs of attainment.

[e] Known control costs consist of modeled control strategy costs presented in Table 5.1, as well as supplemental costs and "giveback" costs presented in Appendix 5a.4.1 and 5a.4.2.

Our estimates of costs of attainment in 2020 assume a particular trajectory of aggressive technological change. This trajectory leads to a particular level of emissions reductions and costs which we have estimated based on two different approaches, the fixed cost and hybrid approaches. An alternative storyline might hypothesize a much less optimistic technological change path, such that emissions reductions technologies for industrial sources would be more expensive or would be unavailable, so that emissions reductions from many smaller sources might be required for 2020 attainment, at a potentially greater cost per ton. Under this alternative storyline, two outcomes are hypothetically possible: Under one scenario, total costs associated with full attainment might be substantially higher. Under the second scenario, states may choose to take advantage of flexibility in the Clean Air Act to adopt plan with later attainment dates to allow for additional technologies to be developed and for existing programs like EPA's Onroad Diesel, CAIR, Nonroad Diesel, and Locomotive and Marine rules to be fully implemented. If states were to submit plans with attainment dates beyond our 2020 analysis year, benefits would clearly be lower than we have estimated under our analytical storyline. However, in this case, state decision makers, seeking to maximize economic efficiency, would not impose costs, including potential opportunity costs of not meeting their attainment date, when they exceed the expected health benefits that states would realize from meeting their modeled 2020 attainment date. In this case, upper bound costs are difficult to estimate because we do not have an estimate of the point where marginal costs are equal to marginal benefits plus the costs of nonattainment.

Figure 5.8 shows the total costs for both the fixed and hybrid approaches broken out by region.

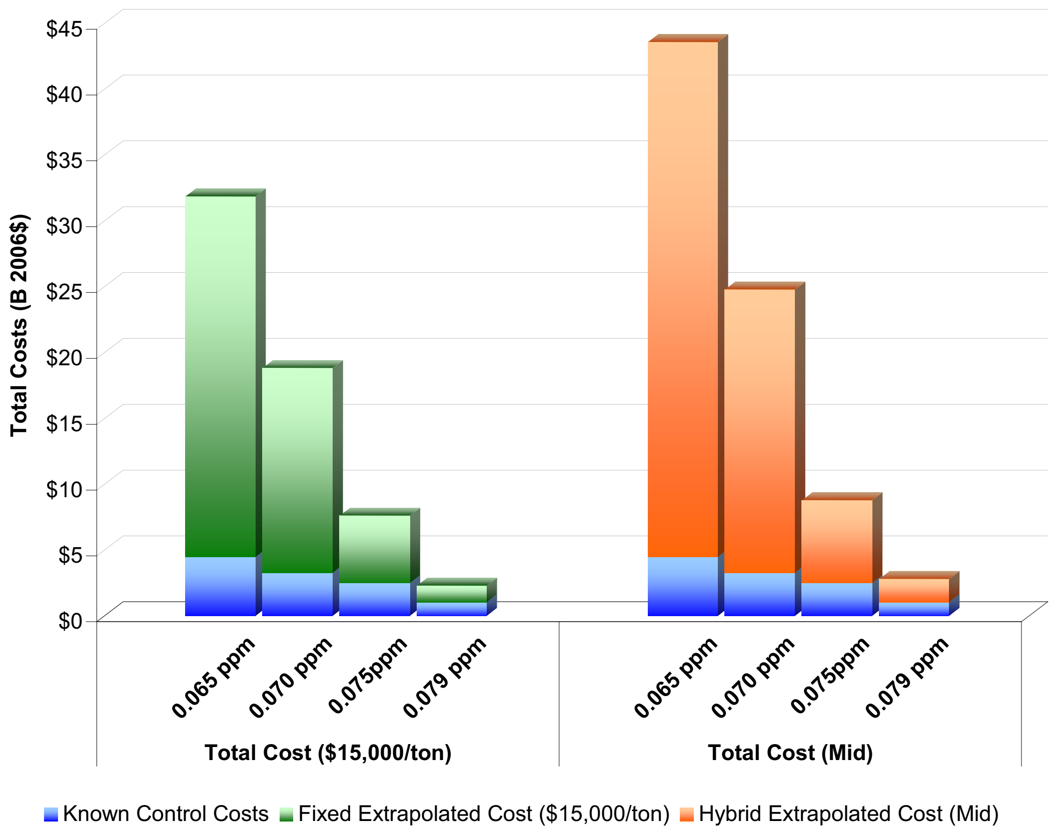
Figure 5.8: Annual Total Costs by Region[a]



[a] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Figure 5.9 separates the total cost under both the fixed and extrapolated cost approaches into the known control costs and the extrapolated costs. This shows graphically the increasing portion of costs that comes from unknown controls as the standard tightens. Depending upon the standard and extrapolated cost methodology (fixed or hybrid) the costs from unknown control technologies ranges from 50% to 89% of the total costs.

Figure 5.9: National Known Control Costs and Extrapolated Costs for Various Standards[a, b]

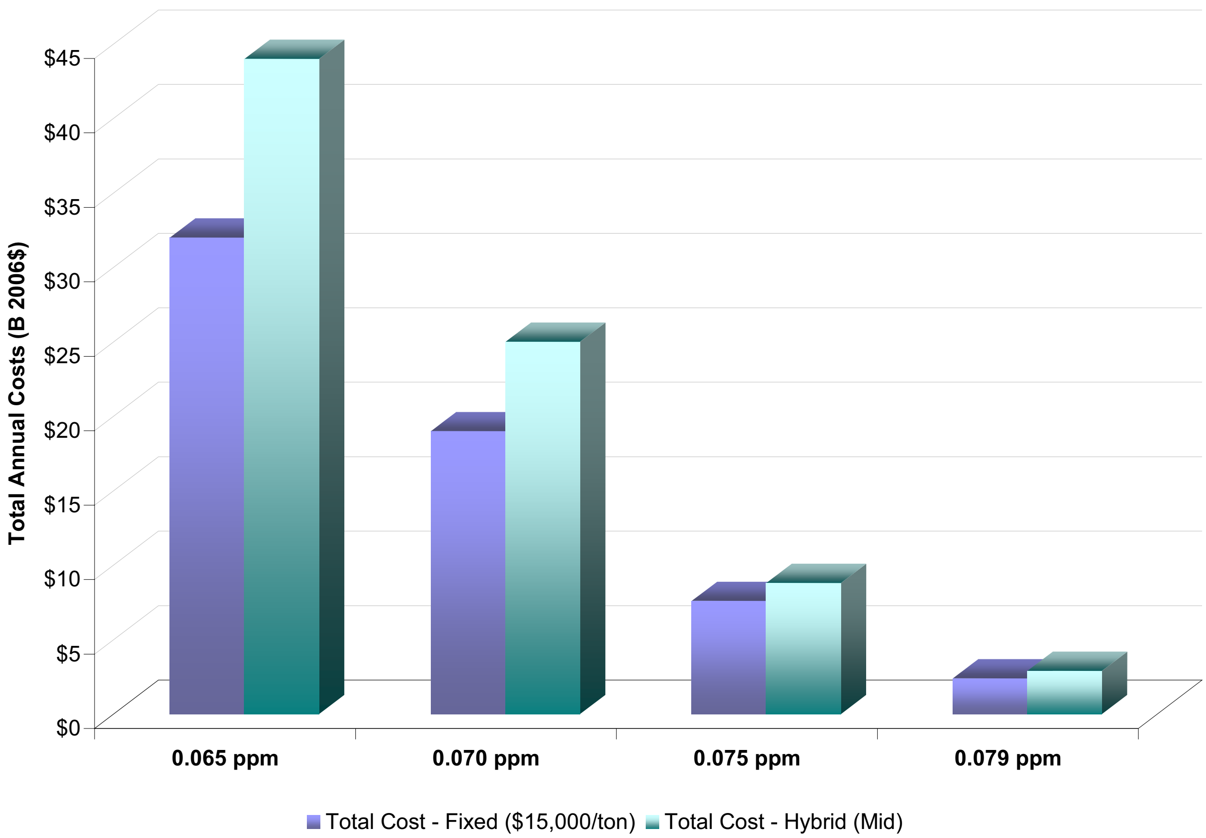


[a] Known control costs consist of modeled control strategy costs presented in Table 5.1, as well as supplemental costs and "giveback" costs presented in Appendix 5a.4.1 and 5a.4.2.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Lastly, Figure 5.10 shows the total cost range by standard. For the final standard of 0.075 ppm the total cost ranges from $7.6 to $8.8 billion.

Figure 5.10: Total Cost Ranges for Various Standards[a]



[a] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

5.4 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.

Technological change will affect baseline conditions for our analysis. This change may lead to potential improvements in the efficiency with which firms produce goods and services, for example, firms may use less energy to produce the same quantities of output. In addition, technological change may result in improvements in the quality of health care, which can have impacts on the baseline health of the population, potentially reducing the susceptibility of the population to the effects of air pollution. While our baseline mortality incidence rates account for

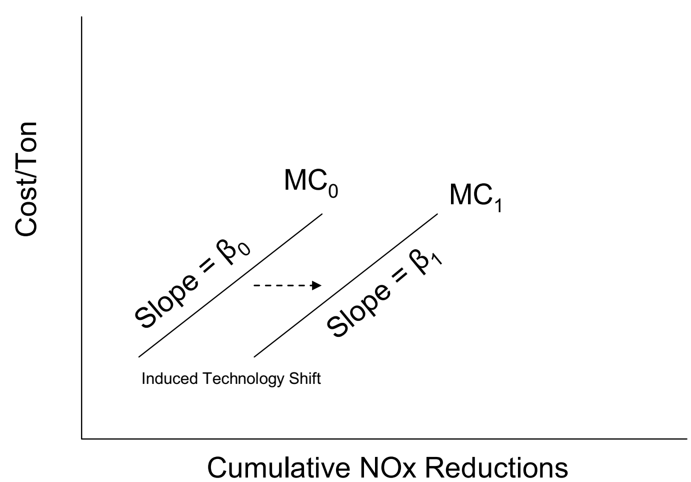
[10] Harrington et al. (2000) and previous studies cited by Harrington.

increasing life expectancy, and thus reflect projected improvements in health care, our baseline incidence rates for other health endpoints such as hospital admissions do not reflect any future

advances in health care, and thus, our estimates of avoided health impacts for these endpoints will potentially be overstated. For other endpoints, such as asthma, there has been an observed upward trend in prevalence, which we have not captured in our incidence rates. For these endpoints, our estimates will potentially be understated. In general, for non-mortality endpoints, there is increased uncertainty in our estimates due to our use of current baseline incidence and prevalence rates.

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 5.11)[11] as well as perhaps a decrease in its slope, reducing marginal costs per unit of abatement, and thus deviate from the assumption of one constantly increasing 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.

Figure 5.11: Technological Innovation Reflected by Marginal Cost Shift



5.4.1 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

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[11] Figure 5.2 shows a linear marginal abatement cost curve. It is possible that the shape of the marginal abatement cost curve is non-linear.

- 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

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.

What is known as “learning by doing” or “learning curve impacts” have 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.

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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.

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:

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

where

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

The percentage adjustments can range from 5 to 20 percent, depending on the sector and technology. Learning curve adjustments were prepared in a memo by IEc (2007) 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 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

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[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.

[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.

our estimates of costs for our control strategies in 2020, but we are not able to include such an analysis in this RIA.

5.4.2 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, such as the time allowed for areas with high levels of ozone pollution to meet the ozone NAAQS, the opportunity for technical advances is greater.

- *Multi-rule study:* Harrington et al. of Resources for the Future (2000) conducted an analysis of the predicted and actual costs of 28 federal and state rules, including 21 issued by EPA and the Occupational Safety and Health Administration (OSHA), and found a tendency for predicted costs to overstate actual implementation costs. Costs were considered accurate if they fell within the analysis error bounds or if they fall within 25 percent (greater or less than) the predicted amount. They found that predicted total costs were overestimated for 14 of the 28 rules, while total costs were underestimated for only three rules. Differences can result because of quantity differences (e.g., overestimate of pollution reductions) or differences in per-unit costs (e.g., cost per unit of pollution reduction). Per-unit costs of regulations were overestimated in 14 cases, while they were underestimated in six cases. In the case of EPA rules, the agency overestimated per-unit costs for five regulations, underestimated them for four regulations (three of these were relatively small pesticide rules), and accurately estimated them for four. Based on examination of eight economic incentive rules, "for those rules that employed economic incentive mechanisms, overestimation of per-unit costs seems to be the norm," the study said.

  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."[15]

  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. Much longer time periods (ranging up to 20 years) are allowed by the statute for meeting the ozone NAAQS in areas with high ozone levels, where a substantial fraction of the estimated cost in this analysis is incurred.

- *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] Note that the original EPA cost analysis also relied on an optimization model like IPM to approximate the results of emissions trading.

[15] Harrington et al., 2000.
[16] Carlson et al., 2000; Ellerman, 2003.

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'sHarrington et al. report that scrubbing turned out to be more efficient (95% removal vs. 80-85% removal) and more reliable (95% vs. 85% reliability) than expected, and that unanticipated opportunities arose to blend low and high sulfur coal in older boilers up to a 40/60 mixture, compared with the 5/95 mixture originally estimated.

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

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

- *EPA Fuel Control Rules:* A 2002 study by two economists with 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:

Table 5.7: Comparison of Inflation-Adjusted Estimated Costs and Actual Price Changes for EPA Fuel Control Rules [A]

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

[a] Anderson et al., 2002.

[17] Anderson et al, 2002.

[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."

- 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 (1997) 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 in 1998 to $3.5k-$5k 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 (ICF, 2005).

We can not estimate the 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.

5.5 References

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.

Babiker, M.H., and T.F. Rutherford. 1997. "Input Output and General Equilibrium Estimates of Embodied CO2: A Data Set and Static Framework for Assessment." University of Colorado at Boulder, Working Paper 97 2. Available at http://debreu.colorado.edu/papers/gtaptext.html.

Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I.S. Wing, and R.C. Hyman. 2001. "The MIT Emissions Prediction and CO2 Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results." MIT Joint Program on the Science and Policy of Global Change, Report No. 71. Available at http://web.mit.edu/globalchange/www/eppa.html.

Bovenberg, L.A., and L.H. Goulder. 1996. "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analysis." American Economic Review 86(4):985-1000. Available at <http://www.aeaweb.org/aer/>.

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[19] Holmstead, 2002.

Brooke, A., D. Kendrick, A. Meeraus, and R. Raman. 1998. GAMS: A User's Guide. GAMS Development Corporation. Available at http://www.gams.com.

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.

Feenberg, D., and E. Coutts. 1993. "An Introduction to the TAXSIM Model." Journal of Policy Analysis and Management 12(1):189 194. Available at http://www.nber.org/~taxsim/.

Fullerton, D., and D. Rogers. 1993. "Who Bears the Lifetime Tax Burden?" Washington, DC: The Brookings Institute. Available at http://bookstore.brookings.edu/ book_details.asp?product%5Fid=10403.

Goulder, L.H., and R.C. Williams. 2003. "The Substantial Bias from Ignoring General Equilibrium Effects in Estimating Excess Burden, and a Practical Solution." Journal of Political Economy 111:898 927. Available at http://www.journals.uchicago.edu/JPE/home.html

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.

Hammit, J.K. (1997). "Are the costs of proposed environmental regulations overestimated? Evidence from the CFC phaseout." Unpublished paper, Center for Risk Analysis, Harvard School of Public Health, Cambridge, MA.

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.

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.

Minnesota IMPLAN Group. 2003. State Level Data for 2000. Available from http://www.implan.com/index.html.

Nestor, D.V., and C.A. Pasurka. 1995. The U.S. Environmental Protection Industry: A Proposed Framework for Assessment. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation. EPA 230-R-95-001. Available at http://yosemite.epa.gov/ee/epa/eermfile.nsf/11f680ff78df42f585256b45007e6235/41b8b642ab9371df852564500004b543/$FILE/EE 0217A 1.pdf.

U.S. Department of Energy, Energy Information Administration. Undated (b). State Energy Price and Expenditure Report. Washington DC. Available at http://www.eia.doe.gov/emeu/states/price_multistate.html.

U.S. Department of Energy, Energy Information Administration. 2001. Manufacturing Energy Consumption Survey 1998. Washington DC. Available at http://www.eia.doe.gov/emeu/mecs/.

U.S. Department of Energy, Energy Information Administration. January 2003. Annual Energy Outlook 2003. DOE/EIA 0383(2003). Washington DC. Available at http://www.eia.doe.gov/oiaf/archive/aeo03/pdf/0383(2003).pdf.

U.S. Department of Energy, Energy Information Administration. January 2004. Annual Energy Outlook 2004. DOE/EIA-0383(2003). Washington, DC. Available at http://www.eia.doe.gov/oiaf/aeo/pdf/0383 (2001).

U.S. Environmental Protection Agency. June 2007. Advisory Council on Clean Air Compliance Analysis (COUNCIL), Council Advisory on OAR's Direct Cost Report and Uncertainty Analysis Plan. Washington, DC. http://www.epa.gov/sab/pdf/council-07-002.pdf.

5a.1 Engineering Cost Information for NonEGU Point and Area Sources

(Full details on controls can be found in Appendix Chapter 3)

5a.1.1 Engineering Costs by Control Measure

Tables 5a.1 and 5a.2 summarize the total incremental annualized engineering costs in 2020 for the modeled control strategy by control measure for nonEGU point and Area sources.

Table 5a.1: NOx NonEGU Point and Area Source Control Measure Annualized Engineering Costs

Control Measure	Source Type	Total Cost (M 2006$)
RACT to 25 tpy (LNB)	Industrial Coal Combustion	$11
	Industrial NG Combustion	$3.3
	Industrial Oil Combustion	$0.98
Switch to Low Sulfur Fuel	Residential Home Heating	$20
Water Heater + LNB Space Heaters	Commercial/Institutional—NG	$7.7
	Residential NG	$12
Biosolid Injection Technology	Cement Kilns	$0.43
LNB	Asphaltic Conc; Rotary Dryer; Conv Plant	$0.39
	Coal Cleaning-Thrml Dryer; Fluidized Bed	$0.79
	Fiberglass Mfg; Textile—Type Fbr; Recup Furn	$1.1
	Fuel Fired Equip; Furnaces; Natural Gas	$0.14
	In-Process Fuel Use; Natural Gas	$4.3
	In-Process Fuel Use; Residual Oil	$0.14
	In-Process; Process Gas; Coke Oven Gas	$0.59
	Lime Kilns	$4.7
	Sec Alum Prod; Smelting Furn	$0.052
	Steel Foundries; Heat Treating	$0.010
	Surf Coat Oper; Coating Oven Htr; Nat Gas	$0.095
LNB + FGR	Fluid Cat Cracking Units	$14
	Fuel Fired Equip; Process Htrs; Process Gas	$3.2
	In-Process; Process Gas; Coke Oven Gas	$3.5
	Iron & Steel Mills—Galvanizing	$0.030
	Iron & Steel Mills—Reheating	$0.58
	Iron Prod; Blast Furn; Blast Htg Stoves	$0.56
	Sand/Gravel; Dryer	$0.049
	Steel Prod; Soaking Pits	$0.11
LNB + SCR	Iron & Steel Mills—Annealing	$1.6
	Process Heaters—Distillate Oil	$38
	Process Heaters—Natural Gas	$420
	Process Heaters—Other Fuel	$110
	Process Heaters—Process Gas	$61
	Process Heaters—Residual Oil	$0.29
NSCR	Rich Burn IC Engines—Gas	$13
	Rich Burn IC Engines—Gas, Diesel, LPG	$2.1
	Rich Burn Internal Combustion Engines—Oil	$6.6
OXY-Firing	Glass Manufacturing—Containers	$5.1

Control Measure	Source Type	Total Cost (M 2006$)
	Glass Manufacturing—Flat	$48
	Glass Manufacturing—Pressed	$22
SCR	Ammonia—NG-Fired Reformers	$10
	Cement Manufacturing—Dry	$120
	Cement Manufacturing—Wet	$93
	IC Engines—Gas	$220
	ICI Boilers—Coal/Cyclone	$2.3
	ICI Boilers—Coal/Wall	$34
	ICI Boilers—Coke	$0.89
	ICI Boilers—Distillate Oil	$12
	ICI Boilers—Liquid Waste	$1.6
	ICI Boilers—LPG	$1.1
	ICI Boilers—Natural Gas	$110
	ICI Boilers—Process Gas	$25
	ICI Boilers—Residual Oil	$31
	Natural Gas Prod; Compressors	$3.3
	Space Heaters—Distillate Oil	$0.088
	Space Heaters—Natural Gas	$2.1
	Sulfate Pulping—Recovery Furnaces	$24
SCR + Steam Injection	Combustion Turbines—Natural Gas	$55
SCR + Water Injection	Combustion Turbines—Oil	$0.69
SNCR	By-Product Coke Mfg; Oven Underfiring	$10
	Comm./Inst. Incinerators	$2.3
	ICI Boilers—Coal/Stoker	$10
	Indust. Incinerators	$0.42
	In-Process Fuel Use; Bituminous Coal	$0.058
	Municipal Waste Combustors	$7.2
	Nitric Acid Manufacturing	$2.5
	Solid Waste Disp; Gov; Other Inc	$0.16
SNCR—Urea	ICI Boilers—MSW/Stoker	$0.29
SNCR—Urea Based	ICI Boilers—Coal/FBC	$0.13
	ICI Boilers—Wood/Bark/Stoker—Large	$8.4
	In-Process; Bituminous Coal; Cement Kilns	$0.33
	In-Process; Bituminous Coal; Lime Kilns	$0.034

Table 5a.2: VOC NonEGU Point and Area Source Control Measure Annualized Engineering Costs

Control Measure	Source	Total Cost (M 2006$)
CARB Long-Term Limits	Consumer Solvents	$320
Catalytic Oxidizer	Conveyorized Charbroilers	$240
Equipment and Maintenance	Oil and Natural Gas Production	$210
Gas Collection (SCAQMD/BAAQMD)	Municipal Solid Waste Landfill	$1.1
Incineration >100,000 lbs bread	Bakery Products	$5.8
Low Pressure/Vacuum Relief Valve	Stage II Service Stations	$16
	Stage II Service Stations—Underground Tanks	$15
OTC Mobile Equipment Repair and Refinishing Rule	Aircraft Surface Coating	$2
	Machn, Electric, Railroad Ctng	$12
OTC Solvent Cleaning Rule	Cold Cleaning	$16
SCAQMD—Low VOC	Rubber and Plastics Mfg	$2.6

Control Measure	Source	Total Cost (M 2006$)
SCAQMD Limits	Metal Furniture, Appliances, Parts	$19
SCAQMD Rule 1168	Adhesives—Industrial	$69
Solvent Utilization	Large Appliances	$4.1
	Metal Furniture	$0.90
	Paper SIC 26	$3.5
Switch to Emulsified Asphalts	Cutback Asphalt	$0
Permanent Total Enclosure (PTE)	Fabric Printing, Coating and Dyeing	$0.069
	Paper and Other Web Coating	$0.85
Petroleum and Solvent Evaporation	Printing and Publishing	$4.4
	Surface Coating	$0.42

5a.1.2 Engineering Costs of Supplemental Controls

5a.1.1.1 Low Emission Combustion (LEC)

The average cost effectiveness for large IC engines using LEC technology was estimated to be $760/ton (ozone season, 2006 dollars).[1] The EC/R report on IC engines (Ec/R, September 1, 2000) estimates the average cost effectiveness for IC engines using LEC technology to range from $600–1,200/ton (ozone season) for engines in the 2,000–8,000 bhp range. The key variables in determining average cost effectiveness for LEC technology are the average uncontrolled emissions at the existing source, the projected level of controlled emissions, annualized costs of the controls, and number of hours of operation in the ozone season. The ACT document uses an average uncontrolled level of 16.8 g/bhp-hr, a controlled level of 2.0 g/bhp-hr (87% decrease), and nearly continuous operation in the ozone season. The EPA believes the ACT document provides a reasonable approach to calculating cost effectiveness for LEC technology.

5a.1.1.2 Leak Detection and Repair (LDAR) for Fugitive Leaks

The control efficiency is 80 percent reduction of VOC at an annualized engineering cost of $6,900 per ton.

5a.1.1.3 Enhanced LDAR for Fugitive Leaks

The control efficiency of this measure is estimated at 50 percent at a engineering cost of $4,360/ton of VOC reduced.[2]

[1] "NOx Emissions Control Costs for Stationary Reciprocating Internal Combustion Engines in the NOx SIP Call States," E.H. Pechan and Associates, Inc., Springfield, VA, August 11, 2000. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/cost/pechan8-11.pdf

5a.1.1.4 Flare Gas Recovery

The control efficiency of this measure is 98 percent reduction of VOC emissions at an annualized engineering cost of $3,860/ton. Costs may become negligible as the size of the flare increases due to recovery credit.[3]

5a.1.1.5 Cooling Towers

There is not a general estimate of control efficiency for this measure; one is to apply a continuous flow monitor until VOC emissions have reached a level of 1.7 tons/year for a given cooling tower.[4] The annualized engineering cost for a continuous flow monitor is $90,000– this is constant over a variety of cooling tower sizes.

5a.1.1.6 Wastewater Drains and Separators

The control efficiency is 65 percent reduction of VOC emissions at an annualized engineering cost of $4,360/ton. This is based on actual sampling and cost data for 5 refineries in the Bay Area Air Quality Management District (BAAQMD).[5]

5a.1.1.7 Work Practices and Use of Low VOC Coatings in Solvent Utilization and Other Processes

The control efficiency is 90 percent reduction of VOC emissions at an engineering cost of $1,200/ton (2006 dollars). This is based on analyzes applied to the 2002 National Emissions Inventory (NEI) and summarized in the proposed CTG for paper, film and foil coatings, metal furniture, and large appliances published by US EPA in July 2007.[6]

5a.2 Engineering Cost Information for EGU Sources

(Full details on controls can be found in Appendix Chapter 3)

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[3] MARAMA Multipollutant Rule Basis for Flares, part of "Assessment of Control Technology Options for Petroleum Refineries in the mid-Atlantic Region." February 19, 2007. Found on the Internet at http://www.marama.org/reports/021907_Refinery_Control_Options_TSD_Final.pdf.

[4] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.

[5] Bay Area Air Quality Management District (BAAQMD). Proposed Revision of Regulation 8, Rule 8: Wastewater Collection Systems. Staff Report, March 17, 2004.

[6] U.S. Environmental Protection Agency. Consumer and Commercial Products: Control Techniques Guidelines in Lieu of Regulations for Paper, Film, and Foil Coatings; Metal Furniture Coatings; and Large Appliance Coatings. 40 CFR 59. July 10, 2007. Available on the Internet at http://www.epa.gov/ttncaaa1/t1/fr_notices/ctg_ccp092807.pdf. It should be noted that this CTG became final in October 2007.

5a.2.1 Cost of Controls as a Result of Lower Nested Caps within the MWRPO, OTC, and East Texas and other Local Controls Outside of these Regions Nationwide

As previously discussed, the power sector will achieve significant emission reductions under the Clean Air Interstate Rule (CAIR) over the next 10 to 15 years. When fully implemented, CAIR (in conjunction with NOx SIP Call) will reduce ozone season NOx emissions by over 60 percent from 2003 levels within the CAIR states. These reductions will greatly improve air quality and will lessen the challenges that some areas face when solving nonattainment issues significantly.

Power sector impacts analyzed in detail in the Final PM NAAQS RIA 15/35 and in the Proposed Ozone NAAQS RIA (http://www.epa.gov/ttn/ecas/ria.html) provides the baseline for this RIA. The analysis and projections in this section attempt to show the potential impacts of the additional controls applied (see section 3.3.3 of this RIA) to facilitate attainment of the more stringent 8-hr ozone standard. Generally, the incremental impacts of these controls on the power sector are marginal.

Projected Costs. EPA projects that the annualized incremental cost of the new ozone standard approach is \$0.15 billion in 2020 (\$2004)[7]. The additional annualized costs reflect additional retrofits (SCR and SNCR) and generation shifts. Annualized cost of CAIR is projected to be \$6.17 billion in 2020 (\$2004). The approach applied in this RIA would add \$0.15 billion incremental to this cost. Annualized cost of the EGU controls (in \$2004) for the entire country for fossil units > 25MW is about \$5,500. Table 5.a3 below summarizes increase in NOx control (SCR and SNCR) capacity.

Table 5a.3: NOx Control (SCR and SNCR) Capacity (GWs)

	Baseline CAIR/CAMR/CAVR	Modeled Control Strategy
Retrofits (GWs)		
SCR	57.0	66.4
SNCR	2.1	4.5
Total Controls (GWs) (Existing + Retrofits + New Units)		
SCR	219.6	229.9
SNCR	11.8	15.0

Projected Generation Mix. Coal-fired generation and natural gas/oil-fired generation are projected to remain almost unchanged. Installation of approximately 9.4 GWs of SCR and 2.4 GWs of SNCR incremental to the base case are projected as a result of the lower sub-regional caps. There are very small changes in the generation mix. Coal-fired generation decreases about 6,000 GWh (a decrease of approximately 0.1% of the total generation) and gas-fired generation increases a similar amount. Hydro, nuclear, other, and renewable based generation projected to remain the same. Projected retirements of both coal and oil/gas units remained same compared to the base case approach.

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[7] IPM calculates costs in 2004\$. All costs presented in Chapter 5 are in 2006\$. The costs presented here were converted to 2006\$ prior to being compared or added to other control measure costs.

Projected Nationwide Retail Electricity Prices. Retail electricity prices are projected to decrease marginally, about 1%. The extension of the cap-and-trade approach in the form of lower sub-regional caps allows industry to meet the requirements of CAIR in the most cost-effective manner, thereby minimizing the costs passed on to consumers. Retail electricity prices are projected to increase less than 1% within the MWRPO, OTC, and East Texas, and decrease elsewhere.

5a.3 Engineering Cost Information for Onroad and Nonroad Mobile Sources

(Full details on controls can be found in Appendix Chapter 3)

Table 5a.4 and 5a.5 summarize the total incremental engineering costs for the modeled control strategy by mobile source control measure.

Table 5a.4: NOx Mobile Modeled Control Strategy Incremental Annualized Engineering Costs by Control Measure

Sector	Control Measure	Total Cost (M$)
Onroad	Eliminate Long Duration Idling	$—
	Low RVP	$—
	Onroad Retrofit	$280
	Continuous Inspection and Maintenance	$—
	Commuter Programs	$79
Nonroad	Nonroad Retrofit	$150

Table 5a.5: VOC Mobile Modeled Control Strategy Incremental Annualized Engineering Costs by Control Measure

Sector	Control Measure	Total Cost (M$)
Onroad	Low RVP	$95
	Onroad Retrofits	$—
	Continuous Inspection and Maintenance	$—
	Commuter Programs	$—
Nonroad	Low RVP	$36
	Nonroad Retrofits & Engine Rebuilds	$—
	International Aircraft NOx Standard	$—

5a.3.1 Diesel Retrofits and Engine Rebuilds

To calculate engineering costs for the use of selective catalytic reduction as a retrofit technology, the assumption was made that all relevant vehicles would be affected by the control. Therefore, all on-road heavy duty diesel vehicles that received a retrofit were assumed to employ selective catalytic reduction as a retrofit technology. The average cost of a selective catalytic reduction system ranges from $10,000 to $20,000 per vehicle depending on the size of the engine, the sales volume, and other factors. One study calculated the average estimated cost of this system to be $15,000 per heavy duty diesel vehicle. (Source: AirControlNET Documentation, III-160). OTAQ conducted an additional assessment of current SCR costs and calculated that for the year 2020, the cost of SCRs will be approximately $13,000 per unit. This estimate reflects an economy of scale cost reduction of 33%, which is consistent with trends in other mobile source control technologies that enter large scale production[8].

The rebuild/upgrade kit is applied to nonroad equipment. OTAQ estimates the engineering cost of this kit to be $2,000 to $4,000 per vehicle. For this analysis, the average estimated cost is $3,000 per vehicle.

The cost effectiveness numbers are presented in Tables 5a.6, 5a.7, and 5a.8.

Table 5a.6: Summary of Cost Effectiveness for Rebuild/Upgrade Kit for Various Nonroad Vehicles

Nonroad Vehicle	Retrofit Technology	Range of $/ton NOx Emission Reduced		Range of $/ton HC Emission Reduced	
Tractors/Loaders/Backhoes	Rebuild/ Upgrade kit	$1,300	$2,200	$9,600	$18,900
Excavators		$1,100	$4,200	$8,100	$43,400
Crawler Tractor/Dozers		$1,100	$4,200	$8,300	$43,500
Skid Steer Loaders		$1,000	$1,600	$7,400	$14,800
Agricultural Tractors		$1,200	$4,900	$9,300	$34,300

Table 5a.7: Summary of Cost Effectiveness for SCR for Various Nonroad Vehicles

Nonroad Vehicle	Retrofit Technology	Range of $/ton NOx Emission Reduced		Range of $/ton HC Emission Reduced	
Tractors/Loaders/Backhoes	SCR	$2,900	$5,300	$32,200	$63,700
Excavators		$2,700	$10,400	$27,400	$146,200
Crawler Tractor/Dozers		$2,800	$10,400	$27,900	$146,700
Skid Steer Loaders		$2,600	$4,000	$24,900	$52,100
Agricultural Tractors		$3,000	$7,600	$31,200	$115,500

Table 5a.8: Summary of Cost Effectiveness for SCR for Various Highway Vehicles

Highway Vehicle	Retrofit Technology	Range of $/ton NOx Emission Reduced		Range of $/ton HC Emission Reduced	
Class 6&7 Truck	SCR	$5,600	$14,100	$46,900	$126,200
Class 8b Truck		$1,100	$2,500	$14,900	$44,600

5a.3.2 Implement Continuous Inspection and Maintenance Using Remote Onboard Diagnostics (OBD)

Continuous I/M can significantly lower test costs and "convenience" costs of I/M programs. Using the radio-frequency approach as an example, the costs of periodic testing to Remote OBD can be compared. Note that this is just an example to illustrate the difference in cost of traditional

[8] The expected emissions reductions from SCR retrofits are based on data derived from EPA regulations (Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-duty Highway Engines and Vehicles published October 2000), interviews with component manufacturers, and EPA's Summary of Potential Retrofit Technologies available at www.epa.gov/otaq/retrofit/retropotentialtech.htm.

periodic I/M and Remote OBD. In this scenario, the assumption is that all 1996 and newer vehicles currently subject to I/M will participate in a mandatory Remote OBD program. The national fleet of vehicles subject to I/M are considered over a 10 year period a static set of vehicles. The estimated cost of setting up and maintaining a data processing and reporting system is shown in Table 5a.9 and ranges from 50¢ to $3.00 per vehicle in the program per year.[9] For the purposes of this example, we will assume $1 to $3 per vehicle per year. These estimates assume one record per vehicle per month is actually stored (although additional readings will usually be taken since vehicles will routinely pass receivers many times a month). This cost does not include installing Remote OBD on the vehicle or the network of receivers to pick up signals from equipped vehicles, which is covered by the $50 fee discussed above. If we assume an average vehicle life span of 14 years,[10] with the first test at 4 years of age, the typical vehicle will get 5 inspections in a biennial program and 10 in an annual program (not including additional change of ownership inspections, which are required in some areas). Thus, in a Remote OBD program, an additional cost of $10–$30 will be incurred for each vehicle over its life to cover data processing and reporting.

Table 5a.9: Remote OBD VID Service Cost Estimate Per Vehicle Per Year

Number of Vehicles in Remote OBD Program	Level 1 Database Design, Installation, Maintenance, and Communications	Level 2 Add Reporting	Level 3 Add Auditing
250,000	$1.50	$2.00	$3.00
250,001–500,000	$1.00	$1.50	$2.75
500,001–1,500,000	$0.75	$1.00	$2.50
>1,500,000	$0.50	$0.75	$2.00

In addition to test costs, Remote OBD avoids most of the consumer convenience and indirect costs associated with I/M—the time and fuel it takes to drive to the station, get a test, and return home. The one-time installation of the transmitter requires a visit to the test station, but no further visits are required. Hard data are not available on the actual average time motorists spend driving to a test station, getting a test, and returning to their point of origin or to their next stop in a trip chain. In some centralized programs, wait times can be very long. In decentralized programs, motorists often drop off their vehicle (requiring two trips to the test station). For the sake of illustrating the convenience costs associated with I/M, a reasonable range for the typical test cycle is one to two hours. If we assign a cost of $20 per hour[11] and a half-gallon of gas (10 miles round trip with an average fuel economy of 20 mpg) at $3 per gallon, the total cost of the typical cycle is $21.50 to $41.50. Over the life of the vehicle, this would amount to $104 to $208 in a biennial program or $208 to $415 in an annual program. Compare this to the one time installation trip for Remote OBD at a cost of $21.5 to $41.50, it is clear that substantial savings are realized.

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[9] Table provided by Systech International, Inc. and Gordon-Darby, Inc. It should be noted that careful design of the data management system is necessary to achieve these cost levels.
[10] Greenspan, A. & D. Cohen, *Motor Vehicle Stocks, Scrappage, and Sales*; October 1996
[11] This is the same dollar amount assumed in EPA's original Technical Support Document published along with the 1992 Enhanced I/M Rule.

For the purposes of illustrating the nationwide costs and benefits of doing remote OBD, the following analysis assumes 100% participation. It is likely, however, that in the short run states will gradually introduce remote OBD initially on a voluntary basis (except possibly for fleets), and that participation rates will build over time as motorists recognize the cost and convenience advantages. Another caveat is that those states that require motorists to get safety checks, the convenience costs may not be fully realized (see Discussion of Issues, below). Table 5a.10 shows the lifetime inspection and convenience costs of a mandatory, nationwide remote OBD program versus a periodic OBD program (assuming the current nationwide mix of annual and biennial testing and current test costs; see Appendix 3) for a static fleet of about 80 million vehicles. Note that in reality, fleet size generally grows over time and vehicles come and go. Thus, this is a simplifying assumption for the purposes of illustrating the comparative costs. The "low" and "high" refer to the range of convenience costs (1 to 2 hours) and oversight costs in the case of Remote OBD ($1–$3). Current periodic OBD testing costs about $12 billion[12] over a 10-year lifecycle with an additional $9 to $17 billion in convenience costs for a total of $21 to $29 billion. By contrast, Remote OBD has a test and install cost of $4 to $5 billion over the same 10 year period, and a convenience cost of $1 to $2 billion for a total of about $5 to $7 billion. Thus, nationwide installation of Remote OBD would save the nation's motorists about $16 to $22 billion in inspection and convenience costs over a 10 year period.

Table 5a.10: Range of Lifetime Inspection and Convenience Costs of I/M

		Periodic OBD ($B 2006)	Remote OBD ($B 2006)	Savings ($B 2006)
Test/Install Cost	Low	$12	$4	$8
	High	$12	$5	$7
Convenience Cost	Low	$9	$1	$8
	High	$17	$2	$15
Total	Low	$21	$5	$16
	High	$29	$7	$22

Given that Continuous I/M will actually reduce the cost of I/M, implementation of this measure is highly cost-effective. More information on I/M can be found at http://www.epa.gov/otaq/regs/im/im-tsd.pdf and www.epa.gov/obd/regtech/inspection.htm.

Cost-Effectiveness of Measure: $0/ton NOx

5a.3.3 Eliminating Long Duration Truck Idling

For purposes of this RIA, we identified this measure as a no cost strategy i.e., $0/ton NOx. Both TSEs and MIRTs have upfront capital costs, but these costs can be fully recovered by the fuel savings. The examples below illustrate the potential rate of return on investments in idle reduction strategies.

[12] Test volumes and costs were derived from Sierra Research's annual I/M summary for 2005 and updated in some cases by members of the workgroup.

Truck Stop Electrification

The average price of TSE technology is $11,500 per parking space. The average service life of this technology is 15 years. Truck engines at idle consume approximately 1 gallon per hour of idle. Current TSE projects are operating in environments where trucks are idling, on average, for 8 hours per day per space for 365 days per year (or about 2,920 hours per year). Since TSE technology can completely eliminate long duration idling at truck spaces (i.e., a 100% fuel savings), this translates into 2,920 gallons of fuel saved per year per space. At current diesel prices ($2.90/gallon), this fuel savings translates into $8,468. Therefore, an $11,500 capital investment should be recovered within about 17 months. In this scenario, TSE investments offer over a 70% annual rate of return over the life of the technology.

While it is technically feasible to electrify all parking spaces that support long duration idling trucks, we should note that TSE technology is generally deployed at a minimum of 25-50 parking spaces per location to maximize economies of scale. The financial attractiveness of installing TSE technology will depend on the demonstrated truck idling behavior—the greater the rates of idling, the greater the potential emissions reductions and associated fuel and cost savings.

Mobile Idle Reduction Technologies

The price of MIRT technologies ranges from $1,000-$10,000. The most popular of these technologies is the auxiliary power unit (APU) because it provides air conditioning, heat, and electrical power to operate appliances. The average price of an APU is $7,000. The average service life of an APU is 10 years. An APU consumes two-tenths of a gallon per hour, so the net fuel savings is 0.80 gallons per hour. EPA estimates that trucks idle for 7 hours per rest period, on average, and about 300 days per year (or 2,100 hours per year). Since idling trucks consume 1 gallon of fuel per hour of idle, APUs can reduce fuel consumption for truck drivers/owners by approximately 1,680 gallons per year. At current diesel prices ($2.90/gallon), truck drivers/owners would save $4,872 on fuel if they used an APU. Therefore, a $7,000 capital investment should be recovered within about 18 months. In this scenario, APU investments offer almost a 70% annual rate of return over the life of the technology.

Cost-Effectiveness of Measure: $0/ton NOx

5a.3.4 Commuter Programs

We used the Transportation Research Board's (TRB) cost-effectiveness analysis of Congestion Mitigation and Air Quality Improvement Program (CMAQ) projects to estimate the cost-effectiveness of this measure.[13] TRB conducted an extensive literature review and then synthesized the data to develop comparable estimates of cost-effectiveness of a wide range of CMAQ-funded measures. We took the average of the median cost-effectiveness of a sampling of

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[13] Transportation Research Board, National Research Council, 2002. *The Congestion Mitigation and Air Quality Improvement Program: assessing 10 years of experience*, Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program.

CMAQ-funded measures and then applied this number to the overarching commuter reduction measure. The CMAQ-funded measures we selected were:

- regional rideshares
- vanpool programs
- park-and-ride lots
- regional transportation demand management
- employer trip reduction programs

We felt that these measures were a representative sampling of commuter reduction incentive programs. There is a great deal of variability, however, in the type of programs and the level of incentives that employers offer which can impact both the amount of emissions reductions and the cost of commuter reduction incentive programs.

We chose to apply the resulting average cost-effectiveness estimate to one pollutant—NO_x—in order to be able to compare commuter reduction programs to other NO_x reduction strategies. TRB reported the cost-effectiveness of each measure, however, as a $/ton reduction of both VOC and NOx by applying the total cost of the program to a 1:4 weighted sum of VOC and NOx [[total emissions reduction = (VOC * 1) + (NO_x * 4)). There was not enough information in the TRB study to isolate the $/ton cost-effectiveness for just NO_x reductions, so we used the combined NO_x and VOC estimate. The results are presented in Table 5a.11.

Table 5a.11: Cost-Effectiveness of Best Workplaces for Commuters Type Measures from the 2002 TRB Study

	$/ton (2000$) 1:4 VOC:NOx (reported in the RIA as $/ton NOx)		
	Low	**High**	**Median**
Regional Rideshare	$1,200	$16,000	$7,400
Vanpool Programs	$5,200	$89,000	$10,500
Park-and-ride lots	$8,600	$70,700	$43,000
Regional TDM	$2,300	$33,200	$12,500
Employer trip reduction programs	$5,800	$175,500	$22,700
Average of All Measures	$4,620	$76,900	$19,200

Cost-Effectiveness of Measure: $19,200/ton NOx

5a.3.5 Reduce Gasoline RVP from 7.8 to 7.0

Michigan has conducted the most recent study on the cost of reducing RVP to 7.0. The analysis was undertaken as part of their proposed revision to Michigan's SIP for their 7.0 low vapor pressure request for Southeast Michigan. According to their analysis, the costs of the program are:

- 0.6–3.0¢ per gallon
- \$1–\$11 per vehicle per year
- Total annual cost =\$6.9–\$48.1 million

Cost-Effectiveness of Measure: Cost per ton will be \$5,700 to \$36,000 / ton VOC

For more information on RVP:

- Michigan Department of Environmental Quality and Southeast Michigan Council of Governments. *Proposed Revision to State of Michigan State Implementation Plan for 7.0 Low Vapor Pressure Gasoline Vapor Request for Southeast Michigan*. May 24, 2006.
- U.S. EPA. *Guide on Federal and State Summer RVP Standards for Conventional Gasoline Only*. EPA420-B-05-012. November 2005

5a.3.6 Aircraft Engine NOx Standard

The Committee on Aviation Environmental Protection (CAEP) is a committee within the International Civil Aviation Organization (ICAO) that makes recommendations to the ICAO for environmental standards for aircraft. ICAO is a United Nations body that sets voluntary international standards for aircraft. Manufacturers in the U.S. and other countries generally comply with these standards. A few years ago, ICAO set a new standard (CAEP/6) for NOx emissions from commercial aircraft to reduce emissions 12% compared to the existing standard. Compliance with this standard is reflected in the analysis. No costs are attributed to EPA rulemaking.

5a.4 Characterization of Unknown Controls

5a.4.1 Supplemental Control Information

Supplemental emission controls came from a variety of sources. The 0.065 ppm standard geographic areas were broader than those for the modeled control strategy; therefore additional local known controls were available for mobile sources as well as nonEGU point and Area. In addition, supplemental controls were achieved through controls applied to select natural gas and oil fired electric generating units. Other supplemental controls applied to nonEGU point and Area sources are described in the appendix to Chapter 3 (3a.1.6 Supplemental Controls). Lastly, for the Eastern Lake Michigan area, the cut point for applying VOC controls was raised from \$5,000/ton (2006\$) to \$15,000/ton (2006\$). Table 5a.12 summarizes the emission reductions achieved through the application of supplemental control measures. The total annualized cost of these measures is broken down by extrapolated cost area in Table 5a.13 and is presented at a seven percent discount rate.

Table 5a.12: Supplemental Local Control Measure Emission Reductions [annual tons/year] Applied for Various Standards[a]

2020 Extrapolated Cost Area	0.065 ppm		0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC	NOX	VOC
Ada Co., ID	2,600	340						
Atlanta, GA	16,000	3,500						
Baton Rouge, LA	8,300	23	7,200					
Boston-Lawrence-Worcester, MA	5,200	3,600						
Buffalo-Niagara Falls, NY	630	140	190					
Campbell Co., WY	2,600	69						
Charlotte-Gastonia-Rock Hill, NC-SC	15,000	3,300						
Cincinnati-Hamilton, OH-KY-IN	9,400	3,700						
Cleveland-Akron-Lorain, OH	5,100	390	2,400					
Dallas-Fort Worth, TX	5,100		3,100					
Denver-Boulder-Greeley-Ft Collins-Love, CO	7,000	4,300						
Detroit-Ann Arbor, MI	2,100		2,100					
Dona Ana CO., NM	560	200						
Eastern Lake Michigan, IL-IN-WI	33,000	82,000	29,000	75,000	29,000	74,000	8,200	9,800
El Paso Co., TX	1,700							
Houston, TX	49		53					
Huntington-Ashland, WV-KY	21,000	1,200						
Jackson Co., MS	7,800	410						
Jefferson Co, NY	1,100	710						
Las Vegas, NV	1,000	1,300						
Memphis, TN-AR	14,000	1,100						
Norfolk-Virginia Beach-Newport News	9,100	2,400						
Northeast Corridor, CT-DE-MD-NJ-NY-PA	9,500	750	8,100		7,600			
Phoenix-Mesa, AZ	5,000	3,300						
Pittsburgh-Beaver Valley, PA	4,500	1,400						
Richmond-Petersburg, VA	820	530						
Sacramento Metro, CA	5,600		5,600		5,600		5,600	
Salt Lake City, UT	3,600	2,200						
San Juan Co., NM	16,000	190						
St Louis, MO-IL	18,000	3,400						
Toledo, OH	180	50						
TOTAL by Pollutant	**230,000**	**120,000**	**58,000**	**75,000**	**42,000**	**74,000**	**14,000**	**9,800**

[a] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

Table 5a.13: Supplemental Local Control Measure Total Annualized Costs [M 2006$] Applied for Various Standards (ppm) [a]

2020 Extrapolated Cost Area	0.065 ppm		0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC	NOX	VOC
Ada Co., ID	$6.0	$0.8						
Atlanta, GA	$44	$5.8						
Baton Rouge, LA	$52	$0.1	$48					
Boston-Lawrence-Worcester, MA	$13	$1.7						
Buffalo-Niagara Falls, NY	$2.6	$0.3	$0.9					
Campbell Co., WY	$10	$0.2						
Charlotte-Gastonia-Rock Hill, NC-SC	$50	$7.6						
Cincinnati-Hamilton, OH-KY-IN	$30	$7.1						
Cleveland-Akron-Lorain, OH	$27	$1.0	$13					
Dallas-Fort Worth, TX	$16		$15					
Denver-Boulder-Greeley-Ft Collins-Love, CO	$20	$4.9						
Detroit-Ann Arbor, MI	$10		$10					
Dona Ana CO., NM	$1.9	$0.7						
Eastern Lake Michigan, IL-IN-WI	$130	$750	$120	$690	$120	$680	$33	$100
El Paso Co., TX	$8.1							
Houston, TX	$0.7		$0.6					
Huntington-Ashland, WV-KY	$81	$3.40						
Jackson Co., MS	$37	$1.50						
Jefferson Co, NY	$3.9	$1.20						
Las Vegas, NV	$3.6	$4.50						
Memphis, TN-AR	$46	$2.40						
Norfolk-Virginia Beach-Newport News	$23	$3.50						
Northeast Corridor, CT-DE-MD-NJ-NY-PA	$60	$0.99	$55		$52			
Phoenix-Mesa, AZ	$7.9	$6.80						
Pittsburgh-Beaver Valley, PA	$19	$3.10						
Richmond-Petersburg, VA	$2.0	$1.20						
Sacramento Metro, CA	$13		$13		$13		$13	
Salt Lake City, UT	$11	$1.70						
San Juan Co., NM	$54	$0.52						
St Louis, MO-IL	$72	$4.80						
Toledo, OH	$0.6	$0.17						
TOTAL by Pollutant	**$860**	**$820**	**$280**	**$690**	**$190**	**$680**	**$46**	**$100**
TOTAL COSTS	**$1,680**		**$970**		**$870**		**$146**	

[a] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

5a.4.2 Modeled Control Strategy Costs Not Needed

As presented in Chapter 4, there were areas in our Modeled control strategy that were “over controlled.” Table 4.8 provides the amount of emissions that were not needed to meet the various ozone standards in 2020. Given these targets, the modeled control strategy emission reductions were analyzed to asses what measures could be removed. Table 5a.14 and 5a.15 respectively, show the amount of emission reductions and costs that were removed from the analysis. It was not possible in all extrapolated cost areas to remove all the emissions presented in Table 4.8. This was due to the nature of the EGU trading program, as well as the application of measures statewide for mobile sources. The emission reductions that were not able to be removed from the analysis of attainment for these standards is presented in Table 5a.16. it is important to note that since there was “over control” for 0.070ppm, 0.075 ppm, and 0.079ppm, the full costs of attainment of these levels of the standard will be an overestimate.

Table 5a.14: Modeled Control Strategy Control Measure Emissions Reductions [annual tons/year] removed from Extrapolated Analysis for Various Standards

2020 Extrapolated Cost Area	0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC
Allegan Co., MI			2,600	240	2,600	240
Atlanta, GA	22,000	3,400	22,000	3,400	22,000	3,400
Baton Rouge, LA			81,000		110,000	1,300
Boston-Lawrence-Worcester-Portsmouth, MA-NH			12,000	3,800	12,000	3,800
Buffalo-Niagara Falls, NY			6,000	1,300	7,000	1,400
Charlotte-Gastonia-Rock Hill, NC-SC	3,200		14,000		14,000	
Cincinnati-Hamilton, OH-KY-IN	29,000	4,000	29,000	4,000	31,000	4,100
Cleveland-Akron-Lorain, OH			24,000	4,100	30,000	4,600
Dallas-Fort Worth, TX			25,000	1,800	25,000	1,800
Denver, CO	12,000	3,600	15,000	4,100	15,000	4,100
Detroit-Ann Arbor, MI			30,000	3,600	30,000	3,600
Eastern Lake Michigan, IL-IN-WI-MI			83	8	83	8
Hancock, Knox, Lincoln & Waldo Cos, ME	7,800		9,300	460	9,300	460
Houston-Galveston-Brazoria, TX						
Huntington-Ashland, WV-KY	1,200	84	1,200	84	1,200	84
Indianapolis, IN	760	190	760	190	760	190
Jefferson Co., NY			1,200	630	1,700	660
Las Vegas, NV			1,500	1,300	1,800	1,300
Muskegon Co., MI	290	90	420	100	420	100
Norfolk-Virginia Beach-Newport News, VA	530		640	85	780	93
Northeast Corridor, CT-DE-DC-NY-NJ-PA-VA					87,000	19,000
Phoenix, AZ	7,600	3,200	7,600	3,200	7,600	3,200
Pittsburgh-Beaver Valley, PA	17,000		23,000	1,500	25,000	1,700
Providence (All RI), RI	1,500	690	1,500	690	1,500	690
Richmond-Petersburg, VA	310		310	58	300	64
Salt Lake City, UT	7,400	2,100	7,400	2,100	7,400	2,100
St Louis, MO-IL	29,000	3,300	29,000	3,300	29,000	3,300
Toledo, OH	1,500	42	1,500	42	1,600	49
Rest of VA					910	50
Rest of OH					46	4
Rest of MI			420	35	420	35
Rest of NY					110	9
Rest of KY	1,100	82	1,100	82	1,100	82
Rest of PA					180	14
TOTALS	**140,000**	**21,000**	**350,000**	**40,000**	**470,000**	**62,000**

Table 5a.15: Modeled Control Strategy Control Measure Annualized Total Costs [M 2006$] Removed from Extrapolated Analysis for Various Standards

2020 Extrapolated Cost Area	0.070 ppm		0.075 ppm		0.079 ppm	
	NOX	VOC	NOX	VOC	NOX	VOC
Allegan Co., MI			$10	$0.9	$10	$0.9
Atlanta, GA	$66	$5.7	$66	$5.7	$66	$5.7
Baton Rouge, LA			$180		$490	$4.1
Boston-Lawrence-Worcester-Portsmouth, MA-NH			$32	$2.8	$32	$2.8
Buffalo-Niagara Falls, NY			$17	$2.3	$20	$2.3
Charlotte-Gastonia-Rock Hill, NC-SC	$3.8		$33		$33	
Cincinnati-Hamilton, OH-KY-IN	$99	$9.0	$99	$9.0	$110	$9.0
Cleveland-Akron-Lorain, OH			$110	$12	$130	$12
Dallas-Fort Worth, TX			$80	$2.1	$80	$2.1
Denver, CO	$41	$4.8	$49	$4.8	$49	$4.8
Detroit-Ann Arbor, MI			$130	$12	$130	$12
Eastern Lake Michigan, IL-IN-WI-MI			$0.2		$0.2	
Hancock, Knox, Lincoln & Waldo Cos, ME	$19		$24	$0.9	$24	$0.9
Houston-Galveston-Brazoria, TX						
Huntington-Ashland, WV-KY	$4.8	$0.2	$4.8	$0.2	$4.8	$0.2
Indianapolis, IN	$3.4	$0.8	$3.4	$0.8	$3.4	$0.8
Jefferson Co., NY			$4.5	$1.2	$5.8	$1.2
Las Vegas, NV			$4.7	$4.4	$5.8	$4.4
Muskegon Co., MI	$0.9	$0.4	$1.2	$0.4	$1.2	$0.4
Norfolk-Virginia Beach-Newport News, VA	$1.4		$2.1	$0.3	$2.6	$0.3
Northeast Corridor, CT-DE-DC-NY-NJ-PA-VA					$300	$21
Phoenix, AZ	$20	$6.7	$20	$6.7	$20	$6.7
Pittsburgh-Beaver Valley, PA	$48		$82	$3.9	$89	$3.9
Providence (All RI), RI	$3.0	$0.3	$3.0	$0.3	$3.0	$0.3
Richmond-Petersburg, VA	$0.6		$0.6	$0.3	$0.8	$0.3
Salt Lake City, UT	$18	$1.7	$18	$1.7	$18	$1.7
St Louis, MO-IL	$130	$4.9	$130	$4.9	$130	$4.9
Toledo, OH	$6.0	$0.2	$6.0	$0.2	$6.3	$0.2
Rest of VA					$2.7	
Rest of OH					$0.2	
Rest of MI			$1.2		$1.2	
Rest of NY					$0.3	
Rest of KY	$3.1		$3.1		$3.1	
Rest of PA					$0.5	
TOTAL by Pollutant	**$460**	**$35**	**$1,100**	**$78**	**$1,800**	**$100**
TOTAL	**$500**		**$1,200**		**$1,900**	

Table 5a.16: Emission Reductions Not Needed [annual tons/year] Remaining After Removing Control Measures Not Needed to Meet Various Ozone Standards [a]

2020 Extrapolated Cost Area	0.070 ppm	0.075 ppm	0.079 ppm
	NOX	NOX	NOX
Allegan Co., MI		460	460
Atlanta, GA	8,700	8,700	8,700
Baton Rouge, LA		(1)	7,606
Boston-Lawrence-Worcester-Portsmouth, MA-NH		1,800	1,800
Buffalo-Niagara Falls, NY		1,000	
Charlotte-Gastonia-Rock Hill, NC-SC	(10)	(40)	(40)
Cincinnati-Hamilton, OH-KY-IN	12,000	12,000	9,000
Cleveland-Akron-Lorain, OH		8,900	14,100
Dallas-Fort Worth, TX		18,000	18,000
Denver, CO	4,300	11,000	11,000
Detroit-Ann Arbor, MI		20,000	20,000
Eastern Lake Michigan, IL-IN-WI-MI			
Hancock, Knox, Lincoln & Waldo Cos, ME	2	6	6
Houston-Galveston-Brazoria, TX			
Huntington-Ashland, WV-KY	10	10	10
Indianapolis, IN	5,800	5,800	5,800
Jefferson Co., NY		700	250
Las Vegas, NV		6,400	6,100
Muskegon Co., MI	130	0	0
Norfolk-Virginia Beach-Newport News, VA	(8)	140	
Northeast Corridor, CT-DE-DC-NY-NJ-PA-VA			11,242
Phoenix, AZ	(90)	(90)	(90)
Pittsburgh-Beaver Valley, PA	(6)	6,700	4,400
Providence (All RI), RI	(4)	(4)	(4)
Richmond-Petersburg, VA	(5)	(5)	8
Salt Lake City, UT			
St Louis, MO-IL	2	1,200	1,200
Toledo, OH	110	110	
TOTALS	**30,000**	**100,000**	**120,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

5a.4.3 Fixed Cost Approach Detailed Results and Sensitivities

The range of values from the fixed cost ($10,000/ton) to the fixed cost ($20,000/ton) is presented in Figure 5a.1. You can see that as the amount of unknown emissions increases for the alternate primary standards, the range of total extrapolated cost values becomes larger. The detailed costs by geographic area and alternate primary standard are presented in Tables 5a.17 through 5a.20.

Figure 5a.1: Fixed Cost Approach Sensitivity Analysis Results Ranges

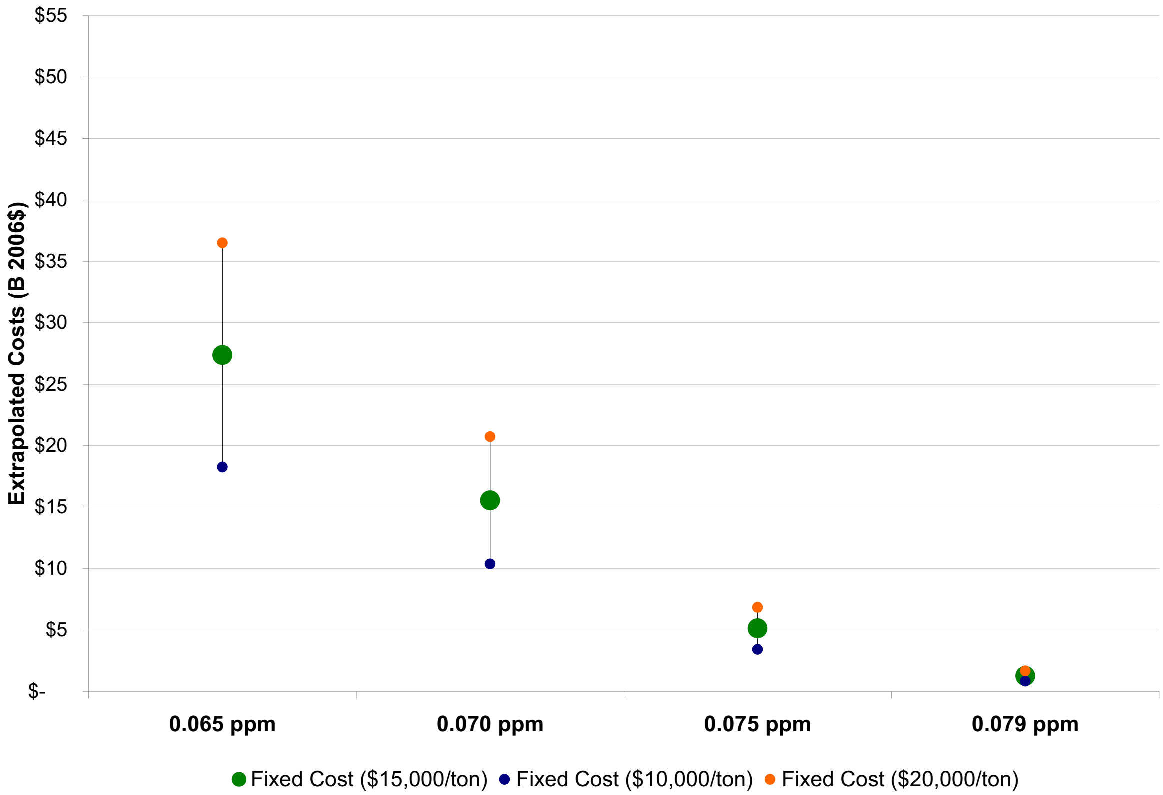


Table 5a.17: Extrapolated Cost by Geographic Area to Meet 0.065 ppm Alternate Standard Fixed Cost Approach [a, b]

2020 Extrapolated Cost Area	Fixed Cost Approach Extrapolated Costs (M 2006$)		
	($10,000/ton)	($15,000/ton)	($20,000/ton)
Ada Co., ID	$28	$42	$55
Atlanta, GA	$55	$83	$110
Baton Rouge, LA	$1,600	$2,500	$3,300
Boston-Lawrence-Worcester, MA	$85	$130	$170
Buffalo-Niagara Falls, NY	$180	$270	$360
Campbell Co., WY	$0.5	$0.8	$1.0
Charlotte-Gastonia-Rock Hill, NC-SC	$470	$710	$940
Cleveland-Akron-Lorain, OH	$780	$1,200	$1,600
Dallas-Fort Worth, TX	$480	$720	$960
Denver-Boulder-Greeley-Ft Collins-Love, CO	$16	$25	$33
Detroit-Ann Arbor, MI	$1,000	$1,500	$2,000
Dona Ana CO., NM	$4.1	$6.2	$8.2
Eastern Lake Michigan, IL-IN-WI	$6,400	$9,600	$13,000
Houston, TX	$1,800	$2,700	$3,600
Huntington-Ashland, WV-KY	$8.0	$12	$16
Jefferson Co, NY	$62	$93	$120
Las Vegas, NV	$39	$59	$78
Memphis, TN-AR	$11	$16	$21
Norfolk-Virginia Beach-Newport News	$210	$310	$410
Northeast Corridor, CT-DE-MD-NJ-NY-PA	$3,400	$5,100	$6,800

2020 Extrapolated Cost Area	Fixed Cost Approach Extrapolated Costs (M 2006$)		
	($10,000/ton)	($15,000/ton)	($20,000/ton)
Pittsburgh-Beaver Valley, PA	$130	$190	$250
Sacramento Metro, CA	$1,300	$2,000	$2,600
Salt Lake City, UT	$4.3	$6.5	$8.6
San Juan Co., NM	$13	$19	$25
St Louis, MO-IL	$170	$250	$330
Total Extrapolated Cost	**$18,000**	**$27,000**	**$36,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

Table 5a.18: Extrapolated Cost by Geographic Area to Meet 0.070 ppm Alternate Standard Fixed Cost Approach[a, b]

2020 Extrapolated Cost Area	Extrapolated Costs (M 2006$)		
	($10,000/ton)	($15,000/ton)	($20,000/ton)
Baton Rouge, LA	$490	$740	$990
Buffalo-Niagara Falls, NY	$37	$56	$75
Cleveland-Akron-Lorain, OH	$110	$170	$220
Detroit-Ann Arbor, MI	$87	$130	$170
Eastern Lake Michigan, IL-IN-WI	$7,000	$7,500	$10,000
Houston, TX	$1,600	$2,300	$3,100
Northeast Corridor, CT-DE-MD-NJ-NY-PA	$2,200	$3,300	$4,400
Sacramento Metro, CA	$890	$1,300	$1,800
Total Extrapolated Cost	**$10,000**	**$16,000**	**$21,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

Table 5a.19: Extrapolated Cost by Geographic Area to Meet 0.075 ppm Alternate Standard Fixed Cost Approach[a, b]

2020 Extrapolated Cost Area	Extrapolated Costs (M 2006$)		
	($10,000/ton)	($15,000/ton)	($20,000/ton)
Eastern Lake Michigan, IL-IN-WI	$740	$1,800	$1,500
Houston, TX	$1,200	$1,600	$2,500
Northeast Corridor, CT-DE-MD-NJ-NY-PA	$650	$980	$1,300
Sacramento Metro, CA	$440	$660	
Total Extrapolated Cost	**$3,400**	**$5,100**	**$6,800**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

Table 5a.20: Extrapolated Cost by Geographic Area to Meet 0.079 ppm Alternate Standard Fixed Cost Approach[a, b]

2020 Extrapolated Cost Area	Extrapolated Costs (Thousands 2006$)		
	($10,000/ton)	($15,000/ton)	($20,000/ton)
Houston, TX	$810	$1,200	$1,600
Sacramento Metro, CA	$18	$28	$37
Total Extrapolated Costs (NOX + VOC)	**$830**	**$1,200**	**$1,700**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

5a.4.4 Hybrid Approach

5a.4.4.1 Hybrid Approach Equations

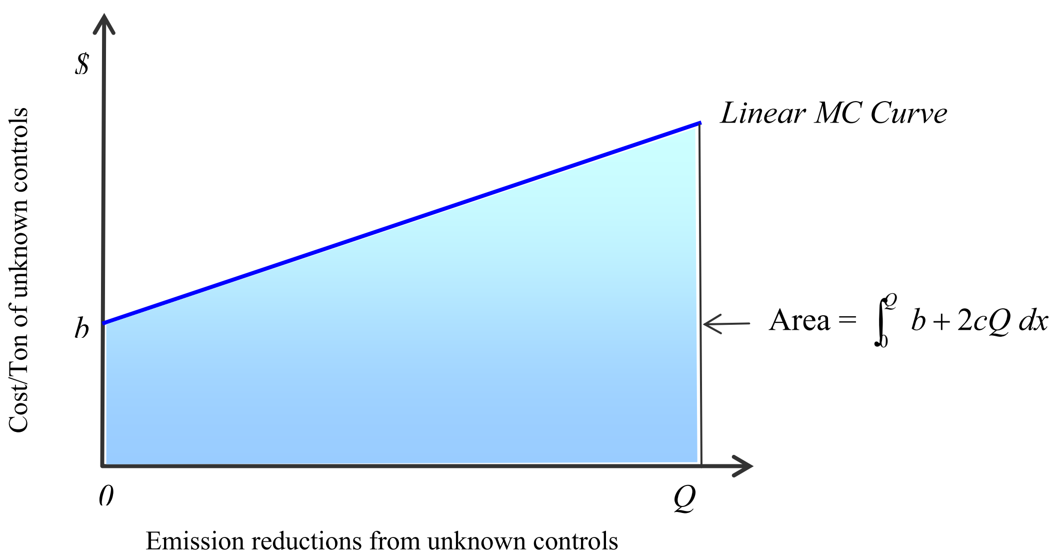
We begin with a linear increasing marginal cost (*MC*) curve represented here as

$$MC \quad b + 2cQ$$

Where (b+2cQ) is a nonnegative function, and b is the intercept and 2c represents the slope, and Q is the quantity of emissions reduced from unknown controls.

For geographic areas that have reached the baseline in the modeled control strategy the total cost (*TC*) is calculated by taking the integral of the marginal cost function from 0 of emission reductions from unknown controls to all emissions reductions needed from unknown controls (Q).

Figure 5a.2: Example Extrapolated Marginal Cost for Geographic Areas Meeting the Baseline in the Modeled Control Strategy



$$\text{Evaluate } \int_0^Q b + 2cQ \, dx \qquad bQ + cQ^2 + a \; - \; b0 + c0^2 + a$$

Where *MC* is nonnegative for $0 \leq \; b + 2cQ \; \leq Q$ the definite integral of *MC* equals the area of the shaded region, which is the total cost (*TC*)

$$TC = bQ + cQ^2$$

To calculate average cost (*AC*) divide *TC* by *Q*

$$\frac{TC}{Q} \quad \frac{bQ + cQ^2}{Q}$$

$$AC = b + cQ$$

Replace the intercept *b* with the national cost/ton jumping off point (*N*), and the slope (*c*) of the average cost curve with $\frac{NM}{E_0}$ where *M* is the multiplier, and E_0 represents the known emission reductions from the modeled control strategy. This slope represents; control technology changes, energy technology changes, relative price changes, technological innovation, and geographic distribution of sources with uncontrolled emissions, and emission reductions from known controls. Lastly, *Q* is represented by E_1 (the total unknown emission reductions)

$$AC \quad N + \left(\frac{NM}{E_0}\right) E_1$$

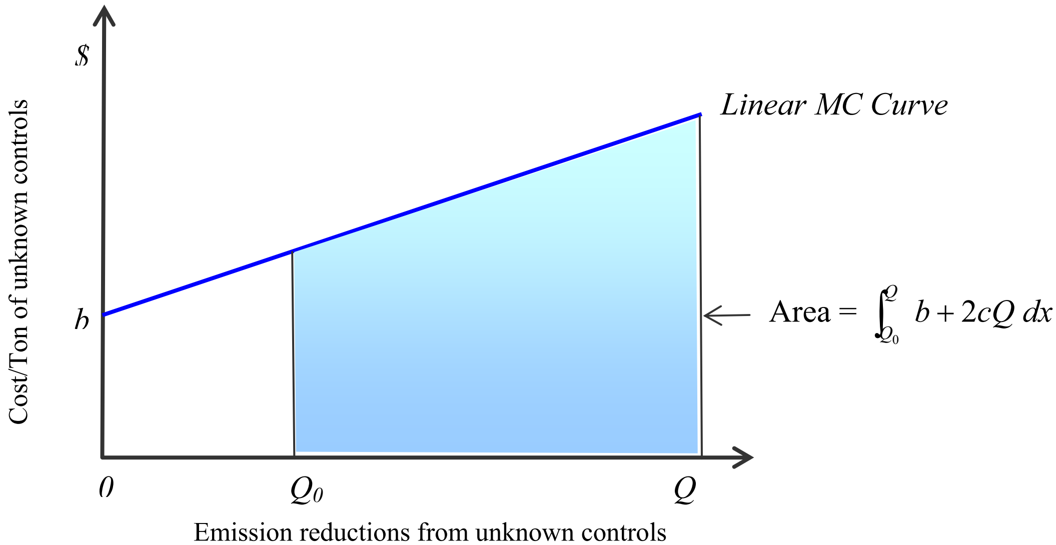
If we replace $\frac{E_1}{E_0}$ with *R*, and pull out *N* the equation becomes

$$AC = N(1+RM)$$

For geographic areas that have not reached the baseline in the modeled control strategy (Houston and parts of California), the total cost is calculated between Q_0 and *Q*, where Q_0 represents the quantity of emission reductions from unknown controls to reach the current ozone standard. Therefore the quantity of emissions that are extrapolated is

$Q - Q_0$.

Figure 5a.3: Example Extrapolated Marginal Cost for Geographic Areas Not Meeting the Baseline in the Modeled Control Strategy



$$\text{Evaluate } \int_{Q_0}^{Q} b + 2cQ\, dx \qquad bQ + cQ^2 + a \; - \; bQ_0 + cQ_0{}^2 + a$$

Where *MC* is nonnegative for $Q_0 \leq \; b + 2cQ \; \leq Q$ the definite integral of *MC* equals the area of the shaded region, which is the total cost (*TC*)

$$bQ - bQ_0 + cQ^2 - cQ_0{}^2$$

$$TC = \; b(Q - Q_0) + c(Q^2 - Q_0{}^2)$$

To calculate average cost (*AC*) divide *TC* by (Q - Q_0)

$$\frac{TC}{Q} \quad \frac{b(Q - Q_0) + c(Q^2 - Q_0{}^2)}{(Q - Q_0)}$$

$$AC = b + c(Q + Q_0)$$

Replace the intercept *b* with the national cost/ton jumping off point (*N*), and the slope (*c*) with $\frac{NM}{E_0}$ where *M* is the multiplier, and E_0 represents the known emission reductions from the modeled control strategy. This slope represents; control technology changes, energy technology changes, relative price changes, technological innovation, and geographic distribution of sources with uncontrolled emissions, and emission reductions from known controls. Lastly, *Q* is represented by E_1 (the total unknown emission reductions), and Q_0 is represented by E_{084} (unknown emission reductions to reach the current standard)

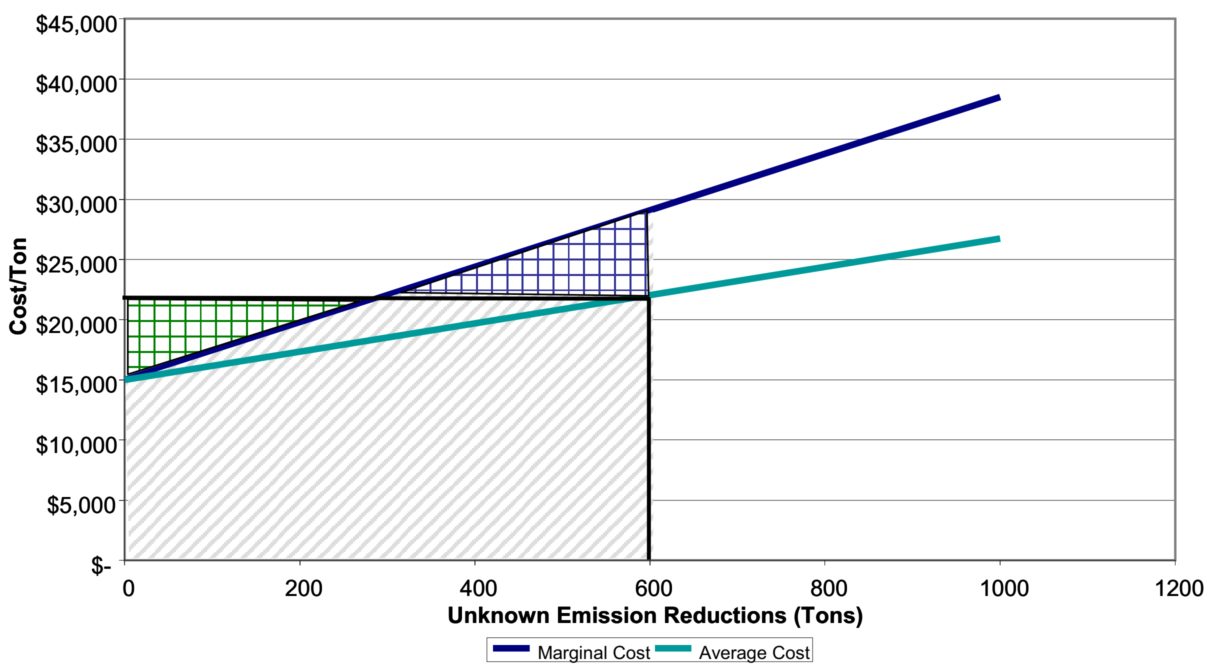
$$AC \quad N + \left(\frac{NM}{E_0}\right)(E_1 + E_{084})$$

If we replace $\frac{E_1}{E_0}$ with R, replace $\frac{E_{084}}{E_0}$ with R_s and pull out N the equation becomes

$$AC = N\,(1 + RM + R_s M)$$

Figure 5a.4 shows a graphic al example that in the hybrid approach the total cost will be identical if calculated using the marginal cost framework or average cost framework. The total cost using the marginal cost framework is the grey area plus the blue area. The total cost using the average cost framework is the grey area plus the green area. By the nature of geometry, the blue area and the green area are equal. Therefore the total cost under either framework is equal.

Figure 5a.4: Example Marginal Cost versus Average Cost for the Hybrid Approach



5a.4.4.3 Hybrid Approach Detailed Results by Geographic Area

Tables 5a.21 through 5a.24 present the detailed results by geographic area and standard for the hybrid approach (mid).

Table 5a.21: Extrapolated Cost by Geographic Area to Meet 0.065 ppm Alternate Primary Standard Using Hybrid Approach (Mid) [a, b, c]

2020 Extrapolated Cost Area		Ratio of Unknown to Known Emission Reductions	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Ada Co., ID		0.81	$18,000	$49
Atlanta, GA		0.10	$15,000	$85
Baton Rouge, LA		0.95	$18,000	$3,000
Boston-Lawrence-Worcester, MA		0.36	$16,000	$140
Buffalo-Niagara Falls, NY		1.60	$21,000	$370
Campbell Co., WY		0.01	$15,000	$0.75
Charlotte-Gastonia-Rock Hill, NC-SC		1.20	$19,000	$910
Cleveland-Akron-Lorain, OH		1.11	$19,000	$1,500
Dallas-Fort Worth, TX		0.85	$18,000	$860
Denver-Boulder-Greeley-Ft Collins-Love, CO		0.04	$15,000	$25
Detroit-Ann Arbor, MI		1.65	$21,000	$2,100
Dona Ana CO., NM		0.27	$16,000	$6.6
Eastern Lake Michigan, IL-IN-WI	NOX	2.00	$22,000	$14,000
	VOC	2.19	$23,000	
El Paso Co., TX		0.00	$15,000	
Houston, TX[d]		1.78	$24,000	$4,200
Huntington-Ashland, WV-KY		0.02	$15,000	$12
Jefferson Co, NY		1.18	$19,000	$120
Las Vegas, NV		0.37	$16,000	$64
Memphis, TN-AR		0.04	$15,000	$16
Norfolk-Virginia Beach-Newport News		0.64	$17,000	$360
Northeast Corridor, CT-DE-MD-NJ-NY-PA		2.15	$23,000	$7,700
Pittsburgh-Beaver Valley, PA		0.35	$16,000	$210
Sacramento Metro, CA		1.90	$22,000	$2,800
Salt Lake City, UT		0.03	$15,000	$6.5
San Juan Co., NM		0.07	$15,000	$19
St Louis, MO-IL		0.23	$16,000	$260
Total Extrapolated Cost				**$39,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[c] Houston did not reach the baseline, and therefore has an additional R to reach the current standard of 0.62.

[d] Houston did not reach the baseline, and therefore has an additional R to reach the current standard of 0.62.

Table 5a.22: Extrapolated Cost by Geographic Area to Meet 0.070 ppm Alternate Primary Standard Using Hybrid Approach (Mid) [a, b]

2020 Extrapolated Cost Area		Ratio of Unknown to Known Emission Reductions	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Baton Rouge, LA		0.31	$16,000	$800
Buffalo-Niagara Falls, NY		0.39	$16,000	$61
Cleveland-Akron-Lorain, OH		0.18	$16,000	$170
Detroit-Ann Arbor, MI		0.14	$16,000	$130
Eastern Lake Michigan, IL-IN-WI	NOX	1.65	$21,000	$11,000
	VOC	1.86	$22,000	
Houston, TX[c]		1.63	$23,000	$3,600
Northeast Corridor, CT-DE-MD-NJ-NY-PA		1.47	$20,000	$4,400
Sacramento Metro, CA		1.30	$20,000	$1,700
Total Extrapolated Cost				$22,000

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.
[c] Houston did not reach the baseline, and therefore has an additional R to reach the current standard of 0.62.

Table 5a.23: Extrapolated Cost by Geographic Area to Meet 0.075 ppm Alternate Primary Standard Using Hybrid Approach (Mid) [a, b]

2020 Extrapolated Cost Area		Ratio of Unknown to Known Emission Reductions	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Eastern Lake Michigan, IL-IN-WI	NOX	0.50	$17,000	$2,000
	VOC	0.36	$16,000	
Houston, TX[c]		1.36	$22,000	$2,400
Northeast Corridor, CT-DE-MD-NJ-NY-PA		0.46	$17,000	$1,100
Sacramento Metro, CA		0.67	$17,000	$770
Total Extrapolated Cost				**$6,300**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.
[c] Houston did not reach the baseline, and therefore has an additional R to reach the current standard of 0.62.

Table 5a.24: Extrapolated Cost by Geographic Area to Meet 0.075 ppm Alternate Primary Standard Using Hybrid Approach (Mid) [a, b, c]

2020 Extrapolated Cost Area	Ratio of Unknown to Known Emission Reductions	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Houston, TX[d]	1.17	$21,000	$1,700
Sacramento Metro, CA	0.07	$15,000	$28
Total Extrapolated Cost			**$1,800**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.
[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.
[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

[d] Houston did not reach the baseline, and therefore has an additional R to reach the current standard of 0.62.

5a.4.4.3 Hybrid Approach Sensitivity Analysis Results

Sensitivity analysis was performed on the variable M to explore the degree that this variable effects total costs of attainment across alternate primary standards. The lowest value of M (0.12), as well as the highest (0.47) was used. The detailed results of these sensitivity analyses are presented in Tables 5a.25 through 5a.29. Figure 5a.5 shows graphically the range of values for national extrapolated costs for the four levels of the alternate primary standard analyzed.

Figure 5a.5: Hybrid Approach Sensitivity Analysis Results Ranges

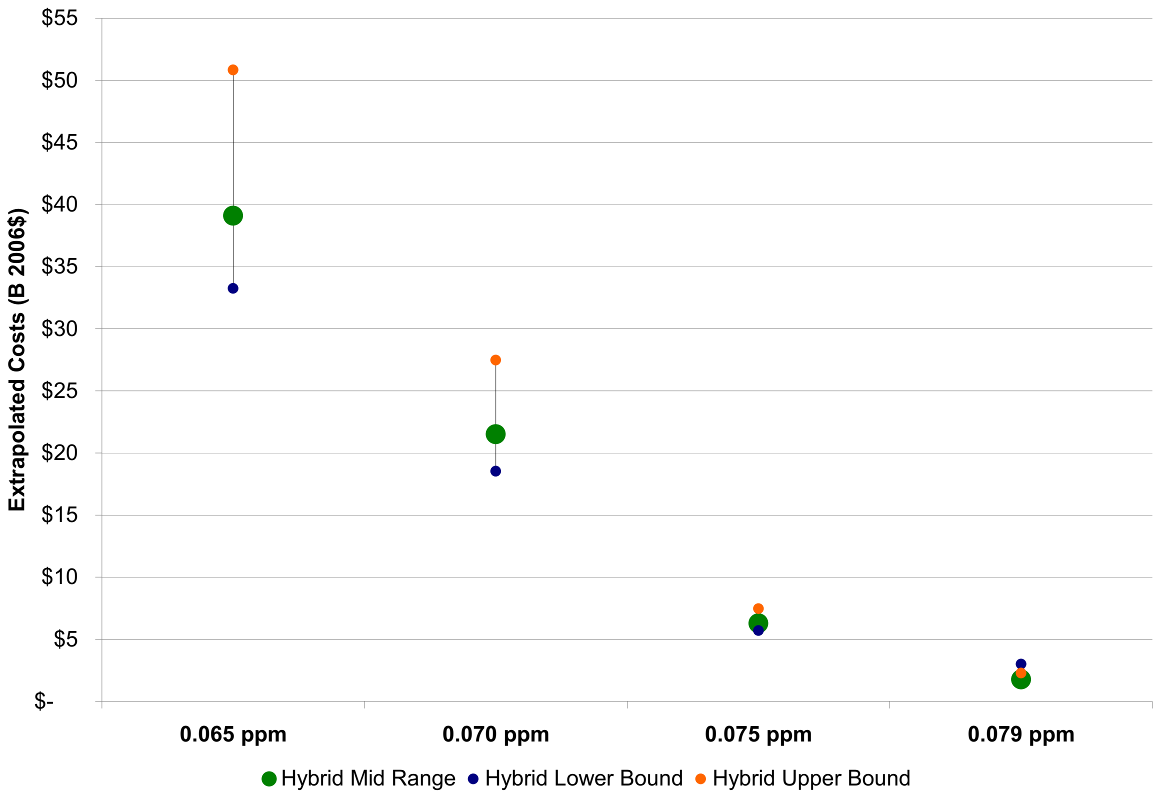


Table 5a.25: Extrapolated Cost by Geographic Area to Meet 0.065 ppm Alternate Standard Hybrid Approach Sensitivities [a, b, c]

2020 Extrapolated Cost Area		Hybrid Approach (Low)		Hybrid Approach (High)	
		Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Ada Co., ID		$16,000	$46	$21,000	$57
Atlanta, GA		$15,000	$84	$16,000	$86
Baton Rouge, LA		$17,000	$2,700	$22,000	$3,600
Boston-Lawrence-Worcester, MA		$16,000	$130	$18,000	$150
Buffalo-Niagara Falls, NY		$18,000	$320	$26,000	$480
Campbell Co., WY		$15,000	$0.75	$15,000	$0.75
Charlotte-Gastonia-Rock Hill, NC-SC		$17,000	$810	$23,000	$1,100
Cleveland-Akron-Lorain, OH		$17,000	$1,300	$23,000	$1,800
Dallas-Fort Worth, TX		$17,000	$790	$21,000	$1,000
Denver-Boulder-Greeley-Ft Collins-Love, CO		$15,000	$25	$15,000	$25
Detroit-Ann Arbor, MI		$18,000	$1,800	$27,000	$2,700
Dona Ana CO., NM		$15,000	$6.4	$17,000	$6.9
Eastern Lake Michigan, IL-IN-WI	NOX	$19,000	$12,000	$29,000	$19,000
	VOC	$19,000		$31,000	
Houston, TX		$19,000	$3,400	$32,000	$5,700
Huntington-Ashland, WV-KY		$15,000	$12	$15,000	$12
Jefferson Co, NY		$17,000	$110	$23,000	$140
Las Vegas, NV		$16,000	$61	$18,000	$69
Memphis, TN-AR		$15,000	$16	$15,000	$16
Norfolk-Virginia Beach-Newport News		$16,000	$330	$20,000	$400
Northeast Corridor, CT-DE-MD-NJ-NY-PA		$19,000	$6,400	$30,000	$10,000
Pittsburgh-Beaver Valley, PA		$16,000	$200	$17,000	$220
Sacramento Metro, CA		$18,000	$2,400	$28,000	$3,700
Salt Lake City, UT		$15,000	$6.5	$15,000	$6.6
San Juan Co., NM		$15,000	$19	$16,000	$19
St Louis, MO-IL		$15,000	$250	$17,000	$280
Total Extrapolated Cost			**$33,000**		**$51,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 5a.26: Extrapolated Cost by Geographic Area to Meet 0.070 ppm Alternate Standard Hybrid Approach Sensitivities [a, b, c]

2020 Extrapolated Cost Area		Hybrid Approach (Low)		Hybrid Approach (High)	
		Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Baton Rouge, LA		$16,000	$770	$17,000	$850
Buffalo-Niagara Falls, NY		$16,000	$59	$18,000	$67
Cleveland-Akron-Lorain, OH		$15,000	$170	$16,000	$180
Detroit-Ann Arbor, MI		$15,000	$130	$16,000	$140
Eastern Lake Michigan, IL-IN-WI	NOX	$18,000	$9,000	$27,000	$14,000
	VOC	$18,000		$28,000	
Houston, TX		$19,000	$3,000	$31,000	$4,800
Northeast Corridor, CT-DE-MD-NJ-NY-PA		$18,000	$3,800	$25,000	$5,500
Sacramento Metro, CA		$17,000	$1,500	$24,000	$2,100
Total Extrapolated Cost			**$19,000**		**$27,000**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 5a.27: Extrapolated Cost by Geographic Area to Meet 0.075 ppm Alternate Standard Hybrid Approach Sensitivities [a, b, c]

2020 Extrapolated Cost Area		Hybrid Approach (Low)		Hybrid Approach (High)	
		Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Eastern Lake Michigan, IL-IN-WI	NOX	$16,000	$2,000	$19,000	$2,300
	VOC	$16,000		$18,000	
Houston, TX		$19,000	$2,000	$29,000	$3,100
Northeast Corridor, CT-DE-MD-NJ-NY-PA		$16,000	$1,000	$18,000	$1,200
Sacramento Metro, CA		$16,000	$710	$20,000	$870
Total Extrapolated Cost			**$5,700**		**$7,500**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 5a.28: Extrapolated Cost by Geographic Area to Meet 0.079 ppm Alternate Standard Hybrid Approach Sensitivities [a, b, c]

2020 Extrapolated Cost Area	Hybrid Approach (Low)		Hybrid Approach (High)	
	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)	Average Cost/Ton (2006$)	Hybrid Approach Extrapolated Cost (M 2006$)
Houston, TX	$18,000	$1,500	$28,000	$2,200
Sacramento Metro, CA	$15,000	$28	$15,000	$29
Total Extrapolated Cost		**$1,500**		**$2,300**

[a] All estimates rounded to two significant figures. As such, totals will not sum down columns.

[b] These estimates do not reflect benefits or costs for the San Joaquin Valley or South Coast Air Basins. Please see Appendix 7b for analysis of these areas.

[c] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Appendix 5b: Economic Impact of Modeled Controls

5b.1 Synopsis

This appendix presents the economic impact results of the illustrative modeled control strategy. Given the possible impacts of ozone precursor control measures on manufacturing industries, the transportation sector, electricity generators, consumers, and U.S. Gross Domestic Product (GDP) as a whole, we believe it is important to gauge the extent to which other parts of the economy might also be affected by implementing an alternate primary ozone standard. Therefore, an analysis of the economy-wide effects of implementing the alternate standard is conducted by inputting estimated direct engineering costs to EPA's computable general equilibrium model (Economic Model for Policy Analysis, or EMPAX-CGE).

Before the appendix commences with a background and description of EMPAX-CGE followed by a presentation of the results, three points are highlighted below that will assist the reader in interpreting the economic impacts and relating these impacts to the modeled control strategy engineering costs presented in Chapter 5.

(a) The selection criteria for the modeled control strategy, and its related compliance costs, is designed to select the least cost controls, from an engineering cost standpoint, that generate the greatest ozone reductions, but not necessarily the lowest economic impact. Therefore, although the control strategy is selected to reduce ozone at the lowest engineering cost, it does not necessarily represent the lowest impact strategy from an economic impact standpoint. Thus, while this economic impact analysis presents results for the modeled control strategy approach detailed in Chapter 3 of the RIA, it should not be viewed as reflecting the approach with the smallest economic impact. Instead, the results should be viewed as guidance or useful information for states preparing their implementation plans. It is likely that states will design implementation plans that apply alternative control strategies and in some cases design plans that take into account secondary impacts to industries and consumers within their boundaries. In such a case, the end result would be a set of State Implementation Plans (SIPs) that could be more economically optimal and may have lower impacts than those described below.

(b) The costs analyzed in this economic impact appendix include only the modeled engineering costs detailed in Chapter 5 for the alternate primary ozone standard. Thus, the economic impacts presented in this appendix reflect only the modeled engineering costs. Not included in estimating these economic impacts are the extrapolated cost estimates detailed in Chapter 5. This is because the extrapolated cost estimates are not available by industry, a necessary input to the operation of EMPAX. Therefore, the engineering costs for the illustrative modeled control strategy that are input to EMPAX in this analysis are those that reflect the $2.8 billion (2006 dollars) in 2020 for the application of known controls.

(c) In the interest of learning how possible changes in manufactured-goods prices might affect businesses and households, along with how changes in electricity/energy prices might affect industry groups that are large energy users, EPA employed the "EMPAX-CGE" computable general equilibrium (CGE) model, which has been peer reviewed and used in recent analyses of the Clean Air Interstate Rule (CAIR), the Clean Air Visibility Rule (CAVR), and the $PM_{2.5}$ NAAQS. As with similar models, EMPAX-CGE focuses on the cost-side of spillover effects on the economy. This implies its estimated industry-sector impacts may be overstated because EMPAX-CGE is not configured to capture the beneficial economic consequences of the increased labor availability and productivity expected to result from air quality improvements. EPA continues to investigate the feasibility of incorporating labor productivity gains and other beneficial effects of air quality improvements in CGE models and will incorporate labor productivity gains and other effects of air quality model improvements within future versions of EMPAX-CGE as is feasible.

EMPAX-CGE may also be used to generate the social costs associated with a regulation. The social costs associated with a regulation are those costs that result from the reaction of consumers and producers to the direct engineering costs of a regulation. The welfare of consumers and producers may be affected positively or negatively depending on the nature of the regulation, and this welfare change is a measure of the social costs. Such a welfare change could result from higher prices on output, which may lead to less demand by consumers and less output by producers. These changes due to the higher output prices are estimated as part of social costs. We apply the equivalent variation (EV) approach to estimate social costs using EMPAX-CGE in this RIA. This the first application of EV to estimate social costs as part of analysis using a CGE model in an RIA of this type. We explain how the EV approach can be used to estimate social costs, and why it is a better approach to estimating social cost than one using GDP in section 5b.4.4 of this appendix . Given a substantial number of caveats on results generated by EMPAX-CGE, we include social cost and do not compare these costs to the monetized benefits estimates provided later in this RIA. We also intend to solicit review and the advice of the SAB before we use this approach to estimate social costs before conducting any future economic impact analyses using CGE models.

5b.2 Background

To complement the analysis of effects on specific manufacturing sectors from AirControlNET 4.1, implications for mobile sources from MOBILE 6.2, NMIM, and NONROAD, and changes in electricity generation from IPM, the macroeconomic implications of the modeled control strategy have been estimated using EPA's EMPAX-CGE model. The focus of this component of the Ozone RIA is on examining the sectoral and regional distribution of economic effects across the U.S. economy. This section briefly discusses the EMPAX model and the approach used to incorporate findings from other models in EMPAX-CGE.

5b.2.1 Background and Summary of EMPAX-CGE Model

EMPAX was first developed in 2000 to support economic analysis of EPA's maximum achievable control technology (MACT) rules for combustion sources (reciprocating internal combustion engines, boilers, and turbines). The initial framework consisted of a national multimarket partial-equilibrium model with linkages only between manufacturing industries and the energy sector. Modified versions of EMPAX were subsequently used to analyze economic impacts of strategies for improving air quality in the Southern Appalachian mountain region as part of efforts associated with the Southern Appalachian Mountain Initiative (SAMI).

Recent work on EMPAX has extended its scope to cover all aspects of the U.S. economy at a regional level in either static or dynamic modes. Although major regulations directly affect a large number of industries, substantial indirect impacts may also result from changes in production, input use, income, and household consumption patterns. Consequently, EMPAX now includes economic linkages among all industrial and energy sectors as well as households that supply factors of production such as labor and purchase goods (i.e., a CGE framework). This gives the version of EMPAX called EMPAX-CGE the ability to trace economic impacts as they are transmitted throughout the economy and allows it to provide critical insights to policy makers evaluating the magnitude and distribution of costs associated with environmental policies. The dynamic version of EMPAX-CGE employed n this analysis, and its data sources, are described later on in Section 5b.3. EMPAX-CGE underwent peer review in 2006, and the results of that peer review can be found on the EPA Web site.[1] We have incorporated a number of recommendations offered in the peer review, including updating the energy production and consumption data (from DOE) to allow for more up to date characterization of energy markets and revising the uncompensated labor supply elasticities used in the model.

5b.2.2 EMPAX Modeling Methodology for the Modeled Control Strategy

EMPAX-CGE can be used to analyze a wide array of policy issues and is capable of estimating how a change in a single part (or multiple parts) of the economy will influence producers and consumers across the United States. However, some types of policies, including the Ozone National Ambient Air Quality Standard, are difficult to capture adequately within a CGE structure because of the boiler- and firm-specific nature of emission reduction costs. Consequently, an interface has been developed that allows linkages between EMPAX-CGE and the detailed technology models discussed in Chapter 5 (AirControlNET 4.1, MOBILE6.2, NMIM, and IPM 3.0). These linkages give the combined modeling system the advantages of technology detail and broad macroeconomic coverage, thereby permitting EMPAX-CGE to investigate economy-wide policy implications.

The technology models mentioned above estimate engineering cost changes by industry and region of the United States for the sectors of the economy affected by the alternate primary ozone standard. In order for EMPAX-CGE to effectively incorporate these additional costs, they have to be expressed in terms of the productive inputs used in CGE models (i.e., capital, labor, and material inputs produced by other industries). Rather than assume the costs represent a proportional scaling up of all inputs, Nestor and Pasurka (1995) data on purchases made by industries for environmental-protection reasons are used to allocate these additional expenditures across inputs within EMPAX-CGE. Once these expenditures are specified, the incremental engineering costs from the technology models can be used to adjust the production technologies in the CGE model. Also, for the modeled control strategy, linkages are made between EMPAX-

[1] http://www.epa.gov/ttn/ecas/models/empax_peer_review_comments_responses.pdf.

CGE and IPM to handle specific IPM findings related to resource costs and fuel consumption in electricity generation.[2]

5b.3 EMPAX-CGE Model Description: General Model Structure

This section provides additional details on the EMPAX-CGE model structure, data sources, and assumptions. The version of EMPAX-CGE used in this analysis is a dynamic, intertemporally optimizing model that solves in five year intervals from 2005 to 2050. It uses the classical Arrow- Debreu general equilibrium framework wherein households maximize utility subject to budget constraints, and firms maximize profits subject to technology constraints. The model structure, in which agents are assumed to have perfect foresight and maximize utility across all time periods, allows agents to modify behavior in anticipation of future policy changes, unlike dynamic recursive models that assume agents do not react until a policy has been implemented.

Nested CES functions are used to portray substitution possibilities available to producers and consumers. Figure 5b.1 illustrates this general framework and gives a broad characterization of the model.[3] Along with the underlying data, these nesting structures and associated substitution elasticities determine the effects that will be estimated for policies. These nesting structures and elasticities used in EMPAX-CGE are generally based on the Emissions Prediction and Policy Analysis (EPPA) Model developed at the Massachusetts Institute of Technology (Paltsev et al., 2005). This updated version of the EPPA model incorporates some extensions over the EPPA version documented in Babiker et al. (2001) such as specification of transportation purchases by households. These updates to transportation choices have been incorporated in this version of EMPAX-CGE as shown on the left-hand side of Figure 5b.1. Although the two models continue to have different focuses (EPPA is a model focused on analysis of national-level climate change policies while EMPAX is a model focused on regional-level analysis of pollution control policies), both are intended to simulate how agents will respond to environmental policies and as such EPPA provides a strong basis to develop the theoretical structure of EMPAX-CGE.

Given this basic similarity, EMPAX-CGE has adopted a comparable structure. EMPAX-CGE is programmed in the GAMS[4] language (Generalized Algebraic Modeling System) and solved as a mixed complementarity problem (MCP)[5] using MPSGE software (Mathematical Programming

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[2] See Appendix E in the RIA for the Final CAIR rule for additional discussion of these IPM-EMPAX linkages (http://www.epa.gov/interstateairquality/technical.html).

[3] Although it is not illustrated in Figure 6.1, some differences across industries exist in their handling of energy inputs. In addition, the agriculture and fossil-fuel sectors in EMPAX-CGE contain equations that account for the presence of fixed inputs to production (land and fossil-fuel resources, respectively).

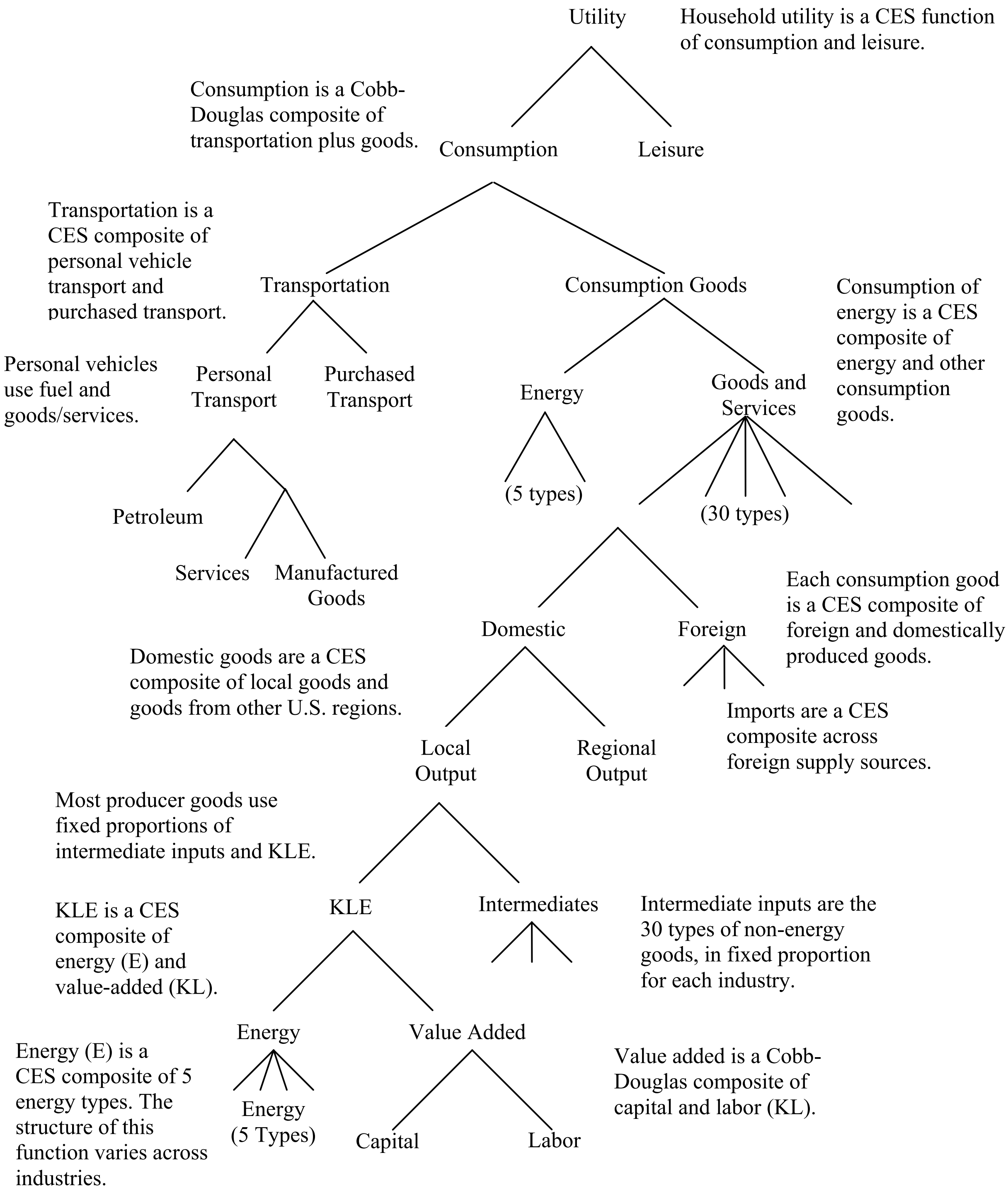
[4] See Brooke, Kendrick, and Meeraus (1996) for a description of GAMS (http://www.gams.com/).

[5] Solving EMPAX-CGE as a MCP problem implies that complementary slackness is a feature of the equilibrium solution. In other words, any firm in operation will earn zero economic profits and any unprofitable firms will cease operations. Similarly, for any commodity with a positive price, supply will equal demand, or conversely any good in excess supply will have a zero price.

Subsystem for General Equilibrium).[6] The PATH solver from GAMS is used to solve the MCP equations generated by MPSGE.

[6] See Rutherford (1999) for MPSGE documentation (http://www.mpsge.org/).

Figure 5b.1: General Production and Consumption Nesting Structure in EMPAX-CGE



5b.3.1 Data Sources

The economic data come from state level information provided by the Minnesota IMPLAN Group[7] and energy data come from EIA.[8] Forecasts for economic growth are taken from EIA's *Annual Energy Outlook 2007* (AEO) and Global Insight.[9] Although IMPLAN data contain information on the value of energy production and consumption in dollars, these data are replaced with EIA data since the policies being investigated by EMPAX-CGE typically focus on energy markets, making it essential to include the best possible characterization of these markets in the model. Although the IMPLAN data are developed from a variety of government data sources at the U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics, these data do not always agree with energy information collected by EIA directly from manufacturers and electric utilities.

EMPAX-CGE combines these economic and energy data to create a balanced social accounting matrix (SAM) that provides a baseline characterization of the economy. The SAM contains data on the value of output in each sector, payments for factors of production and intermediate inputs by each sector, household income and consumption, government purchases, investment, and trade flows. A balanced SAM for the year 2005 consistent with the desired sectoral and regional aggregation is produced using procedures developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000). This methodology relies on optimization techniques to maintain the calculated energy statistics (in both quantity and value terms) while minimizing any changes needed in the other economic data to create a new balanced SAM based on EIA/IMPLAN data for the baseline model year (in essence, industry production functions are adjusted, if necessary, to account for discrepancies between EIA energy data and IMPLAN economic data by matching the energy data and adjusting the use of non-energy inputs so that the industry is in balance, i.e., the value of inputs to production equals the value of output).

These data are used to define economic conditions in 50 states within the United States (plus the District of Columbia), each of which contains 80 industries. Prior to solving EMPAX-CGE, the states and industries are aggregated up to the categories to be included in the analysis. Aggregated regions have been selected to capture important differences across the country in electricity generation technologies, while industry aggregations are controlled by available energy consumption data.

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[7] See http://www.implan.com/index.html for a description of the Minnesota IMPLAN Group and its data.

[8] These EIA sources include *AEO 2007*, the *Manufacturing Energy Consumption Survey*, *State Energy Data Report*, *State Energy Price and Expenditure Report*, and various annual industry profiles.

[9] See http://www.globalinsight.com/ProductsServices/ProductDetail1100.htm for a description of the Global Insight U.S. State Forecasting Service.

Table 5b.1 presents the 35 industry categories included in EMPAX-CGE for policy analysis. Their focus is on maintaining as much detail in the energy intensive and manufacturing sectors[10] as is

Table 5b.1: Industries in Dynamic EMPAX-CGE

EMPAX Industry	NAICS Classifications
Energy	
Coal	2121
Crude Oil[a]	211111, 4861
Electricity (*fossil and nonfossil*)	2211
Natural Gas	211112, 2212, 4862
Petroleum Refining[c]	324, 48691
General	
Agriculture	11
Mining (w/o coal, crude, gas)	21
Construction	23
Manufacturing	
Food Products	311
Textiles and Apparel	313, 314, 315, 316
Lumber	321
Paper and Allied	322
Printing	323
Chemicals	325
Plastic & Rubber	326
Glass	3272
Cement	3273
Other Minerals	3271, 3274, 3279
Iron and Steel	3311, 3312
Aluminum	3313
Other Primary Metals	3314, 3316
Fabricated Metal Products	332
Manufacturing Equipment	333
Computers & Communication Equipment	334
Electronic Equipment	335
Transportation Equipment	336
Miscellaneous remaining	312, 337, 339
Services	
Wholesale & Retail Trade	42, 44, 45
Transportation[b]	481-488
Information	51
Finance & Real Estate	52, 54
Business/Professional	53, 55, 56
Education (w/public)	61
Health Care (w/public)	62
Other Services	71, 72, 81, 92

[a] Although NAICS 211111 covers crude oil and gas extraction, the gas component of this sector is moved to the natural gas industry.

[b] The petroleum refining industry provided oil in delivered terms, which includes pipeline transport.

[c] Transportation does not include NAICS 4862 (natural gas distribution), which is part of the natural gas industry.

[10] Energy-intensive industry categories are based on EIA definitions of energy-intensive manufacturers in the *Assumptions for the Annual Energy Outlook 2007*.

allowed by available energy consumption data and computational limits of dynamic CGE models. In addition, the electricity industry is separated into fossil fuel generation and nonfossil generation, which is necessary because many electricity policies affect only fossil fired electricity.

Figure 5b.2 shows the five regions included in EMPAX-CGE in this analysis, which have been defined based on the expected regional distribution of policy impacts, availability of economic and energy data, and computational limits on model size. These regions have been constructed from the underlying state-level database designed to follow, as closely as possible, the electricity market regions defined by the North American Electric Reliability Council (NERC).[11]

Figure 5b.2: Regions Defined in Dynamic EMPAX-CGE

5b.3.2 Production Functions

All productive markets are assumed to be perfectly competitive and have production technologies that exhibit constant returns to scale, except for the agriculture and natural resource extracting sectors, which have decreasing returns to scale because they use factors in fixed supply (land and fossil fuels, respectively). The electricity industry is separated into two distinct sectors: fossil fuel generation and nonfossil generation. This allows tracking of variables such as heat rates for fossil fired utilities (Btus of energy input per kilowatt hour of electricity output).

[11] Economic data and information on nonelectricity energy markets are generally available only at the state level, which necessitates an approximation of the NERC regions that follows state boundaries.

All markets, must clear (i.e., supply must equal demand in every sector) in every period, and the income of each agent in the model must equal their factor endowments plus any net transfers. Markets in EMPAX clear in the 5 regions included in the dynamic model. Along with the underlying data, the nesting structures shown in Figure 5b-1 and associated substitution elasticities define current production technologies and possible alternatives.

5b.3.3 Utility Functions

Each region in the dynamic version of EMPAX-CGE contains four representative households, classified by income, that maximize intertemporal utility over all time periods in the model subject to budget constraints, where the income groups are:

- $0 to $14,999,
- $15,000 to $29,999,
- $30,000 to $49,999, and
- $50,000 and above.[12]

The percentage of U.S. households in each of these household classes is: 13% - $0 to $14,999; 18% - $15,000 to $29,999, 20% - $30,000 to $49,999, and 49% - $50,000 and above.[13] These representative households are endowed with factors of production including labor, capital, natural resources, and land inputs to agricultural production. Factor prices are equal to the marginal revenue received by firms from employing an additional unit of labor or capital. The value of factors owned by each representative household depends on factor use implied by production within each region. Income from sales of these productive factors is allocated to purchases of consumption goods to maximize welfare.

Within each time period, intratemporal utility received by a household is formed from consumption of goods and leisure. All consumption goods are combined using a Cobb Douglas structure to form an aggregate consumption good. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure depends on empirical estimates of labor supply elasticities and indicates how willing households are to trade off leisure time for consumption. Over time, households consider the discounted present value of utility received from all periods' consumption of goods and leisure.

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[12] Computational limitations on EMPAX-CGE limit the number of household classes to four, and this is due to the complex modeling needed for the dynamic version of the model. We intend to review and potentially increase the number of household classes in future version of EMPAX-CGE, and will better reflect higher income household classes as part of that effort.

[13] U.S. Census Bureau, Current Population Survey, 2007 Annual Social and Economic Supplement. HINC-01. Selected Characteristics of Households, by Total Money Income. Found on the Internet at (http://pubdb3.census.gov/macro/032007/hhinc/new01_001.htm)

Following standard conventions of CGE models, factors of production are assumed to be intersectorally mobile within regions, but migration of productive factors is not allowed across regions. This assumption is necessary to calculate welfare changes for the representative household located in each region in EMPAX-CGE. EMPAX-CGE also assumes that ownership of natural resources and capital embodied in nonfossil electricity generation is spread across the United States through capital markets.

5b.3.4 Trade

In EMPAX-CGE, all goods and services are assumed to be composite, differentiated "Armington" goods made up of locally manufactured commodities and imported goods. Output of local industries is initially separated into output destined for local consumption by producers or households and output destined for export. This local output is then combined with goods from other regions in the United States using Armington trade elasticities that indicate agents make relatively little distinction between output from firms located within their region and output from firms in other regions within the United States. Finally, the domestic composite goods are aggregated with imports from foreign sources using lower trade elasticities to capture the fact that foreign imports are more differentiated from domestic output than are imports from other regional suppliers in the United States.

5b.3.5 Tax Rates and Distortions

Taxes and associated distortions in economic behavior have been included in EMPAX-CGE because theoretical and empirical literature found that taxes can substantially alter estimated policy costs (e.g., Bovenberg and Goulder [1996]; Goulder and Williams [2003]). For example, existing labor taxes distort economic choices because they encourage people to work below the levels they would choose in an economy without labor taxes and reduces economic efficiency[14]. When environmental policies raise production costs for firms and the price of goods and services, people may choose to work even less; the additional economic costs from this decision has been described as the "tax interaction" effect.

EMPAX-CGE considers these interaction effects by utilizing tax data from several sources and by explicitly modeling household labor supply decisions. The IMPLAN economic database provides information on taxes such as indirect business taxes (all sales and excise taxes) and social security taxes. However, since IMPLAN reports factor payments for labor and capital at their gross of tax values, we use additional data sources to determine personal income and capital tax rates. Information from the TAXSIM model at the National Bureau of Economic Research (Feenberg and Coutts, 1993), along with user cost of capital calculations from Fullerton and Rogers (1993), are used to establish tax rates. Elasticity parameters describing labor supply choice ultimately determine how distortionary existing taxes are in the CGE model. EMPAX-CGE currently uses elasticities based on the relevant literature (i.e., 0.4 for the compensated labor supply elasticity and 0.15 for the uncompensated labor supply elasticity). These elasticity

[14] These efficiency losses are often expressed in terms of overall marginal excess burden; the cost associated with raising an additional dollar of tax revenue. Estimates range from \$0.10 to \$0.35 per dollar (Ballard et al., 1985).

values give an overall marginal excess burden associated with the existing tax structure of approximately 0.3.

5b.3.6 Intertemporal Dynamics and Economic Growth

There are four sources of economic growth in EMPAX-CGE: technological change from improvements in energy efficiency, growth in the available labor supply (from both population growth and changes in labor productivity), increases in stocks of natural resources, and capital accumulation. Energy consumption per unit of output tends to decline over time because of improvements in production technologies and energy conservation. These changes in energy use per unit of output are modeled as AEEIs (Autonomous Energy Efficiency Improvements), which are used to replicate energy consumption forecasts by industry and fuel from EIA.[15] The AEEI values provide the means for matching expected trends in energy consumption that have been taken from the AEO forecasts. They alter the amount of energy needed to produce a given quantity of output by incorporating improvements in energy efficiency and conservation. Labor force and regional economic growth, electricity generation, changes in available natural resources, and resource prices are also based on the AEO forecasts.

Savings provide the basis for capital formation and are motivated through people's expectations about future needs for capital. Savings and investment decisions made by households determine aggregate capital stocks in EMPAX-CGE. The IMPLAN dataset provides details on the types of goods and services used to produce the investment goods underlying each region's capital stocks. Adjustment dynamics associated with formation of capital are controlled by using quadratic adjustment costs experienced when installing new capital, which imply that real costs are experienced to build and install new capital equipment.

Prior to investigating policy scenarios, it is necessary to establish a baseline path for the economy that incorporates economic growth and technology changes that are expected to occur in the absence of the policy actions. Beginning from the initial balanced SAM dataset, the model is calibrated to replicate forecasts from the AEO 2007. Upon incorporating these forecasts, EMPAX-CGE is solved to generate a baseline based on them through 2030. Once this baseline is established, it is possible to run the "counterfactual" policy experiments discussed below.

5b.3.7 Caveats Regarding EMPAX Modeling and the Results of this Analysis

The results generated by EMPAX-CGE that are provided in this RIA appendix, which include estimates of price and output changes by industry and energy impacts, have a number of caveats and limitations associated with them that one should be cognizant of. They are as follows:

As mentioned above, the current EMPAX-CGE model only considers the costs of policies and ignores the beneficial economic consequences of air quality improvements such as increased labor availability and productivity. If these health-related improvements were included in the model, any production decreases estimated by the model might be partially offset.

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[15] See Babiker et al. (2001) for a discussion of how this methodology was used in the EPPA model (EPPA assumes that AEEI parameters are the same across all industries in a country, while AEEI values in EMPAX-CGE are industry specific).

The extent of these potential benefits, along with current estimates of GDP impacts, depend on the labor supply elasticities in the model that have been chosen from the CGE literature on labor markets and tax distortions as discussed above. More flexible labor supply elasticities would allow additional response in labor markets to policy impacts, potentially with both positive and negative effects. Other critical assumptions in EMPAX-CGE largely revolve around the production technologies and input substitution options, which are based on the MIT EPPA model.

It is also highly uncertain as to which industries will be affected in the future when moving beyond where known engineering controls can currently apply. This mix of industries affected may be different than those current controls apply to, and tighter ozone standards may lead to consideration of controls to industries previously unaffected by measures related to ozone implementation. Ozone SIPs sometimes provide a "black box" (as per Section 182(e)(5) of the Clean Air Act) for additional controls to be supplied by unknown measures, and individual sectors where these controls may apply are never specified.[16]

EMPAX requires identification of costs by industry (by NAICS or SIC code) in order to operate. The capability of EMPAX to generate impacts is thus dependent on the extent to which the input costs by industry are defined. With a lack of knowledge of affected industries, there is also a lack of knowledge of affected consumers or households (thus, no way to estimate completely household welfare impacts).

Results from EMPAX are strongly influenced by elements in its baseline data set such as energy production and consumption data taken from the Energy Information Administration's Annual Energy Outlook (AEO). The current EMPAX version uses such energy data taken from the latest AEO version available (2007). This version of the AEO does not incorporate effects on energy production and consumption data associated with provision of the Energy Independence and Security Act of 2007 (or EISA) signed by the President on December 19, 2007.[17] Such effects include increased biofuels production, increased vehicle fuel efficiency, and new minimum energy efficiency standards for many electric appliances and products. The effects of EISA will be incorporated in a revised version of the AEO that will be released to the public in March, 2008.[18]

EMPAX keeps the location of labor constant in response to a supply shock. Hence, labor is not allowed to migrate between regions based on changes in wage rates. By not allowing labor migration, some inaccuracies in estimated changes in labor and wage rates may take place. These inaccuracies in estimated labor and wage rate changes may offset the inclusion of other

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[16] Section 182 (e) (5) of the Clean Air Act allows estimation of reductions (or so-called "black box" measures) in ozone SIPs that are not allocated by source category or sectors. An example of this is on pp. 6-12 and 6-13 in the 2003 California Air Quality Management Plan for Ozone and PM found at http://www.aqmd.gov/aqmp/docs/2003AQMPChap6.pdf.
[17] The entire text of this legislation can be read at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf. This is found at the Government Printing Office's official web site.
[18] This is noted on the Energy Information Administration web site at http://www.eia.doe.gov/oiaf/aeo/index.html.

effects into EMPAX that would lead to reduced economic impact estimates such as how improvements in air quality lead to increased labor productivity.

Other caveats that can typically be applied to CGE analyses, including this one, cover issues such as transitional dynamics in the economy. CGE models such as EMPAX, which assume foresight on the part of businesses and households, will allow agents to adapt to anticipated policy impacts coming in the future. These adaptations may occur more quickly than if agents adopted a wait-and-see approach to new regulations. The alternative, recursive-dynamic structure used in CGE models such as MIT EPPA imply that no anticipation or adjustments will occur until the policy is in place, which tends to overstate the costs of policies.

Finally, in addition to transition dynamics, while CGE models are ideally suited for analyzing broad, economy-wide impacts of policies, they are not able to examine firm-specific impacts on profits/losses or estimate how particular types of disadvantaged households may be affected by policies. Similarly, environmental justice concerns may not be fully addressed.

5b.4 EMPAX-CGE Results for the Modeled Control Strategy

This section compares the modeled control strategy to a baseline for the economy that includes the current ozone standard (effectively, 0.084 ppm), along with other rules used to form the basis of the AEO 2007 forecasts by EIA such as the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). Impacts are measured assuming a 2020 implementation year and are the result of engineering costs described in Section 5.1. Thus, the following graphs compare the modeled control strategy to a baseline economic growth path in EMPAX-CGE that includes the current ozone standard and currently implemented legislation in the AEO 2007 forecasts.

5b.4.1 Projected Energy Impacts and Impacts on U.S. Industries of Incremental Costs From Modeled Control Strategy

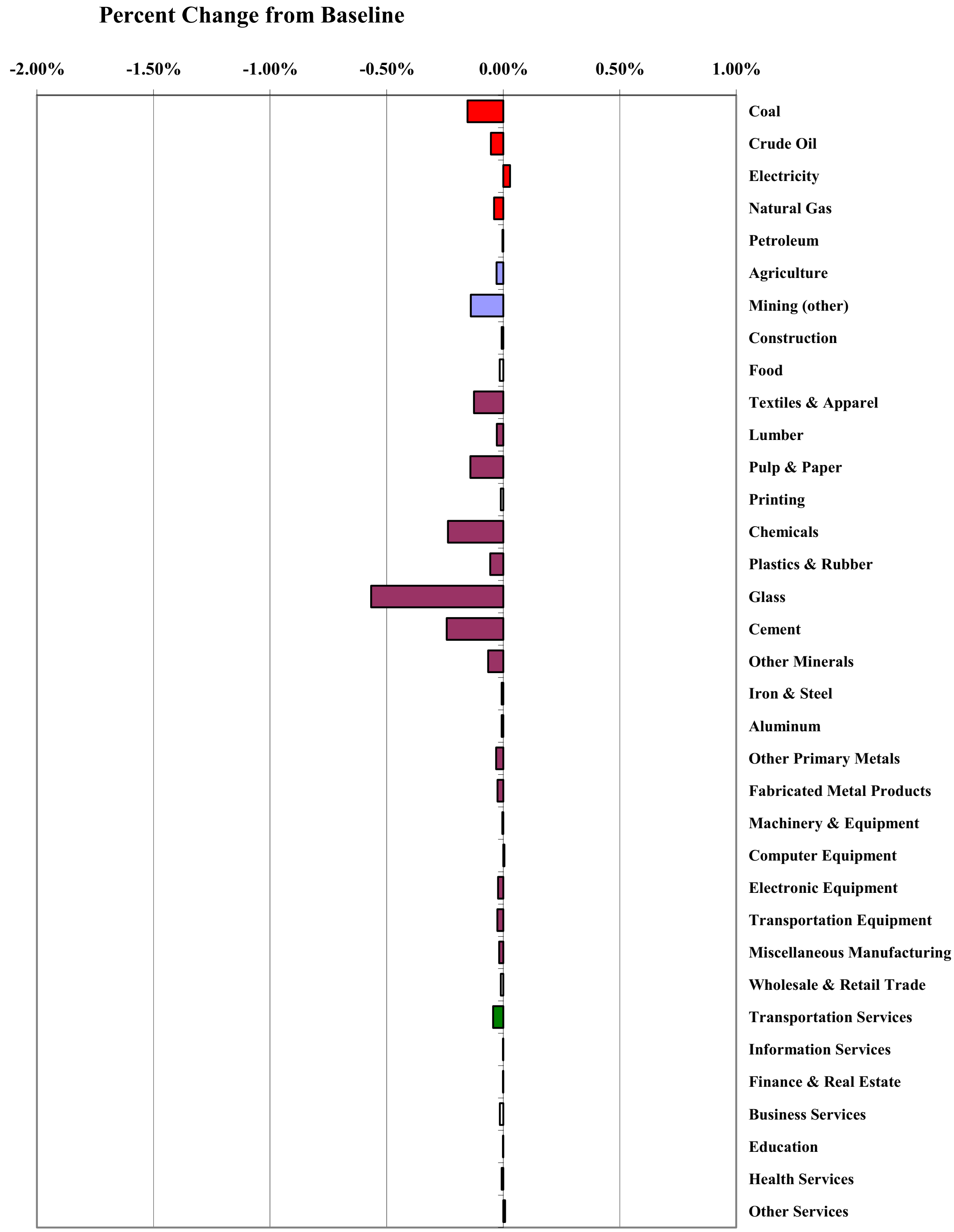
Impacts of the modeled control strategy on manufacturing costs can affect output and prices of all industries in the EMPAX-CGE model. These effects may increase or decrease output and/or revenue, depending on their implications for production costs and technologies and shifts in household demands. In general, the impacts on energy producers and other industries will be dependent on the control strategy and follow a pattern similar to the stringency of the ozone standard.

As shown in Figure 5b.3, impacts on energy and industrial output quantities are generally small across all industries for modeled control strategy. Outside of the energy-intensive sectors,[19] estimated changes in output of most manufactured goods are less than five one-hundredths of one percent (0.05%). Effects on coal output are somewhat higher, but impacts on other types of energy producers are low and can be positive or negative, which limits any spillover effects to other businesses and households. These changes in output quantities are different than any

[19] Energy-intensive sectors include food processing, pulp and paper, chemicals, glass, cement, iron and steel, and aluminum manufacturing. The definition of energy-intensive sectors applied in EMPAX-CGE is identical to that used by the U.S. Energy Information Administration (EIA) for their AEO modeling.

changes in gross output revenues, which include effects of changes in both quantity and output prices (which reflect changes in production costs) and may be either positive or negative, regardless of changes in output quantities. Also, across the economy as a whole, although there is almost no change in the quantity of services produced, these changes in output can potentially be larger in absolute terms than any changes in energy-related industries, which are much smaller than service industries in the U.S. economy. For more information on energy impacts at a nationwide level, please refer to Chapter 8 where we provide energy impact results in response to Executive Order 13211.

Figure 5b.3: Modeled Control Strategy Impacts on U.S. Domestic Output Quantity, 2020



Source: EMPAX-CGE.

As described in Chapter 3, selected control options for the modeled control strategy involve additional actions by electric utilities, which tend to slightly decrease coal consumption (influencing U.S. coal production) and increase natural gas use. EMPAX-CGE uses these findings on coal and gas use directly from the IPM model (as described in Appendix E in the RIA for the Final CAIR rule).[20] As part of its economy-wide estimation, EMPAX-CGE then considers how these changes in electricity markets affect other consumers of energy. Outside of electricity, other energy-producing industries also engage in additional measures, which can affect energy users such as energy-intensive manufacturers. Cement, chemicals and glass production are influenced by direct control costs on their respective industries and any changes in energy markets. Note, however, that across energy-intensive industries as a group, output quantities decline on average by less than a two-tenths of a percent (<0.2%).

5b.4.2 Projected Regional Impacts

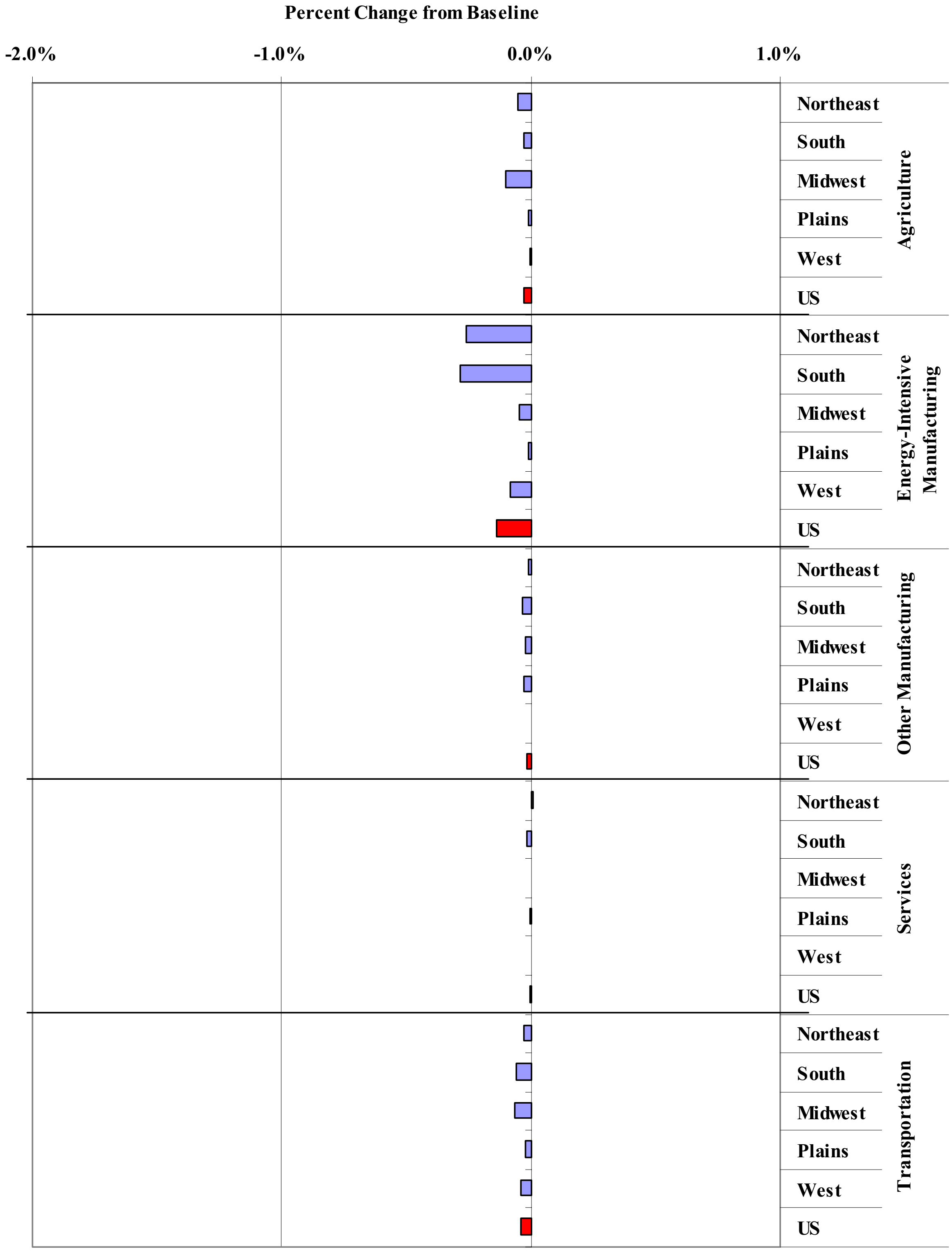
Regional effects will tend to show variation that does not appear at the national level. To examine how such variations might occur in response to the modeled control strategy, this section presents findings for selected industries and groups for the five regions in EMPAX-CGE. These divergences between average national impacts and regional effects arise from several sources such as:

- differences in control measures from the AirControlNET, IPM, and MOBILE models;
- differences in regional mixes of generation technologies (coal, gas, oil, and nonfossil use), which may be averaged out at a national level;
- differences in regional production and consumption patterns for electricity and nonelectricity energy goods;
- differences in industrial composition of regional economies;
- differences in household consumption patterns; and
- differences in regional growth forecasts.

Figure 5b.4 first presents regional impacts on industrial output from the modeled control strategy. Except for energy producers (shown in Figure 5b.5), this graph summarizes results for all the industries shown in Figure 5b.3, where similar industries are grouped together to facilitate the presentation. Aside from energy-intensive manufacturing (illustrated in more detail in Figure 5b.6), the adjustments in output are on the order of a few one-hundredths of one percent.

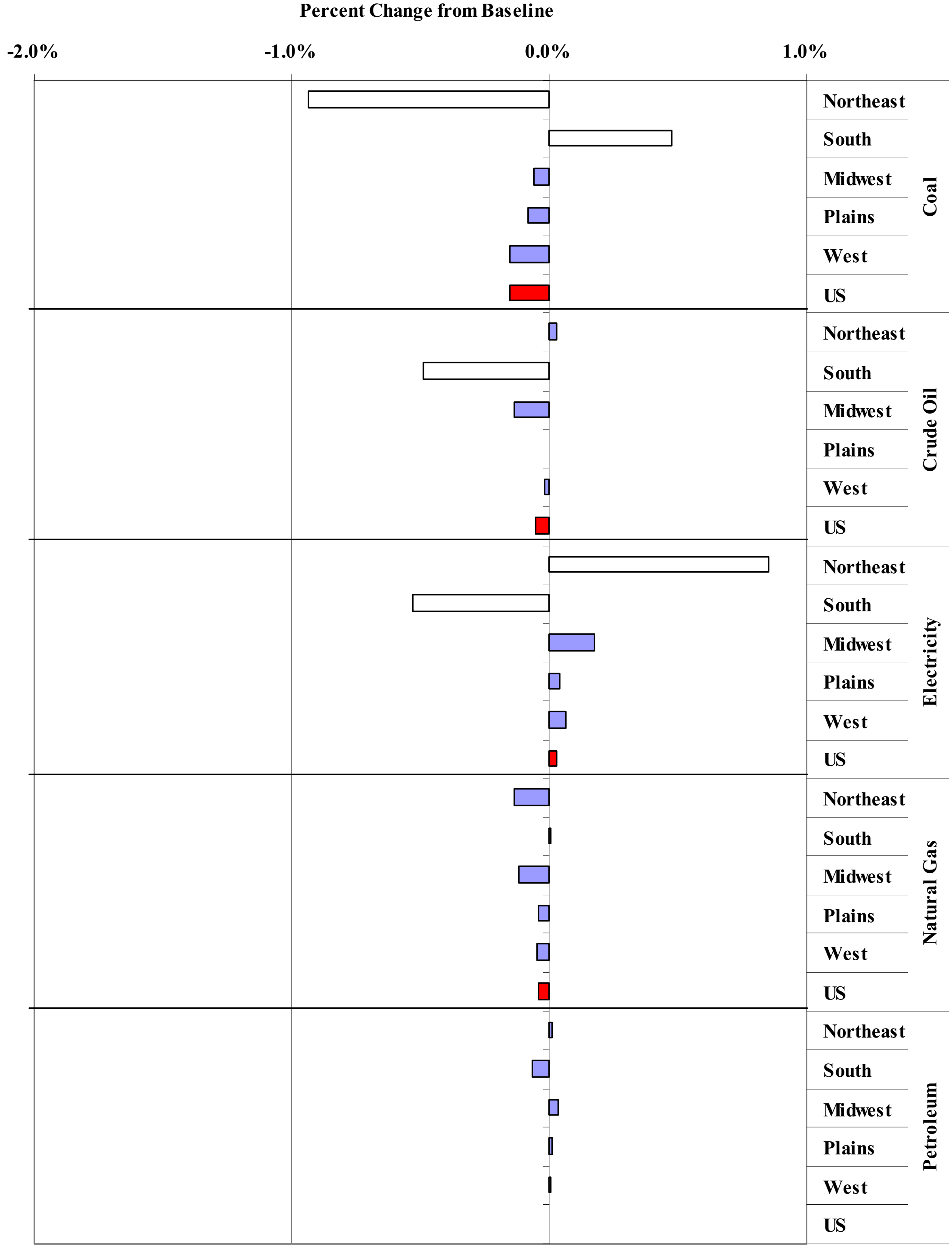
[20] See http://www.epa.gov/interstateairquality/technical.html for additional discussion of these linkages.

Figure 5b.4: Modeled Control Strategy Impacts on Regional Energy-Intensive Output Quantities, 2020



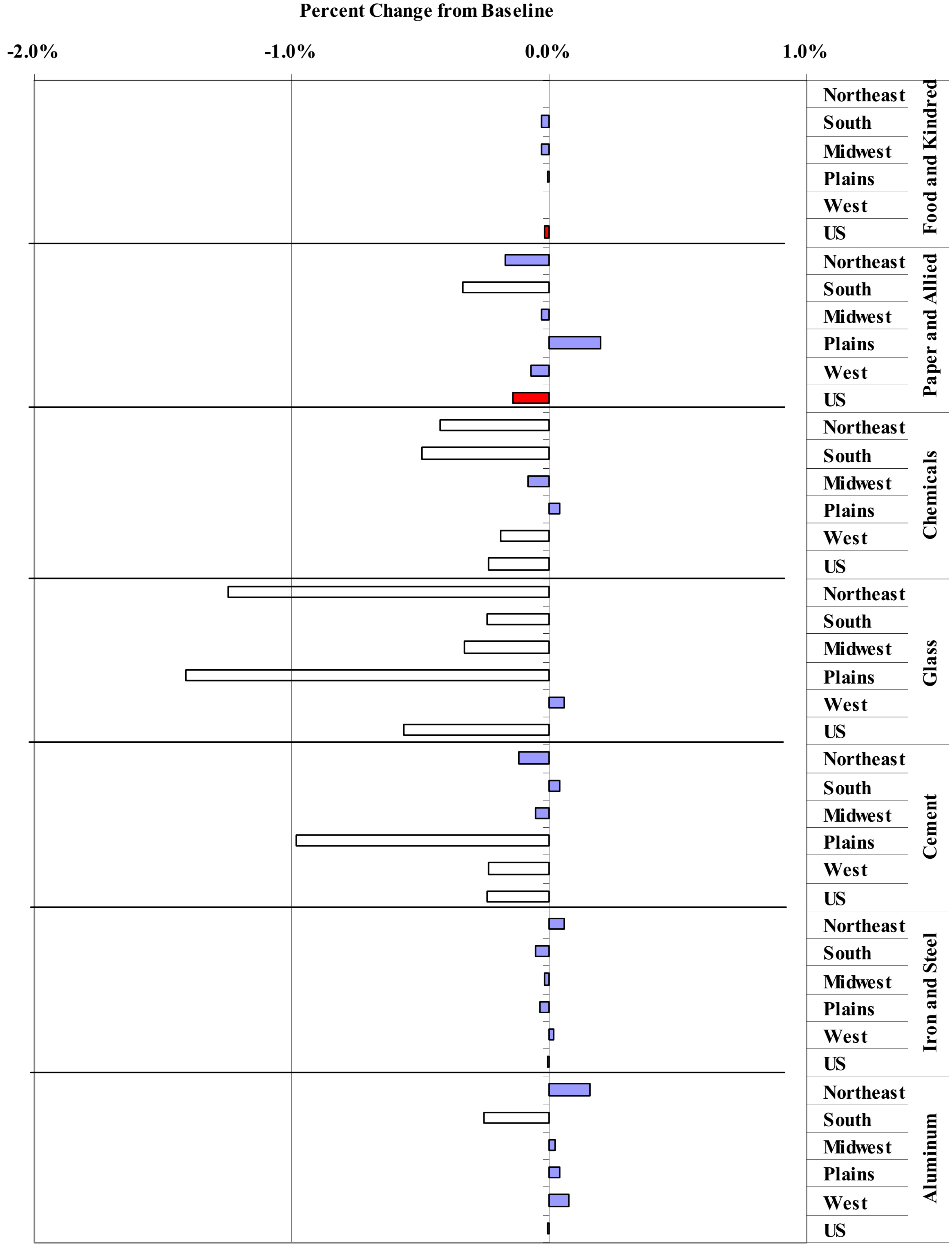
Source: EMPAX-CGE.

Figure 5b.5: Modeled Control Strategy Impacts on Regional Industry Output Quantities, 2020



Source: EMPAX-CGE.

Figure 5b.6: Modeled Control Strategy Impacts on Regional Energy Output Quantities, 2020



Unlike the broader industries, energy production that is more directly affected by the standards shows more regional variation than seen in the U.S. results in Figure 5b.3. However, all impacts are still less than one percent (<1.0%) across the regions with most adjustments smaller than that. Under the modeled control strategy, coal consumption by electric utilities tends to decrease slightly in 2020, except in the South. Natural gas use in electricity rises, but is offset by declines in other parts of the economy. Such results reflect the impacts from applying the EGU control strategy discussed in Chapter 3 of the RIA. This control strategy is applying primarily to EGUs in the Northeast and is applied only to coal-fired units. This leads to the costs of power generation becoming relatively cheaper in the South relative to the Northeast. Also, there are few controls applied to coal-fired EGUs in the South. The net impact from these effects is that EMPAX estimates that coal-fired power generation in the South decreases while it increases in the Northeast. These EMPAX results are shown in percentage and physical terms in Table 5b-2. The crude oil and petroleum refining industries react to the alternative standard by minor changes in output, although refining in some regions rises in cases where they may have a small comparative advantage as fewer refiners need to install additional controls.

Table 5b.2 Results from EMPAX in 2020 for Changes in Fuel Use and Generation by EGUs in Northeast and South Regions Under Modeled Control Strategy

Region	Baseline Use of Coal (trillion BTU) by EGUs	Use of Coal Under Modeled Control Strategy (trillion BTU)	Percent Difference in Coal Use (%)	Baseline Use of Natural Gas (trillion BTU) by EGUs	Use of Natural Gas Under Modeled Control Strategy (trillion BTU)	Percent Difference in Natural Gas Use (%)	Electricity Generation in Baseline (millions kWh)	Electricity Generation Under Modeled Control Strategy (millions kWh)	Percent Difference in Electricity Generation (%)
North-east	2,622	2,598	-0.9	871	870	-0.1	681,046	687,175	0.9
South	7,689	7,728	0.5	1,497	1,506	0.1	1,392,374	1,339,336	-0.5

BTU = British Thermal Unit

kWh = kilowatt-hour

Figure 5b.6 illustrates how changes in energy markets may affect those industries particularly reliant on energy inputs to their production processes. As with the U.S. average results from Figure 5b.3, even though the energy-intensive sectors show more regional variation, based on differences in production methods and changes in manufacturing costs, the majority of the impacts are on the order of a few tenths of one percent. However, there are measurable impacts in the output of specific industries. Under the modeled control strategy, energy-intensive output tends to be redistributed slightly from eastern to western regions as decreases in industries such as glass manufacturing in some regions are partially offset by increases in other regions.[21]

When examining such findings, however, it is important to note that these impacts and redistributions are directly related to the specific control strategy assumed in this illustrative analysis. As previously stated, these results represent the impact of the modeled control strategy presented by EPA. It is expected that States will evaluate the best strategies for achieving compliance and may choose options that could significantly alter these regional effects. Therefore, SIPs will likely be different than the strategy developed in this RIA and could be designed to alleviate any disproportionate impacts on sensitive industries. For example, given the impact on glass and cement production, assumed with this scenario, affected States may design SIP strategies that mitigate the impact on these particular industries, perhaps distributing costs more uniformly among all sectors.

5b.4.3 Projected Macroeconomic Impact: GDP

The combination of economic interactions affecting business and household behavior will be reflected in the changes in GDP estimated by a CGE model. The impacts on GDP are provided here only for illustration of the macroeconomic impacts of this standard. They are not meant to illustrate the social costs associated with the modeled control strategy applied to attain the 0.070 alternate Ozone standard

Figure 5b.7 illustrates GDP in the EMPAX-CGE model's baseline forecast and the modeled control strategy. As shown, the estimated GDP impact is negligible and, in fact, it is not possible to adjust the scale of the graph to the point where the two lines do not overlap. Projected decrease in GDP for the modeled control strategy is roughly 0.02 percent (0.02%), respectively, for the year 2020. This is equivalent to a $3.6 billion decrease in GDP during the implementation year. In absolute terms, these estimated changes in U.S. GDP are extremely small relative to the total size of the economy. Even these small costs could be reduced if the CGE analyses were extended to include benefits associated with any alternate primary ozone standard such as improvements in labor productivity from environmental improvements.

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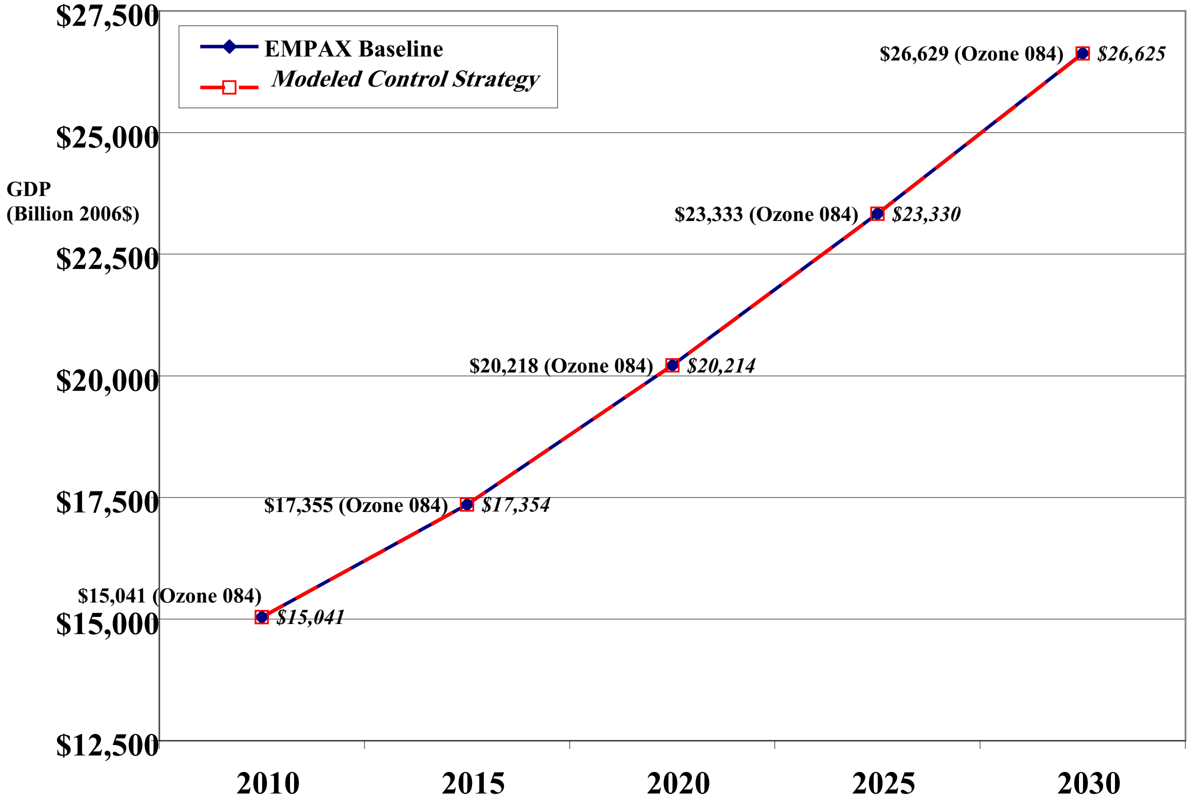
[21] Redistribution of production will also tend to occur among states in each region, with some states' increasing output to offset any declines in neighboring states.

Figure 5b.7: Change in U.S. GDP Compared to EMPAX-CGE Baseline



Source: Department of Energy, Energy Information Administration; EMPAX-CGE

5b.4.4 Social Cost Approaches and Estimates

To provide an estimate of the social costs associated with the modeled control strategy, EMPAX-CGE monetizes welfare changes from the general equilibrium simulation using Hicksian equivalent variation (EV), which is related in concept to the producer/consumer surplus measures used in partial-equilibrium models. EV is a long-recognized technique to estimate welfare gains and losses in economic theory, having been developed by Sir John Hicks in 1939.[22] EV provides an estimate of the change in income that would provide an equivalent change in household welfare as the policy being considered and includes changes in utility households receive from both consumption and leisure time.[23] It is a technique that is widely used by economists to measure welfare change. For example, Chipman and Moore (1980) showed that

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[22] Hicks introduced this concept into economic theory in his book "Value and Capital: An inquiry into some fundamental principles of economic theory," published in 1939.

[23] Including leisure time in the model and household decisions allows the labor supply to expand or contract in response to changes in wage rates, etc. It is also essential when modeling interactions between tax interactions and the economy.

EV is appropriate for welfare comparisons.[24] However, as calculated using EMPAX-CGE currently, it excludes measures of the standard's environmental benefits (e.g., environment, public health, and labor productivity). In addition, these social cost estimates from EMPAX-CGE do not incorporate extrapolated costs since these costs do not have a clear link to specific industries. The general equilibrium model estimates that the relative change in infinite-horizon[25] and average annual welfare losses are extremely small (approximately 0.025%). Over the 2005-2020 time horizon used in EMPAX-CGE for this analysis, the social costs are 93 percent of the engineering costs for the illustrative modeled control strategy when estimated in present value terms (2006 dollars).[26,27] We estimate social costs using a 5 percent real interest rate to discount future production and consumption as per EPA guidance from the SAB provided in 2003.

We use EV to provide an estimate of social costs in this analysis instead of a metric such as GDP since changes in GDP are a poor measure of impacts on consumer welfare. Although GDP is a common metric among policymakers for expressing "costs to society," it is a poor measure of "social costs." GDP as a measure of welfare has been criticized for many years by different economists. Much of that criticism is well summarized in a response to the 2004 Draft Thompson Report to Congress prepared by Arik Levinson and quoted as follows: "… GDP growth is a poor measure of welfare. It measures the flow of economic activity rather than the flow of assets. If there is over-fishing, regulations that reduce fish catch will reduce GDP in the short run, but increase long-run economic prosperity… Finally, GDP excludes non-traded benefits: environmental quality, health, workplace safety…" [28] Changes in household consumption are much closer to changes in the welfare of households (ignoring leisure) than changes in GDP. For example, since consumption is around two-thirds of GDP, a ballpark estimate might be that any changes in consumption will only be around two-thirds as large in dollar terms as changes in GDP. GDP also does not account for the value of leisure, which is accounted for directly in estimates of welfare impacts using an EV approach as mentioned above. Regarding exports and imports, GDP does account directly for the effect of export and

[24] Chipman, John S., and James C. Moore. 1980. Compensating Variation, Consumer's Surplus, and Welfare. American Economic Review 70 (5): 933-49.

[25] By infinite horizon, what is meant is an infinite number of time horizons. Since it is not computationally feasible for EMPAX-CGE to provide estimates to this many time horizons, the model approximates an infinite horizon. Turn to p. 6-9 of the EMPAX-CGE documentation at http://www.epa.gov/ttnecas1/models/empax_model_documentation.pdf for details.

[26] It should be noted that we will not compare this social cost estimate with the benefits estimates for alternate primary standards presented later in this RIA. We do not make this comparison for two key reasons: 1) the lack of linkage between air quality changes and effect categories such as labor productivity and health care costs among households; and 2) our inability to provide extrapolated costs by industry to serve as input to EMPAX.

[27] As mentioned in Chapter 5, the engineering cost estimate for the modeled control strategy of $2.8 billion (2006$) is calculated using the Equivalent Uniform Annual Cost (EUAC) method. The EUAC method does *not* generate the present value of the annual costs of controls on a year-by-year basis from 2005 to 2020.

[28] Levinson, Arik. Response to 2004 Draft Report to Congress on the Costs and Benefits of Federal Regulation and Unfunded Mandates on State, Local, and Tribal Entities (or "Thompson Report"). Submitted to the U.S. Office of Management and Budget. June 2, 2004. Found on the Internet at http://www.whitehouse.gov/omb/inforeg/2004_cb/c.pdf.

imports upon U.S. expenditure on goods and services. The effect of purchasing imports upon household welfare as measured by the EV approach is accounted for indirectly through changes in household consumption and does not account for changes due to exports. We conclude thatThus, GDP is a poor metric for estimating welfare impacts in comparison to the EV approach, and therefore social costs. [29]

As part of being a dynamic, forward-looking model, EMPAX uses an interest rate to place a value on the future (including both the benefits of consumption and costs of production). We have been using a 5% real interest rate, based on the MIT EPPA model referred to earlier in this chapter and SAB guidance as discussed in U.S. EPA (2003). This interest rate will form the basis for how the model reacts to any engineering costs it sees coming in the future. Following the guidance provided in OMB's Circular A-4, we also provide social cost estimates in this appendix over the same 2005-2020 time horizon that reflect a 3% real interest rate, and a 7% real interest rate. These social cost estimates are 90 and 91 percent, respectively, of the engineering costs when costs are calculated in present value terms.

This is the first application of EV to estimate social costs as part of analysis using a CGE model in an RIA of this type. We intend to solicit review and advice from the SAB before its use in future economic impact analyses using CGE models.

5b.5 References

Babiker, M.H., and T.F. Rutherford. 1997. "Input Output and General Equilibrium Estimates of Embodied CO_2: A Data Set and Static Framework for Assessment." University of Colorado at Boulder, Working Paper 97 2. Available at http://www.mpsge.org/mainpage/mpsge.htm.

Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I.S. Wing, and R.C. Hyman. 2001. "The MIT Emissions Prediction and CO2 Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results." MIT Joint Program on the Science and Policy of Global Change, Report No. 71. Available at <http://web.mit.edu/globalchange/www/eppa.html>.

Ballard, C. J. Shoven, and J. Whalley. 1985. "General Equilibrium Computations of the Marginal Welfare Costs of Taxation in the United States" American Economic Review 75(1): 128-138.

Bovenberg, L.A., and L.H. Goulder. 1996. "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analysis." American Economic Review 86(4):985-1000. Available at <http://www.aeaweb.org/aer/>.

Brooke, A., D. Kendrick, A. Meeraus, and R. Raman. 1998. GAMS: A User's Guide. GAMS Development Corporation. Available at http://www.gams.com.

[29] We provide estimates of the changes in GDP in 2020 from implementation of the modeled control strategy in Chapter 6, but only to provide information on this commonly known macroeconomic metric.

Feenberg, D., and E. Coutts. 1993. "An Introduction to the TAXSIM Model." Journal of Policy Analysis and Management 12(1):189 194. Available at http://www.nber.org/~taxsim/.

Fullerton, D., and D. Rogers. 1993. "Who Bears the Lifetime Tax Burden?" Washington, DC: The Brookings Institute. Available at http://bookstore.brookings.edu/ book_details.asp?product%5Fid=10403.

Global Insight. 2007. "U.S. State, Metropolitan Area, and County-level Forecasting Services." <http://www.globalinsight.com/ProductsServices/ProductDetail1100.htm>

Goulder, L.H., and R.C. Williams. 2003. "The Substantial Bias from Ignoring General Equilibrium Effects in Estimating Excess Burden, and a Practical Solution." Journal of Political Economy 111:898 927. Available at <http://www.journals.uchicago.edu/JPE/home.html>

Minnesota IMPLAN Group. 2006. State Level Data for 2004. Available from http://www.implan.com/index.html.

Nestor, D.V., and C.A. Pasurka. 1995. The U.S. Environmental Protection Industry: A Proposed Framework for Assessment. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation. EPA 230-R-95-001. Available at http://yosemite.epa.gov/ee/epa/eermfile.nsf/11f680ff78df42f585256b45007e6235/41b8b642ab9371df852564500004b543/$FILE/EE 0217A 1.pdf.

Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker. 2005. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4." MIT Joint Program on the Science and Policy of Global Change, Report No. 125. Cambridge, MA. <http://web.mit.edu/globalchange/www/eppa.html>.

Rutherford, T.F. 1999. "Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax." Computational Economics 14(1):1 46. Available at http://www.gams.com/solvers/mpsge/syntax.htm.

Rutherford, T.F., and S.V. Paltsev. 2000. "GTAP Energy in GAMS: The Dataset and Static Model." University of Colorado at Boulder, Working Paper 00 2. Available at http://www.mpsge.org/mainpage/mpsge.htm.

U.S. Department of Energy, Energy Information Administration. Undated (a). State Energy Data Report. Washington DC. Available at http://www.eia.doe.gov/emeu/states/ _use_multistate.html.

U.S. Department of Energy, Energy Information Administration. Undated (b). State Energy Price and Expenditure Report. Washington DC. Available at http://www.eia.doe.gov/emeu/states/price_multistate.html.

U.S. Department of Energy, Energy Information Administration. 2003. Manufacturing Energy Consumption Survey 2002. Washington DC. Available at http://www.eia.doe.gov/emeu/mecs/.

U.S. Department of Energy, Energy Information Administration. January 2007. Annual Energy Outlook 2007. DOE/EIA-0383(2007). Washington, DC. Available at http://www.eia.doe.gov/oiaf/aeo/index.html.

U.S. Environmental Protection Agency (EPA), Office of Policy Analysis and Review. 2003. "Benefits and Costs of the Clean Air Act 1990–2020: Revised Analytical Plan For EPA's Second Prospective Analysis."

Chapter 6: Incremental Benefits of Attaining Alternative Ozone Standards Relative to the Current 8-hour Standard (0.08 ppm)

Synopsis

Based on projected emissions and air quality modeling, in 2020, 28 counties in the U.S. with ozone monitors are anticipated to fail to meet an alternative ozone standard of 0.075 ppm for the 4th highest maximum 8-hour ozone concentration. This number falls to 11 for an ozone standard of 0.079 ppm, and increases to 89 for a standard of 0.070 ppm, and increases to 231 for an alternative standard of 0.065 ppm (see Figure 3.4 in Chapter 3). We estimated the health benefits of attaining these alternative ozone standards across the nation using the EPA Environmental Benefits Modeling and Analysis Program (BenMAP) using a two-stage analysis.

In the first stage, we estimated the benefits associated with improving modeled air quality using known control technologies. These control strategies were sufficient to bring some, but not all, areas into attainment with the alternative standards. Thus, for some areas, the benefits computed during this first stage only represented partial attainment. In the second stage, we estimated the benefits of fully attaining the standards in all areas by using a "rollback" method. This method reduced ozone concentrations at nonattaining monitors to a level that would just meet the standards. To estimate the benefits for the 0.075 ppm and 0.079 standards, we deviated from this two-stage approach. Instead, we used an interpolation technique (please see Appendix 6a for more details on this technique). Benefits for the South Coast and San Joaquin areas of California (which are not expected to reach attainment of the current standard until after 2020) are estimated separately and can be found in Appendix 7b.[1] For all alternative standards, we used health impact functions based on published epidemiological studies and valuation functions derived from the economics literature to calculate the monetary value of the adverse health outcomes potentially avoided due to these reductions in ambient ozone levels.[2] Key health endpoints included premature mortality, hospital and emergency room visits, school absences, and minor restricted activity days.

There is considerable uncertainty in the magnitude of the association between ozone and premature mortality. This analysis presents four independent estimates of this association based upon different functions reported in the scientific literature. We also note that this range of estimates do not fully capture the uncertainties within each study. Recognizing that additional research is necessary to clarify the underlying mechanisms causing these effects, we also consider the possibility that the observed associations between ozone and mortality may not be causal in nature. Using the National Morbidity, Mortality and Air Pollution Study (NMMAPS), which was used as the primary basis for the risk analysis presented in our Staff Paper and reviewed by Clean Air Science Advisory Committee (CASAC), we estimated 250 avoided premature deaths annually in 2020 from reducing ozone levels to meet a standard of 0.070 ppm. When added to the other projected benefits from reduced ozone, including 3,000 hospital and

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[1] All subsequent estimates of full attainment ozone benefits and $PM_{2.5}$ co-benefits found in this chapter exclude these two areas of California.
[2] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration

emergency room admissions, 640,000 school absences, and over 1.7 million minor restricted activity days, we estimated a total ozone-related benefit of $2.2 billion/yr (2006$). Using three studies that synthesize data across a large number of individual studies, we estimate between 810 and 1,100 avoided premature deaths annually in 2020 from reducing ozone to 0.070 ppm, leading to total monetized ozone-related benefits of between $6.5 and $9 billion/yr. Alternatively, if there is no causal relationship between ozone and mortality, avoided premature deaths associated with reduced ozone exposure would be zero and total monetized ozone-related morbidity benefits would be $230 million/yr.

For the selected standard of 0.075 ppm, using the NMMAPS ozone mortality study resulted in 71 premature deaths avoided and total monetized benefits of $620 million/yr, incremental to attainment of the 0.08 ppm standard. Using the three synthesis studies, estimated premature deaths avoided for the less stringent standard are between 230 and 320 with total monetized ozone benefits between $1.9 and $2.6 billion/yr. Alternatively, if there is no causal relationship between ozone and mortality, avoided premature deaths associated with reduced ozone exposure would be zero and total monetized ozone-related morbidity benefits would be $73 million/yr.

For a less stringent standard of 0.079 ppm, using the NMMAPS ozone mortality study resulted in 24 premature deaths avoided and total monetized benefits of $220 million/yr, incremental to attainment of the 0.08 ppm standard. Using the three synthesis studies, estimated premature deaths avoided for the less stringent standard are between 80 and 110, with total monetized ozone benefits between $640 and $890 million/yr. Alternatively, if there is no causal relationship between ozone and mortality, avoided premature deaths associated with reduced ozone exposure would be zero and total monetized ozone-related morbidity benefits would be $28 million/yr.

For a more stringent standard of 0.065 ppm, using the NMMAPS ozone mortality study resulted in 450 premature deaths avoided and total monetized benefits of $3.9 billion/yr, incremental to attainment of the 0.08 ppm standard. Using the three synthesis studies, estimated premature deaths avoided for the more stringent standard are between 1,500 and 2,100, with total monetized ozone benefits between $12 and $16 billion/yr. Alternatively, if there is no causal relationship between ozone and mortality, avoided premature deaths associated with reduced ozone exposure would be zero and total monetized ozone-related morbidity benefits would be $420 million/yr.

These estimates reflect EPA's interim approach to characterizing the benefits of reducing premature mortality associated with ozone exposure. EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits associated with alternative ozone control strategies. We expect to receive this advice later this spring.

The monetary benefits of visibility improvements from $PM_{2.5}$ reductions associated with from the 0.070 modeled attainment strategy in selected federal Class I Areas in 2020 is $160 million/yr.

In addition to the direct benefits from reducing ozone, attainment of the standards would likely result in additional health and welfare benefits because reducing the ozone precursors NOx and VOC will also reduce $PM_{2.5}$. Using both modeled and extrapolated reductions in these precursor emissions, we estimated PM-related co-benefits for the four alternative standards. For each alternative standard, we provide a range of estimated benefits based on several different PM mortality effect estimates. These effect estimates were derived from two different sources: the published epidemiology literature and an expert elicitation study conducted by EPA in 2006.

For the 2020 attainment of the 0.075 ppm alternative, incremental to attainment of the 0.08 ppm standard, we estimate total ozone and $PM_{2.5}$-related co-benefits to be between $3.6 and $16 billion/yr; this range encompasses the expert functions and the ozone mortality functions as well as the possibility that there is no causal relationship between ozone and mortality.

For the 2020 attainment of the 0.079 ppm alternative, incremental to attainment of the 0.08 ppm standard, we estimate total ozone and $PM_{2.5}$-related co-benefits to be between $2 and $11 billion/yr; this range encompasses the expert functions and the ozone mortality functions as well as the possibility that there is no causal relationship between ozone and mortality.

For the 2020 attainment of the 0.070 ppm alternative, incremental to attainment of the 0.08 ppm standard, we estimate total ozone and $PM_{2.5}$-related co-benefits to be between $6.5 and $27 billion/yr (3% and 7% discount rates, 2006$); this range encompasses the expert functions and the ozone mortality functions as well as the possibility that there is no causal relationship between ozone and mortality.

For the 2020 attainment of the 0.065 ppm alternative, incremental to attainment of the 0.08 ppm standard, we estimate total ozone and $PM_{2.5}$-related co-benefits of between $11 and $42 billion/yr; this range encompasses the expert functions and the ozone mortality functions as well as the possibility that there is no causal relationship between ozone and mortality.

6.1 Background

The purpose of this analysis is to assess the human health benefits of attaining the selected 8-hour ozone standard of 0.075 ppm as well as alternative standards, including 0.079 ppm, 0.070 ppm, and 0.065 ppm, incremental to attainment of the current 8-hour ozone standard of 0.08 ppm.[3] We applied a damage function approach similar to those used in several recent U.S. EPA regulatory impact analyses, including those for the 2006 Particulate Matter (PM) NAAQS (U.S. EPA, 2006) and the Clean Air Interstate Rule (U.S. EPA, 2005). This approach estimates changes in individual health and welfare endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the individual values. We calculated total benefits simply by summing the values for all non-overlapping health and welfare endpoints. This analysis largely builds on both the analytical approach used in the 2006 PM NAAQS RIA and the analysis of ozone health impacts reported in Hubbell et al. (2005) and the Clean Air Interstate Rule RIA (2005). For a more detailed discussion of the principles of benefits analysis used here, please see those documents, as well as the EPA Guidelines for Economic Analysis (2000).[4,5,6]

[3] This is effectively 0.084 ppm due to current rounding conventions. When calculating benefits in this chapter we followed the rounding convention and rounded to 0.084 ppm.
[4] U.S. EPA. 2006. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for Particle Pollution, Chapter 5. Available at http://www.epa.gov/ttn/ecas/ria.html.

We applied a two-stage approach to estimate the benefits of fully attaining each alternative standard. In the first stage, we estimated the benefits associated with improving modeled air quality using known and available control technologies. These control strategies were sufficient to bring some, but not all, areas into attainment with the various alternative standards. Thus, for some areas, the benefits computed during this first stage only represented partial attainment (see Chapter 3 for details on these control technologies and the results of the air quality modeling). In the second stage, we estimated the benefits of fully attaining the standards in all areas by using a "rollback" method. This method reduced ozone concentrations at residually nonattaining monitors to a level that would just meet the standards (see Appendix 6a for details on this methodology). We tested the sensitivity of our results to different assumptions, including the choice of health effect estimates from epidemiological studies and economic valuation parameters for those health effects. A quantitative assessment of non-health benefits (e.g., benefits from reduced ozone-related crop damage) was beyond the scope of this analysis due to data and resource limitations.

For this assessment, we estimated the benefits of reducing ozone and PM concentrations by applying illustrative control strategies on ozone precursor emissions to attain alternative ozone NAAQS. With the exception of ozone-related premature mortality, we used methods consistent with previous PM and ozone benefits assessments. Specifically, we used the same approach to analyze PM co-benefits as the 2006 PM NAAQS RIA (U.S. EPA, 2006). In addition, we used a nearly identical approach to analyze the ozone benefits as the 2007 Ozone RIA (U.S. EPA, 2007).

All estimates of ozone benefits and $PM_{2.5}$ co-benefits in this chapter are incremental to a baseline of national full attainment with 0.08 ppm.[7] This baseline incorporates emission reductions projected to be achieved through an array of federal rules such as the Clean Air Interstate and Non-Road Diesel Rules, as well as ozone and $PM_{2.5}$ state implementation plans. Moreover, the $PM_{2.5}$ co-benefits are incremental to an assumption of full attainment of the 2006 $PM_{2.5}$ NAAQS. See Chapter 3 for a complete discussion of the baseline. The PM co-benefits presented in this chapter are incremental to the PM benefits estimated in the 2006 PM NAAQS RIA and reflect the PM benefits from NOx reductions associated with each ozone control strategy.

Furthermore, none of the estimates of incidence or monetary benefits provided in this chapter include South Coast and San Joaquin Valley Air Basins. Attainment dates will be determined in the future through the SIP process based on criteria in the CAA, future air quality data, and future rulemakings and are not knowable at this time. For analytical simplicity, and in keeping

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[5] Hubbell, B., A. Hallberg, D.R. McCubbin, and E. Post. 2005. Health-Related Benefits of Attaining the 8-Hr Ozone Standard. Environmental Health Perspectives 113:73–82.
U.S. EPA. 2000. Guidelines for Preparing Economic Analyses.
http://yosemite1.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/Guidelines.pdf

[6] U.S. EPA. 2000. Guidelines for Preparing Economic Analyses.
http://yosemite1.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/Guidelines.pdf

[7] The $PM_{2.5}$ benefits presented below reflect the NOx emission reductions from the ozone control strategy. Reductions from Ocean-Going Vessels burning residual diesel fuel were included both East and West in the baseline PM co-benefits, but not included in the ozone baseline for the west. See chapter 3 for more details of this rule and its application.

with the proposal analysis, we have chosen to use an analysis year of 2020 and generally assume attainment in that year. The exception is the San Joaquin and South Coast California areas where SIP submittals for the current standard show that they would have current standard attainment dates later than 2020. For these two areas in California, we are assuming a new standard attainment date of 2030. Estimates of the costs and benefits of attaining the 0.075 ppm standard and the alternate air quality standards for these two areas in 2030 not included in the primary benefit analysis and are provided in Appendix 7b.

For purposes of this analysis, we assume attainment by 2020 for all areas except San Joaquin Valley and South Coast air basins in California. The state has submitted plans to EPA for implementing the current ozone standard which propose that these two areas of California meet that standard by 2024. We have assumed for analytical purposes that the San Joaquin Valley and South Coast air basin would attain a new standard in 2030. There are many uncertainties associated with the year 2030 analysis. Between 2020 and 2030 several federal air quality rules are likely to further reduce emissions of NOx and VOC, such as, but not limited to National rules for Diesel Locomotives, Diesel Marine Vessels, and Small Nonroad Gasoline Engines. These emission reductions should lower ambient levels of ozone in California between 2020 and 2030. Complete emissions inventories as well as air quality modeling were not available for this year 2030 analysis. Due to these limitations, it is not possible to adequately model 2030 air quality changes that are required to develop robust controls strategies with associated costs and benefits. In order to provide a rough approximation of the costs and benefits of attaining 0.075 ppm and the alternate standards in San Joaquin and South Coast air basins, we have relied on the available data. Available data includes emission inventories, which do not include any changes in stationary source emissions beyond 2020, and 2020 supplemental air quality modeling. This data was used to develop extrapolated costs and benefits of 2030 attainment. These results indicate that benefits would be between $0.13 billion and $2.0 billion for the selected ozone standard of 0.075 ppm in 2030. To view the complete analysis for the San Joaquin Valley and South Coast air basins, see Appendix 7b.3

The remainder of this chapter describes the data and methods used in this analysis, along with the results. Appendix 6a of this RIA provides additional details of the analysis. Section 6.2 discusses the probabilistic framework for the benefits analysis and how key uncertainties are addressed in the analysis. Section 6.3 discusses the literature on ozone- and PM-related health effects and describes the specific set of health impact functions we used in the benefits analysis. Section 6.4 describes the economic values selected to estimate the dollar value of ozone- and PM- related health impacts. Finally, Section 6.5 presents the results and implications of the analysis.

6.2 Characterizing Uncertainty: Moving Toward a Probabilistic Framework for Benefits Assessment

The National Research Council (NRC) (2002) highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers 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.

Two aspects of OAR's strategy have been used in several recent RIAs and are also employed in this analysis.[8,9,10] First, we used Monte Carlo methods for estimating characterizing random sampling error associated with the concentration response functions from epidemiological studies 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 premature mortality. 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. Table 6.4 describes the distributions for unit values.

Second, because characterization of random statistical error omits important sources of uncertainty (e.g., in the functional form of the model—e.g., whether or not a threshold may exist) we used a recently completed expert elicitation of the concentration response function describing the relationship between premature mortality and ambient $PM_{2.5}$ concentration.[11] Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, it is particularly important to attempt to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies.[12] In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs. In addition, we characterize the uncertainty introduced by the inability of existing empirical studies to discern whether the relationship

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[8] U.S. Environmental Protection Agency, 2004a. Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. EPA420-R-04-007. Prepared by Office of Air and Radiation. Available at http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf

[9] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the Clean Air Interstate Rule. EPA 452/-03-001. Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/interstateairquality/tsd0175.pdf

[10] U.S. Environmental Protection Agency, 2006. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

[11] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

[12] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration.

between ozone and pre-mature mortality is causal by providing an effect estimate preconditioned on an assumption that the effect estimate for pre-mature mortality from ozone is zero.

For premature mortality associated with exposure to PM, we follow the same approach used in the RIA for 2006 PM NAAQS (U.S. EPA, 2006), presenting several empirical estimates of premature deaths avoided, and a set of twelve estimates based on results of the expert elicitation study.[13] Even these multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

6.3 Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: 1) an effect estimate from a particular study; 2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); 3) the size of the potentially affected population; and 4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y \quad y_0 \cdot \; e^{\beta \cdot \Delta x} - 1$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary ozone measure. There are other functional forms, but the basic elements remain the same. Chapter 3 described the ozone and PM air quality inputs to the health impact functions. The following subsections describe the sources for each of the other elements: size of potentially affected populations; effect estimates; and baseline incidence rates.

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

6.3.1 *Potentially Affected Populations*

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset (Geolytics 2002). Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2020 using growth factors based on economic projections (Woods and Poole Inc. 2001).

6.3.2 *Effect Estimate Sources*

The most significant monetized benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents outline numerous health effects known or suspected to be linked to exposure to ambient ozone and PM (US EPA, 2006; US EPA, 2005; Anderson et al., 2004). EPA recently evaluated the PM literature for use in the benefits analysis for the 2006 PM NAAQS RIA. Because we use the same literature for the PM co-benefits analysis in this RIA, we do not provide a detailed discussion of individual effect estimates for PM in this section. Instead, we refer the reader to the 2006 PM NAAQS RIA for details.[14]

More than one thousand new ozone health and welfare studies have been published since EPA issued the 8-hour ozone standard in 1997. Many of these studies investigated the impact of ozone exposure on health effects such as changes in lung structure and biochemistry; lung inflammation; asthma exacerbation and causation; respiratory illness-related school absence; hospital and emergency room visits for asthma and other respiratory causes; and premature death.

We were not able to separately quantify all of the PM and ozone health effects that have been reported in the ozone and PM criteria documents in this analysis for four reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; (3) the lack of an established concentration-response relationship; or (4) the inability to appropriately value the effect (for example, changes in forced expiratory volume) in economic terms. Table 6.1 lists the human health and welfare effects of pollutants affected by the alternative standards. Table 6.2 lists the health endpoints included in this analysis.

In order to select appropriate epidemiological studies to use for our effect estimates, we applied several criteria to determine the set of studies that is likely to provide the best estimates of effects in the U.S. To account for the potential effects of different health care systems or underlying health status of populations, we gave preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we gave preference to effect

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[14] U.S. Environmental Protection Agency, 2005. Regulatory Impact Analysis for the PM NAAQS. EPA Prepared by Office of Air and Radiation. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf pp. 5-29.

estimates from models that included both ozone and PM over effect estimates from single-pollutant models.[15,16]

A number of endpoints that are not health-related may also contribute significant monetized benefits. Potential welfare benefits associated with ozone exposure include increased outdoor worker productivity; increased yields for commercial and non-commercial crops; increased commercial forest productivity; reduced damage to urban ornamental plants; increased recreational demand for undamaged forest aesthetics; and reduced damage to ecosystem functions (U.S. EPA 1999, 2006). Although we estimate the value of increased outdoor worker productivity, estimation of other welfare effects is beyond the scope of this analysis.

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[15] U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004.

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

Table 6.1: Human Health and Welfare Effects of Ozone and $PM_{2.5}$

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects[h]—Changes in:
PM/Health[b]	Premature mortality based on both cohort study estimates and on expert elicitation[c,d] Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits UVb exposure (+/-)[e]
PM/Welfare	Visibility in Southeastern, southwestern and California Class I areas	Visibility in northeastern and Midwestern Class I areas Household soiling Visibility in residential and non-Class I areas UVb exposure (+/-)[e]
Ozone/Health[f]	Premature mortality: short-term exposures Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Acute respiratory symptoms	Cardiovascular emergency room visits Chronic respiratory damage Premature aging of the lungs Non-asthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare		Decreased outdoor worker productivity Yields for commercial crops Yields for commercial forests and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the alternative standards.
[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[c] Cohort estimates are designed to examine the effects of long-term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli, 2001 for a discussion of this issue).
[d] While some of the effects of short-term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short-term PM exposure not captured in the cohort estimates included in the primary analysis.
[e] May result in benefits or disbenefits. Appendix 6d includes a sensitivity analysis that partially quantifies this endpoint. This analysis was performed for the purposes of this RIA only.
[f] In addition to primary economic endpoints, there are a number of biological responses that have been associated with ozone health including increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[g] The categorization of unquantified toxic health and welfare effects is not exhaustive.
[h] Health endpoints in the unquantified benefits column include both a) those for which there is not consensus on causality and b) those for which causality has been determined but empirical data are not available to allow calculation of benefits.

Table 6.2: Ozone and PM Related Health Endpoints Basis for the Concentration-Response Function Associated with that Endpoint, and Sub-Populations for which They Were Computed

Endpoint	Pollutant	Study	Study Population
Premature Mortality			
Premature mortality—daily time series, non-accidental	O_3 (8-hour max)	Bell et al (2004) (NMMAPS study)	All ages
		Meta-analyses:	
	O_3 (8-hour max)	Bell et al (2005)	
	O_3 (8-hour max)	Ito et al (2005)	
	O_3 (8-hour max)	Levy et al (2005)	
Premature mortality—cohort study, all-cause	$PM_{2.5}$ (annual avg)	Pope et al. (2002) Laden et al. (2006)	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$ (annual avg)	Expert Elicitation (IEc, 2006)	>24 years
Premature mortality—all-cause	$PM_{2.5}$ (annual avg)	Woodruff et al. (1997)	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$ (annual avg)	Abbey et al. (1995)	>26 years
Nonfatal heart attacks	$PM_{2.5}$ (24-hour avg)	Peters et al. (2001)	Adults (>18 years)
Hospital Admissions			
Respiratory	O_3 (24-hour avg)	Pooled estimate: Schwartz (1995)—ICD 460–519 (all resp) Schwartz (1994a; 1994b)—ICD 480–486 (pneumonia) Moolgavkar et al. (1997)—ICD 480–487 (pneumonia) Schwartz (1994b)—ICD 491–492, 494–496 (COPD) Moolgavkar et al. (1997)—ICD 490–496 (COPD)	>64 years
		Burnett et al. (2001)	<2 years
	$PM_{2.5}$ (24-hour avg)	Pooled estimate: Moolgavkar (2003)—ICD 490–496 (COPD) Ito (2003)—ICD 490–496 (COPD)	>64 years
	$PM_{2.5}$ (24-hour avg)	Moolgavkar (2000)—ICD 490–496 (COPD)	20–64 years
	$PM_{2.5}$ (24-hour avg)	Ito (2003)—ICD 480–486 (pneumonia)	>64 years
	$PM_{2.5}$ (24-hour avg)	Sheppard (2003)—ICD 493 (asthma)	<65 years
Cardiovascular	$PM_{2.5}$ (24-hour avg)	Pooled estimate: Moolgavkar (2003)—ICD 390–429 (all cardiovascular) Ito (2003)—ICD 410–414, 427–428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$ (24-hour avg)	Moolgavkar (2000)—ICD 390–429 (all cardiovascular)	20–64 years
Asthma-related ER visits	O_3 (8-hour max)	Pooled estimate: Jaffe et al (2003)	 5–34 years

Endpoint	Pollutant	Study	Study Population
		Peel et al (2005) Wilson et al (2005)	All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$ (24-hour avg)	Norris et al. (1999)	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$ (annual avg)	Dockery et al. (1996)	8–12 years
Upper respiratory symptoms	PM10 (24-hour avg)	Pope et al. (1991)	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$ (24-hour avg)	Schwartz and Neas (2000)	7–14 years
Asthma exacerbations	$PM_{2.5}$ (24-hour avg)	Pooled estimate: Ostro et al. (2001) (cough, wheeze and shortness of breath) Vedal et al. (1998) (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$ (24-hour avg)	Ostro (1987)	18–65 years
School absence days	O3 (8-hour avg) O3 (1-hour max)	Pooled estimate: Gilliland et al. (2001) Chen et al. (2000)	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O3 (24-hour avg)	Ostro and Rothschild (1989)	18–65 years
	$PM_{2.5}$ (24-hour avg)	Ostro and Rothschild (1989)	18–65 years

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the Science Advisory Board Health Effects Subcommittee (SAB-HES), we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis – Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press.

[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

6.3.2.1 Premature Mortality Effects Estimates

While particulate matter is the criteria pollutant most clearly associated with premature mortality, recent research suggests that short-term repeated ozone exposure also likely contributes to premature death. The 2006 Ozone Criteria Document states, "Consistent with observed ozone-related increases in respiratory- and cardiovascular-related morbidity, several newer multi-city studies, single-city studies, and several meta-analyses of these studies have provided relatively strong epidemiologic evidence for associations between short-term ozone exposure and all-cause mortality, even after adjustment for the influence of season and PM" (EPA, 2006: E-17). The epidemiologic data are also supported by recent experimental data from both animal and human studies, which provide evidence suggestive of plausible pathways by which risk of respiratory or cardiovascular morbidity and mortality could be increased by ambient ozone. With respect to short-term exposure, the Ozone Criteria Document concludes, "This overall body of evidence is highly suggestive that ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to more fully establish underlying mechanisms by which such effects occur" (pg. E-18).

With respect to the time-series studies, the conclusion regarding the relationship between short-term exposure and premature mortality is based, in part, upon recent city-specific time-series studies such as the Schwartz (2004) analysis in Houston and the Huang et al. (2004) analysis in Los Angeles.[17] This conclusion is also based on recent meta-analyses by Bell et al. (2005), Ito et al. (2005), and Levy et al. (2005), and a new analysis of the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) data set by Bell et al. (2004), which specifically sought to disentangle the roles of ozone, PM, weather-related variables, and seasonality. The 2006 Criteria Document states that "the results from these meta-analyses, as well as several single- and multiple-city studies, indicate that co-pollutants generally do not appear to substantially confound the association between ozone and mortality" (p. 7-103). However, CASAC raised questions about the implications of these time-series results in a policy context. Specifically, CASAC emphasized that "…while the time-series study design is a powerful tool to detect very small effects that could not be detected using other designs, it is also a blunt tool" (Henderson, 2006: 3). They point to findings (e.g., Stieb et al., 2002, 2003) that indicated associations between premature mortality and all of the criteria pollutants, indicating that "findings of time-series studies do not seem to allow us to confidently attribute observed effects to individual pollutants" (id.). They note that "not only is the interpretation of these associations complicated by the fact that the day-to-day variation in concentrations of these pollutants is, to a varying degree, determined by meteorology, the pollutants are often part of a large and highly correlated mix of pollutants, only a very few of which are measured" (id.). Even with these uncertainties, the CASAC Ozone Panel, in its review of EPA's Staff Paper, found "…premature total non-accidental and cardiorespiratory mortality for inclusion in the quantitative risk assessment to be appropriate."

[17] For an exhaustive review of the city-specific time-series studies considered in the ozone staff paper, see: U.S. Environmental Protection Agency, 2007. Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. Prepared by the Office of Air and Radiation. Available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/2007_01_ozone_staff_paper.pdf. pp. 5-36.

Consistent with the methodology used in the ozone risk assessment found in the Characterization of Health Risks found in the Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, we included ozone mortality in the primary health effects analysis, with the recognition that the exact magnitude of the effects estimate is subject to continuing uncertainty. We used estimates from the Bell et al. (2004) NMMAPS analysis, as well as effect estimates from the three meta-analyses. In addition, we include the possibility that there is not a causal association between ozone and mortality, i.e., that the effect estimate for premature mortality could be zero. EPA expects to receive advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits associated with alternative ozone control strategies later this spring.

We estimate the change in mortality incidence and estimated credible interval[18] resulting from application of the effect estimate from each study and present them separately to reflect differences in the study designs and assumptions about causality. However, it is important to note that this procedure only captures the uncertainty in the underlying epidemiological work, and does not capture other sources of uncertainty, such as uncertainty in the estimation of changes in air pollution exposure (Levy et al., 2000).

Ozone Exposure Metric. Both the NMMAPS analysis and the individual time series studies upon which the meta analyses were based use the 24-hour average or 1-hour maximum ozone levels as exposure metrics. The 24-hour average is not the most relevant ozone exposure metric to characterize population-level exposure. Given that the majority of the people tend to be outdoors during the daylight hours and concentrations are highest during the daylight hours, the 24-hour average metric is not appropriate. Moreover, the 1-hour maximum metric uses an exposure window different than that that used for the current ozone NAAQS. Together, this means that the most biologically relevant metric, and the one used in the ozone NAAQS since 1997 is the 8-hour maximum standard. Thus, although our analysis at proposal calculated impact functions based on either the 24 hour average or 1-hour maximum ozone levels originally reported in the epidemiogical studies, for the final rule analysis, we have converted ozone mortality health impact functions that use a 24-hour average or 1-hour maximum ozone metric to maximum 8-hour average ozone concentration using standard conversion functions.

This practice is consistent both with the available exposure modeling and with the form of the current ozone standard. This conversion also does not affect the relative magnitude of the health impact function. An equivalent change in the 24-hour average, 1-hour maximum and 8-hour maximum will provide the same overall change in incidence of a health effect. The conversion ratios are based on observed relationships between the 24-hour average and 8-hour maximum ozone values. For example, in the Bell et al., 2004 analysis of ozone-related premature mortality, the authors found that the relationship between the 24-hour average, the 8-hour maximum, and the 1-hour maximum was 2:1.5:1, so that the derived health impact effect estimate based on the 1-hour maximum should be half that of the effect estimate based on the 24-hour values (and the 8-hour maximum three-quarters of the 24-hour effect estimate).

[18] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

In EPA's risk analysis for the ozone NAAQS rule, mortality risks were estimated for 8 urban areas based on application of city-specific effect estimates derived from single city studies and from the Bell et al (2004) and Huang et al (2005) multi-city studies. These effect estimates were based on 24-hour average daily ozone concentrations. While it may have been preferable to use shorter averaging times, conversions from daily averages to shorter averaging times was not appropriate due to the lack of city-specific conversion factors. In our benefits analysis for the ozone NAAQS, we applied national effect estimates based on the pooled multi-city results reported in Bell et al (2004) and the three meta-analysis studies. Bell et al (2004), Bell et al (2005), Levy et al (2005), and Ito et al (2005) all provide national conversion ratios between daily average and 8-hour and 1-hour maxima, based on national data. However, these conversions were not specific to the ozone "warm" season which was the period used in the health risk assessment. As such we were able to convert the national C-R function parameters from daily average to 8-hour average, albeit with the introduction of additional uncertainty due to the use of effect estimates based on a mixture of warm season and all year data in the epidemiological studies. Given the heterogeneity in ratios of daily average to 8-hour and 1-hour maxima that exists between cities, it would be inappropriate to use national conversion ratios to adjust C-R functions for individual cities.

6.3.2.2 Respiratory Hospital Admissions Effect Estimates

Detailed hospital admission and discharge records provide data for an extensive body of literature examining the relationship between hospital admissions and air pollution. This is especially true for the portion of the population aged 65 and older, because of the availability of detailed Medicare records. In addition, there is one study (Burnett et al., 2001) providing an effect estimate for respiratory hospital admissions in children under two.

Because the number of hospital admission studies we considered is so large, we used results from a number of studies to pool some hospital admission endpoints. Pooling is the process by which multiple study results may be combined in order to produce better estimates of the effect estimate, or β. For a complete discussion of the pooling process, see Abt (2005).[19] To estimate total respiratory hospital admissions associated with changes in ambient ozone concentrations for adults over 65, we first estimated the change in hospital admissions for each of the different effects categories that each study provided for each city. These cities included Minneapolis, Detroit, Tacoma and New Haven. To estimate total respiratory hospital admissions for Detroit, we added the pneumonia and COPD estimates, based on the effect estimates in the Schwartz study (1994b). Similarly, we summed the estimated hospital admissions based on the effect estimates the Moolgavkar study reported for Minneapolis (Moolgavkar et al., 1997). To estimate total respiratory hospital admissions for Minneapolis using the Schwartz study (1994a), we simply estimated pneumonia hospital admissions based on the effect estimate. Making this assumption that pneumonia admissions represent the total impact of ozone on hospital admissions in this city will give some weight to the possibility that there is no relationship between ozone and COPD, reflecting the equivocal evidence represented by the different studies. We then used a fixed-effects pooling procedure to combine the two total respiratory hospital admission estimates for Minneapolis. Finally, we used random effects pooling to combine the

[19] Abt Associates, Incorporated. Environmental Benefits Mapping and Analysis Program, Technical Appendices. May 2005. pp. I-3

results for Minneapolis and Detroit with results from studies in Tacoma and New Haven from Schwartz (1995). As noted above, this pooling approach incorporates both the precision of the individual effect estimates and between-study variability characterizing differences across study locations.

6.3.2.3 Asthma-Related Emergency Room Visits Effect Estimates

We used three studies as the source of the concentration-response functions we used to estimate the effects of ozone exposure on asthma-related emergency room (ER) visits: Peel et al. (2005); Wilson et al. (2005); and Jaffe et al. (2003). We estimated the change in ER visits using the effect estimate(s) from each study and then pooled the results using the random effects pooling technique (see Abt, 2005). The study by Jaffe et al. (2003) examined the relationship between ER visits and air pollution for populations aged five to 34 in the Ohio cities of Cleveland, Columbus and Cincinnati from 1991 through 1996. In single-pollutant Poisson regression models, ozone was linked to asthma visits. We use the pooled estimate across all three cities as reported in the study. The Peel et al. study (2005) estimated asthma-related ER visits for all ages in Atlanta, using air quality data from 1993 to 2000. Using Poisson generalized estimating equations, the authors found a marginal association between the maximum daily 8-hour average ozone level and ER visits for asthma over a 3-day moving average (lags of 0, 1, and 2 days) in a single pollutant model. Wilson et al. (2005) examined the relationship between ER visits for respiratory illnesses and asthma and air pollution for all people residing in Portland, Maine from 1998–2000 and Manchester, New Hampshire from 1996–2000. For all models used in the analysis, the authors restricted the ozone data incorporated into the model to the months ozone levels are usually measured, the spring-summer months (April through September). Using the generalized additive model, Wilson et al. (2005) found a significant association between the maximum daily 8-hour average ozone level and ER visits for asthma in Portland, but found no significant association for Manchester. Similar to the approach used to generate effect estimates for hospital admissions, we used random effects pooling to combine the results across the individual study estimates for ER visits for asthma. The Peel et al. (2005) and Wilson et al. (2005) Manchester estimates were not significant at the 95 percent level, and thus, the confidence interval for the pooled incidence estimate based on these studies includes negative values. This is an artifact of the statistical power of the studies, and the negative values in the tails of the estimated effect distributions do not represent improvements in health as ozone concentrations are increased. Instead, these should be viewed as a measure of uncertainty due to limitations in the statistical power of the study. We included both hospital admissions and ER visits as separate endpoints associated with ozone exposure because our estimates of hospital admission costs do not include the costs of ER visits and most asthma ER visits do not result in a hospital admission.

6.3.2.4 Minor Restricted Activity Days Effects Estimate

Minor restricted activity days (MRADs) occur when individuals reduce most usual daily activities and replace them with less-strenuous activities or rest, but do not miss work or school. We estimated the effect of ozone exposure on MRADs using a concentration-response function derived from Ostro and Rothschild (1989). These researchers estimated the impact of ozone and $PM_{2.5}$ on MRAD incidence in a national sample of the adult working population (ages 18 to 65) living in metropolitan areas. We developed separate coefficients for each year of the Ostro and

Rothschild analysis (1976–1981), which we then combined for use in EPA's analysis. The effect estimate used in the impact function is a weighted average of the coefficients in Ostro and Rothschild (1989, Table 4), using the inverse of the variance as the weight.

6.3.2.5 School Absences Effect Estimate

Children may be absent from school due to respiratory or other acute diseases caused, or aggravated by, exposure to air pollution. Several studies have found a significant association between ozone levels and school absence rates. We use two studies (Gilliland et al., 2001; Chen et al., 2000) to estimate changes in school absences resulting from changes in ozone levels. The Gilliland et al. study estimated the incidence of new periods of absence, while the Chen et al. study examined daily absence rates. We converted the Gilliland et al. estimate to days of absence by multiplying the absence periods by the average duration of an absence. We estimated 1.6 days as the average duration of a school absence, the result of dividing the average daily school absence rate from Chen et al. (2000) and Ransom and Pope (1992) by the episodic absence duration from Gilliland et al. (2001). Thus, each Gilliland et al. period of absence is converted into 1.6 absence days.

Following recent advice from the National Research Council (2002), we calculated reductions in school absences for the full population of school age children, ages five to 17. This is consistent with recent peer-reviewed literature on estimating the impact of ozone exposure on school absences (Hall et al. 2003). We estimated the change in school absences using both Chen et al. (2000) and Gilliland et al. (2001) and then, similar to hospital admissions and ER visits, pooled the results using the random effects pooling procedure.

6.3.2.6 Outdoor Worker Productivity

To monetize benefits associated with increased worker productivity resulting from improved ozone air quality, we used information reported in Crocker and Horst (1981). Crocker and Horst examined the impacts of ozone exposure on the productivity of outdoor citrus workers. The study measured productivity impacts. Worker productivity is measuring the value of the loss in productivity for a worker who is at work on a particular day, but due to ozone, cannot work as hard. It only applies to outdoor workers, like fruit and vegetable pickers, or construction workers. Here, productivity impacts are measured as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration. The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income. Given the national median daily income for outdoor workers engaged in strenuous activity reported by the U.S. Census Bureau (2002), $68 per day (2000$), a ten percent reduction in ozone yields about $0.97 in increased daily wages. We adjust the national median daily income estimate to reflect regional variations in income using a factor based on the ratio of county median household income to national median household income. No information was available for quantifying the uncertainty associated with the central valuation estimate. Therefore, no uncertainty analysis was conducted for this endpoint.

6.3.2.7 Visibility Benefits

Changes in the level of ambient $PM_{2.5}$ caused by the reduction in emissions associated with the alternative standards will change the level of visibility throughout the United States. Increases in PM concentrations cause increases in light extinction, a measure of how much the components of the atmosphere absorb light. This chapter contains an estimate of the monetized benefits of improved visibility associated with the simulated emission control strategy to attain the 0.070 ppm ozone standard. The methodology we followed to estimate changes in visibility benefits is consistent with the $PM_{2.5}$ RIA (EPA, 2006), which is described on page 5-60 of that document.

6.3.2.8 Other Unquantified Effects

Direct Ozone Effects on Vegetation. The Ozone Criteria Document notes that "current ambient concentrations in many areas of the country are sufficient to impair growth of numerous common and economically valuable plant and tree species" (U.S. EPA, 2006, page 9-1). Changes in ground-level ozone resulting from the implementation of alternative ozone standards may affect crop and forest yields throughout the affected area. Recent scientific studies have also found that at sufficient concentrations ozone negatively affects the quality or nutritive value of some sensitive crops (U.S. EPA, 2006, page 9-16).

Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of planting decisions, yield response functions, and the supply of and demand for agricultural products. The resulting welfare measures are based on predicted changes in market prices and production costs. Models also exist to measure benefits to silvicultural producers and consumers. There is considerable uncertainty, however, in such estimates, including the fact that the extensive management of agricultural crops may mitigate the potential O3-related effects. For this reason, the estimates of economic crop loss developed using the updated AGSIM model were not relied on for this analysis of alternative O3 standards. In addition, these models have not been adapted for use in analyzing ozone-related forest impacts. Again, because there commercial activities are highly managed the potential benefits of alternative O3 standards are uncertain. Because of these uncertainties and resource limitations, we are unable to provide benefits estimates for the commercial production of agricultural and silvaculture commodities.

An additional welfare benefit of reducing ambient ozone concentrations is the economic value of reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone causes visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 2006, page 9-19). However, present analytic tools and resources preclude us from quantifying the benefits of improved forest aesthetics.

Urban ornamentals (floriculture and nursery crops) are an additional vegetation category that may experience negative effects from exposure to ambient ozone and may affect large economic sectors. However, the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation precludes us from quantifying these direct economic benefits. The farm production value of ornamental crops was estimated at over $14 billion in 2003 (USDA, 2004). This is therefore a potentially important welfare effects category, but information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

Nitrogen Deposition. *Deposition to Estuarine and Coastal Waters*. Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999). A recent study found that for the period 1990–2002, atmospheric deposition accounted for 17 percent of nitrate loadings in the Gulf of Mexico, where severe hypoxic zones have been existed over the last two decades (Booth and Campbell, 2007).[20]

Reductions in atmospheric deposition of NOx are expected to reduce the adverse impacts associated with nitrogen deposition to estuarine and coastal waters. However, direct functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP-based measure of benefits depends on the availability of these functions and on estimates of the value of environmental responses. Because neither appropriate functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

Deposition to Agricultural and Forested Land. Implementation strategies for alternative standards that reduce NO_X emissions will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (US EPA, 1993). Moreover,

[20] Booth, M.S., and C. Campbell. 2007. Spring Nitrate Flux in the Mississippi River Basin: A Landscape Model with Conservation Applications. Environ. Sci. Technol.; 2007; ASAP Web Release Date: 20-Jun-2007; (Article) DOI: 10.1021/es070179e

any positive effect that nitrogen deposition has on forest productivity would enhance the level of carbon dioxide sequestration as well.[21,22,23]

On the other hand, there is evidence that forest ecosystems in some areas of the United States (such as the western U.S.) are nitrogen saturated (US EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification, which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

Ultraviolet Radiation. Atmospheric ozone absorbs a harmful band of ultraviolet radiation from the sun called UV-B, thus providing a protective shield to the Earth's surface. The majority of this protection occurs in the stratosphere where 90% of atmospheric ozone is located. The remaining 10% of the Earth's ozone is present at ground level (referred to as tropospheric ozone) (NAS, 1991; NASA). Only a portion of the tropospheric fraction of UV-B shielding is from anthropogenic sources (e.g., power plants, byproducts of combustion). The portion of ground level ozone associated with anthropogenic sources varies by locality and over time. Even so, it is reasonable to assume that reductions in ground level ozone would lead to increases in the same health effects linked to in UV-B exposures. These effects include fatal and nonfatal melanoma and non-melanoma skin cancers and cataracts. The values of $15,000 per case for non-fatal melanoma skin cancer, $5,000 per case for non-fatal non-melanoma skin cancer, and $15,000 per case of cataracts have been used in analyses of stratospheric ozone depletion (U.S. EPA, 1999). Fatal cancers are valued using the standard VSL estimate, which for 2020 is $6.6 million (2006$). UV-B has also been linked to ecological effects including damage to crops and forest. For a more complete listing of quantified and unquantified UV-B radiation effects, see Table G-4 and G-7 in the Benefits and Costs of the Clean Air Act, 1990–2010 (U.S. EPA, 1999). UV-B related health effects are also discussed in the context of stratospheric ozone in a 2006 report by ICF Consulting, prepared for the U.S. EPA.

There are many factors that influence UV-B radiation penetration to the earth's surface, including latitude, altitude, cloud cover, surface albedo, PM concentration and composition, and gas phase pollution. Of these, only latitude and altitude can be defined with small uncertainty in any effort to assess the changes in UV-B flux that may be attributable to any changes in tropospheric ozone as a result of any revision to the Ozone NAAQS. Such an assessment of UV-B related health effects would also need to take into account human habits, such as outdoor activities (including age- and occupation-related exposure patterns), dress and skin care to adequately estimate UV-B exposure levels. However, little is known about the impact of these factors on individual exposure to UV-B.

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[21] Peter M. Vitousek et. al., "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences" *Issues in Ecology* No. 1 (Spring) 1997.
[22] Knute J. Nadelhoffer et. al., "Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests" *Nature* 398, 145-148 (11 March 1999).
[23] Martin Köchy and Scott D. Wilson, "Nitrogen deposition and forest expansion in the northern Great Plains Journal of Ecology *Journal of Ecology* 89 (5), 807–817.

Moreover, detailed information does not exist regarding other factors that are relevant to assessing changes in disease incidence, including: type (e.g., peak or cumulative) and time period (e.g., childhood, lifetime, current) of exposures related to various adverse health outcomes (e.g., damage to the skin, including skin cancer; damage to the eye, such as cataracts; and immune system suppression); wavelength dependency of biological responses; and interindividual variability in UV-B resistance to such health outcomes. Beyond these well-recognized adverse health effects associated with various wavelengths of UV radiation, the Criteria Document (Section 10.2.3.6) also discusses protective effects of UV-B radiation. Recent reports indicate the necessity of UV-B in producing vitamin D, and that vitamin D deficiency can cause metabolic bone disease among children and adults, and may also increase the risk of many common chronic diseases (e.g., type I diabetes and rheumatoid arthritis) as well as the risk of various types of cancers. Thus, the Criteria Document concludes that any assessment that attempts to quantify the consequences of increased UV-B exposure on humans due to reduced ground-level O3 must include consideration of both negative and positive effects. However, as with other impacts of UVB on human health, this beneficial effect of UVB radiation has not previously been studied in sufficient detail. EPA has conducted a screening level analysis of the effects of reduced ozone concentrations on UVB exposures. This analysis is based on the air quality modeling conducted for the proposed Ozone NAAQS RIA, and is described in Appendix 6d to the this RIA. The screening analysis has been peer-reviewed and a summary of the peer-review comments and responses are provided with the report.

Climate Implications of Tropospheric Ozone. Although climate and air quality are generally treated as separate issues, they are closely coupled through atmospheric processes. Ozone, itself, is a major greenhouse gas and climate directly influences ambient concentrations of ozone.

The concentration of tropospheric ozone has increased substantially since the pre-industrial era and has contributed to warming. Tropospheric ozone is (after carbon dioxide and methane) the third most important contributor to greenhouse gas warming. The National Academy of Sciences recently stated[24] that regulations targeting ozone precursors would have combined benefits for public health and climate. As noted in the OAQPS Staff Paper, the overall body of scientific evidence suggests that high concentrations of ozone on a regional scale could have a discernible influence on climate. However, the Staff Paper concludes that insufficient information is available at this time to quantitatively inform the secondary NAAQS process with regard to this aspect of the ozone-climate interaction

[24] National Academy of Sciences, “Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties,” October 2005.

Climate change can affect tropospheric ozone by modifying emissions of precursors, chemistry, transport and removal.[25] Climate change affects the sources of ozone precursors through physical response (lightning), biological response (soils, vegetation, and biomass burning) and human response (energy generation, land use, and agriculture). Increases in regional ozone pollution are expected due to higher temperatures and weaker circulation. Simulations with global climate models for the 21st century indicate a decrease in the lifetime of tropospheric ozone due to increasing water vapor, which could decrease global background ozone concentrations.

The Intergovernmental Panel on Climate Change (IPCC) recently released a report[26] that projects, with "virtual certainty," declining air quality in cities due to warmer and fewer cold days and nights and/or warmer/more frequent hot days and nights over most land areas. The report states that projected climate change-related exposures are likely to affect the health status of millions of people, in part, due to higher concentrations of ground level ozone related to climate change.

The IPCC also reports[27] that the current generation of tropospheric ozone models is generally successful in describing the principal features of the present-day global ozone distribution. However, there is much less confidence in the ability to reproduce the changes in ozone associated with perturbations of emissions or climate. There are major discrepancies with observed long-term trends in ozone concentrations over the 20th century, including after 1970 when the reliability of observed ozone trends is high. Resolving these discrepancies is needed to establish confidence in the models.

The EPA is currently leading a research effort with the goal of identifying changes in regional US air quality that may occur in a future (2050) climate, focusing on fine particles and ozone. The research builds first on an assessment of changes in US air quality due to climate change, which includes direct meteorological impacts on atmospheric chemistry and transport and the effect of temperature changes on air pollution emissions. Further research will result in an assessment that adds the emission impacts from technology, land use, demographic changes, and air quality regulations to construct plausible scenarios of US air quality 50 years into the future. As noted in the Staff Paper, results from these efforts are expected to be available for consideration in the next review of the ozone NAAQS.

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[25]Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[26] IPCC, Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability, Summary for Policymakers.
[27] Denman, et al, 2007: Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis.*

6.3.3 Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 10 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per million people, that number must be multiplied by the millions of people in the total population.

Table 6.3 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth (Abt Associates, 2005).

6.4 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993). Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

Table 6.3: National Average Baseline Incidence Rates

Endpoint	Source	Notes	Rate per 100 people per year[d] by Age Group <18	18–24	25–34	35–44	45–54	55–64	65+
Mortality	CDC Compressed Mortality File, accessed through CDC Wonder (1996–1998)	non-accidental	0.025	0.022	0.057	0.150	0.383	1.006	4.937
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)	Ostro and Rothschild (1989, p. 243)	incidence	—	780	780	780	780	780	—
School Loss Days	National Center for Education Statistics (1996) and 1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year	all-cause	990.0	—	—	—	—	—	—

Endpoint	Source	Notes		Rate per 100 People per Year
Asthma Exacerbations	Ostro et al. (2001)	Incidence (and prevalence) among asthmatic African-American children	Daily wheeze	0.076 (0.173)
			Daily cough	0.067 (0.145)
			Daily dyspnea	0.037 (0.074)
	Vedal et al. (1998)	Incidence (and prevalence) among asthmatic children	Daily wheeze	0.038
			Daily cough	0.086
			Daily dyspnea	0.045

[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] All of the rates reported here are population-weighted incidence rates per 100 people per year. Additional details on the incidence and prevalence rates, as well as the sources for these rates are available upon request.

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987). We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 6.4. All values are in constant year 2006 dollars, adjusted for growth in real income out to 2020 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. Table 6.4 presents the values for individual endpoints adjusted to year 2020 income levels. The discussion below provides additional details on ozone related endpoints. For details on valuation estimates for PM related endpoints, see the 2006 PM NAAQS RIA.

6.4.1 Mortality Valuation

To estimate the monetary benefit of reducing the risk of premature death, we used the "value of statistical lives" saved (VSL) approach, which is a summary measure for the value of small changes in mortality risk for a large number of people. The VSL approach applies information from several published value-of-life studies to determine a reasonable monetary value of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be roughly $6.6 million at 1990 income levels (2006$), and $7.9 million (2006$) at 2020 income levels. This represents an intermediate value from a variety of estimates in the economics literature (see the 2006 PM NAAQS RIA for more details on the calculation of VSL).

6.4.2 Hospital Admissions Valuation

In the absence of estimates of societal WTP to avoid hospital visits/admissions for specific illnesses, estimates of total cost of illness (total medical costs plus the value of lost productivity) typically are used as conservative, or lower bound, estimates. These estimates are biased downward, because they do not include the willingness-to-pay value of avoiding pain and suffering.

The International Classification of Diseases (ICD-9, 1979) code-specific COI estimates used in this analysis consist of estimated hospital charges and the estimated opportunity cost of time spent in the hospital (based on the average length of a hospital stay for the illness). We based all estimates of hospital charges and length of stays on statistics provided by the Agency for Healthcare Research and Quality (AHRQ 2000). We estimated the opportunity cost of a day spent in the hospital as the value of the lost daily wage, regardless of whether the hospitalized individual is in the workforce. To estimate the lost daily wage, we divided the 1990 median weekly wage by five and inflated the result to year 2000$ using the CPI-U "all items." The resulting estimate is $109.35. The total cost-of-illness estimate for an ICD code-specific hospital stay lasting *n* days, then, was the mean hospital charge plus $109 multiplied by *n.*

Table 6.4: Unit Values for Economic Valuation of Health Endpoints (2006$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence: 1990 Income Level	Central Estimate of Value Per Statistical Incidence: 2020 Income Level	Derivation of Distributions of Estimates
Premature Mortality (Value of a Statistical Life)	$6,600,000	$7,900,000	Point estimate is the mean of a normal distribution with a 95% confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis. The mean of the distribution is consistent with the mean estimate from a third meta-analysis (Kochi et al 2006). The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$410,000	$500,000	The WTP to avoid a case of pollution-related CB is calculated as $WTP_x \quad WTP_{13} * e^{-\beta*(13-x)}$, 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 (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 period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990). Direct medical costs are based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990).
3% discount rate			
Age 0–24	$79,685	$79,685	Lost earnings:
Age 25–44	$88,975	$88,975	Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings:
Age 45–54	$93,897	$93,897	age of onset: at 3% at 7%
Age 55–65	$167,532	$167,532	25–44 $8,774 $7,855
Age 66 and over	$79,685	$79,685	45–54 $12,932 $11,578
			55–65 $74,746 $66,920
7% discount rate			Direct medical expenses: An average of:
Age 0–24	$77,769	$77,769	1. Wittels et al. (1990) ($102,658—no discounting)
Age 25–44	$87,126	$87,126	2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
Age 45–54	$91,559	$91,559	
Age 55–65	$157,477	$157,477	
Age 66 and over	$77,769	$77,769	

Health Endpoint	Central Estimate of Value Per Statistical Incidence		Derivation of Distributions of Estimates
	1990 Income Level	2020 Income Level	
Hospital Admissions			
Chronic Obstructive Pulmonary Disease (COPD)	$16,606	$16,606	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	$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	$24,668	$24,668	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+)	$24,622	$24,622	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)	$10,385	$10,385	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	$384	$384	No distributional information available. Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997) and (2) $260.67, from Stanford et al. (1999).
Respiratory Ailments Not Requiring Hospitalization			
Upper Respiratory Symptoms (URS)	$30	$30	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 $9.2 and $43.1.

Health Endpoint	Central Estimate of Value Per Statistical Incidence		Derivation of Distributions of Estimates
	1990 Income Level	2020 Income Level	
Lower Respiratory Symptoms (LRS)	$19	$21	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 $6.9 and $24.46.
Asthma Exacerbations	$50	$54	Asthma exacerbations are valued at $45 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986). This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma exacerbation is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study. The value is assumed have a uniform distribution between $15.6 and $70.8.
Acute Bronchitis	$429	$453	Assumes a 6-day episode, with the distribution of the daily value specified as uniform with the low and high values based on those recommended for related respiratory symptoms in Neumann et al. (1994). The low daily estimate of $10 is the sum of the mid-range values recommended by IEc (1994) for two symptoms believed to be associated with acute bronchitis: coughing and chest tightness. The high daily estimate was taken to be twice the value of a minor respiratory restricted-activity day, or $110.
Work Loss Days (WLDs)	Variable (U.S. median = $130)		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)	$61	$64	Median WTP estimate to avoid one MRAD from Tolley et al. (1986). Distribution is assumed to be triangular with a minimum of $22 and a maximum of $83, with a most likely value of $52. Range is based on assumption that value should exceed WTP for a single mild symptom (the highest estimate for a single symptom—for eye irritation—is $16.00) and be less than that for a WLD. The triangular distribution acknowledges that the actual value is likely to be closer to the point estimate than either extreme.
School Absence Days	$89	$89	No distribution available

6.4.3 Asthma-Related Emergency Room Visits Valuation

To value asthma emergency room visits, we used a simple average of two estimates from the health economics literature. The first estimate comes from Smith et al. (1997), who reported approximately 1.2 million asthma-related emergency room visits in 1987, at a total cost of $186.5 million (1987$). The average cost per visit that year was $155; in 2000$, that cost was $311.55 (using the CPI-U for medical care to adjust to 2000$). The second estimate comes from Stanford et al. (1999), who reported the cost of an average asthma-related emergency room visit at $260.67, based on 1996–1997 data. A simple average of the two estimates yields a (rounded) unit value of $286.

6.4.4 Minor Restricted Activity Days Valuation

No studies are reported to have estimated WTP to avoid a minor restricted activity day. However, one of EPA's contractors, IEc (1993) has derived an estimate of willingness to pay to avoid a minor *respiratory* restricted activity day, using estimates from Tolley et al. (1986) of WTP for avoiding a combination of coughing, throat congestion and sinusitis. The IEc estimate of WTP to avoid a minor respiratory restricted activity day is $38.37 (1990$), or about $52 ($2000).

Although Ostro and Rothschild (1989) statistically linked ozone and minor restricted activity days, it is likely that most MRADs associated with ozone exposure are, in fact, minor *respiratory* restricted activity days. For the purpose of valuing this health endpoint, we used the estimate of mean WTP to avoid a minor respiratory restricted activity day.

6.4.5 School Absences

To value a school absence, we: (1) estimated the probability that if a school child stays home from school, a parent will have to stay home from work to care for the child; and (2) valued the lost productivity at the parent's wage. To do this, we estimated the number of families with school-age children in which both parents work, and we valued a school-loss day as the probability that such a day also would result in a work-loss day. We calculated this value by multiplying the proportion of households with school-age children by a measure of lost wages.

We used this method in the absence of a preferable WTP method. However, this approach suffers from several uncertainties. First, it omits willingness to pay to avoid the symptoms/illness that resulted in the school absence; second, it effectively gives zero value to school absences that do not result in work-loss days; and third, it uses conservative assumptions about the wages of the parent staying home with the child. Finally, this method assumes that parents are unable to work from home. If this is not a valid assumption, then there would be no lost wages.

For this valuation approach, we assumed that in a household with two working parents, the female parent will stay home with a sick child. From the Statistical Abstract of the United States (U.S. Census Bureau, 2001), we obtained: (1) the numbers of single, married and "other" (widowed, divorced or separated) working women with children; and (2) the rates of participation in the workforce of single, married and "other" women with children. From these two sets of statistics, we calculated a weighted average participation rate of 72.85 percent.

Our estimate of daily lost wage (wages lost if a mother must stay at home with a sick child) is based on the year 2000 median weekly wage among women ages 25 and older (U.S. Census Bureau, 2001). This median weekly wage is $551. Dividing by five gives an estimated median daily wage of $103. To estimate the expected lost wages on a day when a mother has to stay home with a school-age child, we first estimated the probability that the mother is in the workforce then multiplied that estimate by the daily wage she would lose by missing a workday: 72.85 percent times $103, for a total loss of $75. This valuation approach is similar to that used by Hall et al. (2003).

6.5 Results and Implications

6.5.1 Ozone Benefit Estimates

Figure 6.1 summarizes the valuation of ozone benefits. Tables 6.6 through 6.21 summarize the reduction in incidence for ozone- and PM-related health endpoints for each of the alternative ozone standards evaluated. Tables 6.22 through 6.37 summarize the ozone-related economic benefits for each of the alternative standards.[28] Note that incidence and valuation estimates for each standard alternative are presented in separate tables In addition to the mean incidence estimates, we have included 5th and 95th percentile estimates when available, based on the Monte Carlo simulations described above. In the tables for the 0.065 ppm and 0.070 ppm alternative standards, the change in ozone-related incidence from attaining the alternative standards is presented for both the partial attainment scenario and the full attainment scenario (i.e., sum of the change in incidence associated with achieving the partial attainment increment plus the residual attainment increment). As described in Appendix 6a, to calculate the additional change in ozone concentrations to get from partial attainment to full attainment, we rolled back the ozone monitor data so that the 4th highest daily maximum 8-hour average just met the level required to attain the alternative standard. This approach will likely understate the benefits that would occur due to implementation of actual controls to reduce ozone precursor emissions because controls implemented to reduce ozone concentrations at the highest monitor would likely result in some reductions in ozone concentrations at attaining monitors down-wind (i.e., the controls would lead to concentrations below the standard in down-wind locations); estimating benefits that occur at these downwind monitors as a result of air quality improvements below the standard would be appropriate because ozone is a non-threshold pollutant. Therefore, air quality improvements and resulting health benefits from full attainment would be more widespread than we have estimated in our rollback analyses. The incidence and valuation results for attainment of the 0.075 ppm and 0.079 ppm alternatives are derived through an interpolation technique described in Appendix 6a. As such, these estimates are presented as full attainment only.

We model all ozone-related premature mortality and morbidity to occur in the same year as the change in exposure rather than assuming a 'lag' in the change in health state, as we do for PM. Therefore, we do not discount ozone estimates.

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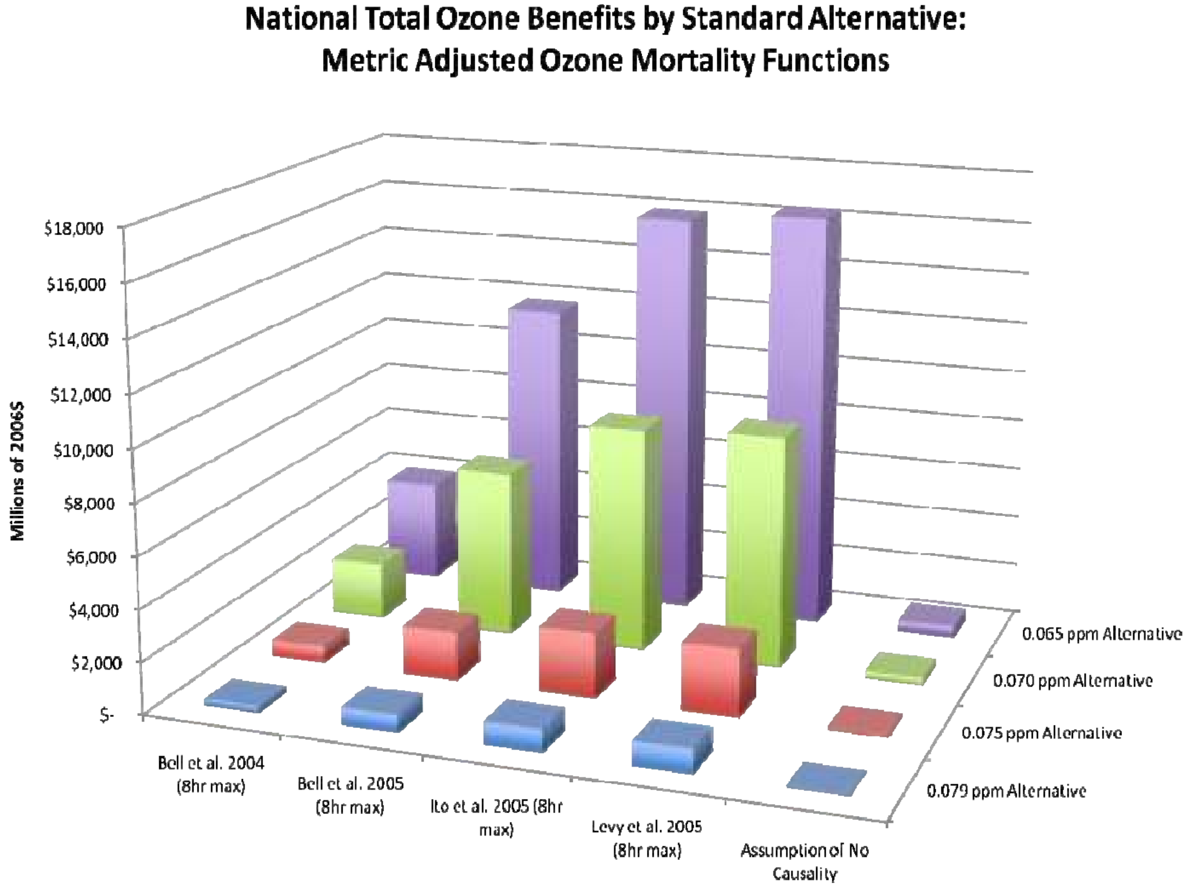
[28] Note that the valuation estimates for ozone benefits are not discounted due to the fact that there is no lag between changes in exposure and premature mortality, as is calculated for $PM_{2.5}$ benefits.

Figure 6.1: Valuation of Ozone Morbidity and Mortality Benefits Results by Standard Alternative*



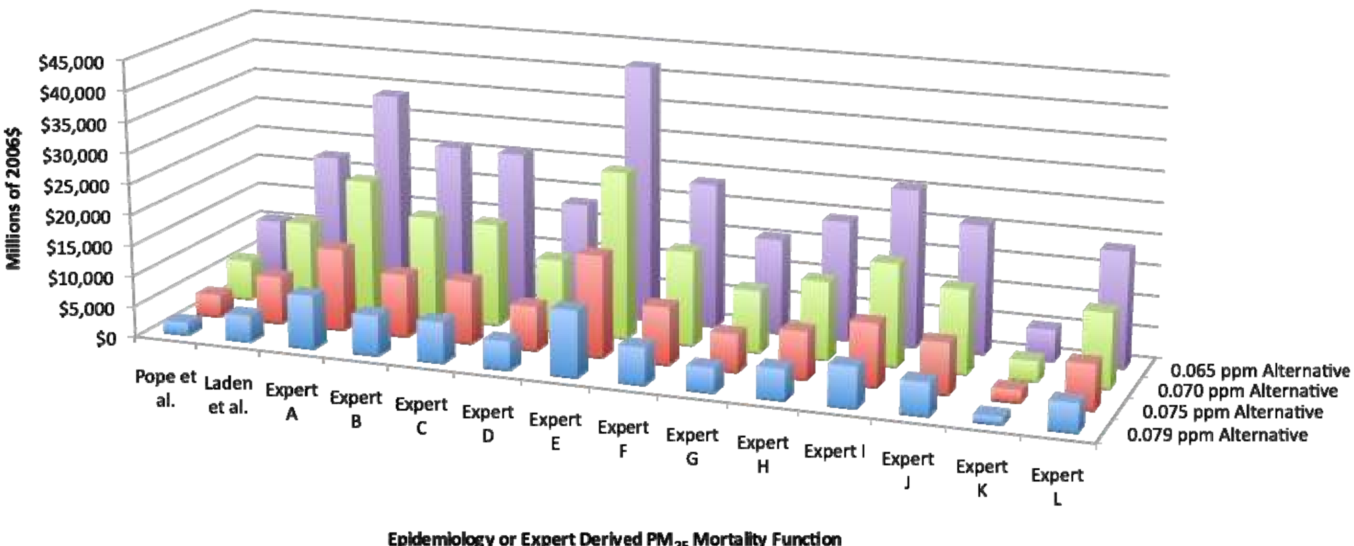
* This figure reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the figure do not reflect benefits for the San Joaquin and South Coast Air Basins.

6.5.2 $PM_{2.5}$ Co-Benefit Estimation Methodology

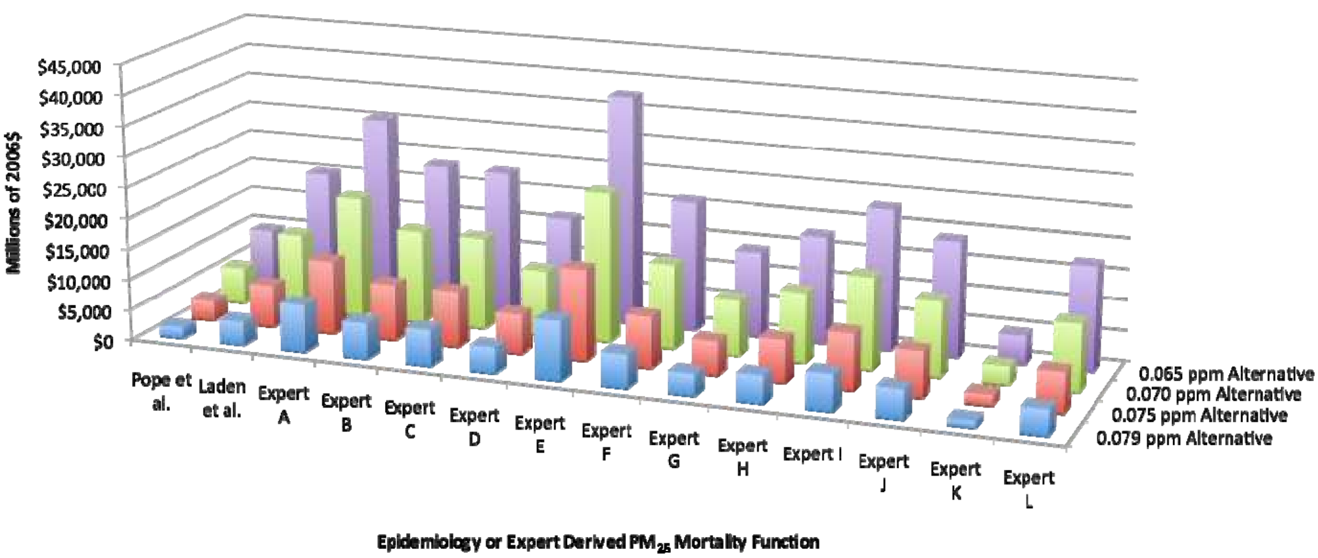
Figure 6.2 summarizes the valuation of PM benefits at a 3% and 7% discounted rate, respectively. A series of tables below present the $PM_{2.5}$ co-benefits associated with full attainment of the 0.065 ppm, 0.070 ppm, 0.075 ppm and 0.079 ppm alternatives. To derive estimates of incidence and valuation for the $PM_{2.5}$ related co-benefits of full attainment of each ozone standard alternative, we applied a scaling technique described below. To estimate total valuation estimates, we applied benefit per-ton metrics; this procedure is detailed further below. Valuation estimates of the $PM_{2.5}$-related full attainment benefits are presented at a 3% discount rate and at a 7% discount rate. All $PM_{2.5}$ co-benefit estimates are incremental to the 2006 PM NAAQS RIA.

Figure 6.2: Valuation of PM Co-Benefits by Standard Alternative at 3% and 7%*

Distribution of $PM_{2.5}$ Benefits by Ozone Standard Alternative (3% Discount Rate)



Distribution of $PM_{2.5}$ Benefits by Ozone Standard Alternative (7% Discount Rate)



* This figure reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the figure do not reflect benefits for the San Joaquin and South Coast Air Basins.

Estimating $PM_{2.5}$ Co-Benefits Resulting from Full Attainment of the Selected Standard and Each Standard Alternative

The modeled $PM_{2.5}$ air quality scenario reflects the $PM_{2.5}$ changes associated with partially attaining 0.070 ppm incremental to a partial attainment of 0.08 ppm; due to analytical limitations it was not possible to model a full-attainment $PM_{2.5}$ scenario for the selected standard or each standard alternative. Thus, using this projected air quality change to estimate $PM_{2.5}$ co-benefits would under or overstate the benefits of attaining each standard alternative; this is due in part to the fact that the model run projects the air quality changes from NOx reductions needed to attain a baseline of 0.08 ppm. Of greater analytical value would be an estimate of the $PM_{2.5}$ co-benefits associated with fully attaining 0.070 ppm incremental to full attainment of the 0.08 ppm standard.

To generate such an estimate, we calculated a new $PM_{2.5}$ baseline that established the $PM_{2.5}$ air quality associated with full attainment of 0.08 ppm. To create such a baseline, EPA utilized benefit $PM_{2.5}$ per-ton estimates. 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 a similar technique in previous Regulatory Impact Analyses.[29] These estimates are based on the sum of the valuation of the Pope (2002) estimates of mortality (3% discount rate, 2006$) and valuation of the morbidity incidence. Readers interested in reviewing the complete methodology for creating the benefit per-ton estimates used in this analysis can consult the Technical Support Document accompanying this RIA.

Estimating the $PM_{2.5}$ benefits that represented the full attainment of both 0.070 ppm incremental to full attainment of 0.08 ppm entailed the following four steps:

1. *Estimate the number of tons of NOx necessary to attain a baseline of 0.08 ppm*. Chapter 4 described the method used to estimate the extrapolated NOx emissions reductions necessary to attain a baseline of 0.08 ppm full attainment.

2. *Calculate the benefits of attaining 0.08 ppm incremental to partial attainment of 0.08 ppm.* To estimate the benefits of fully attaining 0.08 ppm incremental to partial attainment of 0.08 ppm, the relevant benefit per ton is simply multiplied by the total number of extrapolated NOx tons abated. Note that this calculation step allows us to net out the benefits of attaining the current standard, so that all subsequent benefits are incremental to the full attainment of 0.080 ppm.

3. *Calculate the benefits of partially attaining 0.070 ppm incremental to full attainment of 0.08 ppm.* Subtract the benefits of fully attaining 0.080 ppm incremental to the partial

[29] *Final Regulatory Impact Analysis: Industrial Boilers and Process Heaters*. Prepared by Office of Air and Radiation. Available: http://www.epa.gov/ttn/ecas/regdata/EIAs/chapter10.pdf [accessed 18 May 2007].

attainment of 0.08 ppm to create a new estimate of incremental 0.070 ppm partial attainment.

4. *Calculate the $PM_{2.5}$ benefits of fully attaining 0.070 ppm*. Multiplying the estimate of the extrapolated NOx tons necessary to attain 0.070 ppm fully (Table 5.3) produces an estimate of the incremental benefits of fully attaining 0.070 ppm incremental to partial attainment of 0.070 ppm. By adding this incremental benefit estimate to the benefits generated in step 3, we derived a total benefit estimate of attaining 0.070 ppm incremental to 0.08 ppm.

5. *Repeat step 4 to estimate the benefits of 0.075 ppm, 0.079 ppm and 0.065 ppm*. Step 4 may be repeated by substituting the NOx tons necessary to attain the selected alternative of 0.075 ppm and the remaining alternatives of 0.079 ppm and 0.065 ppm to produce an estimate of total $PM_{2.5}$ co-benefits.

The process for estimating the $PM_{2.5}$ co-benefits of fully attaining 0.065 ppm, 0.075 ppm, and 0.079 ppm is identical to the steps above, with the following exception; in step four we substituted the number of extrapolated tons necessary to attain 0.065 ppm, 0.075 ppm, and 0.079 ppm respectively. Table 7-5 below provides the inputs to the calculation steps described above. In the example below, we calculate total benefits using the Pope et al. (2002) mortality estimate. However, in subsequent tables we present benefits using Laden et al. (2006) as well as the twelve expert functions described previously in this document. Note that while our benefit per ton estimates are associated with broad source categories (in this case, NOx emitting Electrical Generating Units, Other NOx emitting point sources and NOx emitting Mobile sources) the extrapolated tons were not. For this reason we simply assumed that the total number of extrapolated NOx tons were evenly distributed between these three source types.

The $PM_{2.5}$ benefits of attaining 0.065 ppm, 0.075 ppm and 0.079 ppm incremental to partial attainment of 0.070 ppm are \$7.5 billion, \$0.6 billion and -\$1 billion respectively. Simulated attainment of the 0.79 ppm alternative required fewer emission reductions than were modeled in the emissions control strategy to simulate attainment with 0.070 ppm. For this reason, we "netted out" the benefits of the incremental NOx emission reductions that were present in the 0.070 ppm control case but not necessary to attain 0.079 ppm.

The benefit per-ton estimates produce estimates of total valuation but not incidence. To estimate total incidence, we applied a simple scaling factor. To estimate $PM_{2.5}$-related incidence associated with the attainment of each ozone alternative, we calculated a separate scaling factor as follows: (1) we calculated the ratio of the full attainment $PM_{2.5}$ valuation estimate (calculated using the benefit per ton metrics described below) to the partial attainment to the partial attainment $PM_{2.5}$ valuation estimate; (2) multiply this scaling ratio against each of the $PM_{2.5}$ partial attainment mortality and morbidity endpoints to generate a scaled estimate of mortality and morbidity. While there are clearly substantial uncertainties inherent in this technique, it does produce useful screening-level estimates of $PM_{2.5}$-related incidence.

The total $PM_{2.5}$ benefits of attaining 0.065 ppm, 0.075 ppm and 0.079 ppm are \$11 billion, \$3.6 billion and \$2 billion respectively. The full attainment $PM_{2.5}$ benefits do not include confidence intervals. Because this full attainment estimate was derived by summing the modeled $PM_{2.5}$

benefits and the benefits derived using the benefit per-ton metrics—and these benefit per ton metrics do not include confidence intervals—the resulting sum of total $PM_{2.5}$ benefits do not include confidence intervals.

Table 6.5: Estimated $PM_{2.5}$ Co-Benefits Associated with Full Attainment of 0.070 ppm Incremental to 0.08 ppm[a]

Calculation	Extrapolated NOx Tons	Benefit per Ton Estimate	Valuation of $PM_{2.5}$ Benefits (Billions 2006$)[b]
Benefits of attaining 0.08 ppm partially and 0.070 ppm partially (i.e. the benefits of the modeled scenario):	—	—	$3.4
Benefits of attaining 0.08 ppm from a baseline of 0.08 ppm partial attainment:	NOx EGU: 37,400 NOx Point: 37,400 NOx Mobile: 37,400	$3,200 $3,000 $4,800	$0.4
Benefits of attaining 0.070 ppm partially, incremental to attainment of 0.08 ppm	—	—	$3
Benefits of attaining 0.070 ppm in 2020 incremental to partial attainment of 0.070 ppm	NOx EGU: 310,000 NOx Point: 310,000 NOx Mobile: 310,000 VOC: 310,000	$3,200 $3,000 $4,800 $430	$3.5
Benefits of attaining 0.070 ppm incremental to attainment of 0.08 ppm			$6.5

[a] Numbers have been rounded to two significant figures and therefore summation may not match table estimates. $PM_{2.5}$ benefit estimates do not include confidence intervals because they are derived using benefit per-ton estimates.

[b] All estimates derived using the Pope et al. (2002) mortality estimate at a 3% and 7% discount rate, in 2006$. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Estimated reductions in ozone mortality incidence provided in Tables 6.6, 6.10, 6.14, and 6.18 represent the number of premature deaths potentially avoided due to reductions in ozone exposure in 2020 using warm season functions from the recent ozone-mortality NMMAPS analysis of 95 U.S. communities (Bell et al., 2004) and three meta-analyses of the available published literature on ozone-mortality effects (Bell et al., 2005; Ito et al., 2005; Levy et al., 2005). These same tables also include the possibility that there is not a causal association between ozone and mortality, i.e., that the estimate for premature mortality avoided could be zero. Model uncertainty, including whether or not the relationship is assumed to be causal, is a key source of uncertainty. Although multiple estimates are presented in these tables, no attempt was made to quantify the likelihood of a causal relationship between short-term ozone exposure and increased mortality or to weigh the results of the various models.

The estimate of central tendency for premature mortality is expressed as the arithmetic mean, with the assumption of a normal distribution, and represents the central estimate of the number of premature deaths avoided in association with the alternative standards based on each study.

Statistical uncertainty associated with the model estimate for each study is characterized by the 95% credible interval[30] around the mean estimate (i.e., 2.5th and 97.5th percent interval). Of the four available studies, the NMMAPS study by Bell et al. (2004) is considered to be the most representative for evaluating potential mortality-related benefits associated with the alternative standards due to its extensive coverage (examination of 95 large communities across the United States over an extended period of time, from 1987 to 2000) and its specific focus on the ozone-mortality relationship. Annual estimates of lives saved from this study are lower than those from the three meta-analyses, possibly due to more stringent adjustment for meteorological factors (Ito et al., 2005; Ostro et al., 2006), publication bias in the meta-analyses (Bell et al., 2005; Ito et al., 2005) or other factors. Clearly, the ozone-mortality reduction estimates are conditional on a causal relationship.

The Ozone Criteria Document (U.S. EPA, 2006) and Staff Paper (U.S. EPA, 2007) concluded that the overall body of evidence is highly suggestive that (short-term exposure to) ozone directly or indirectly contributes to non-accidental cardiopulmonary-related mortality. However, various sources of uncertainty remain, including the possibility that there is no causal relationship between ozone and mortality (i.e., zero effect). For instance, because results of time-series studies implicate all of the criteria air pollutants, and those who would be expected to be potentially more susceptible to ozone exposure are likely to have lower exposure to ozone due to the amount of time that they spend indoors, CASAC[31] stated that it seems unlikely that the observed associations between short-term ozone concentrations and daily mortality are due solely to ozone itself (i.e., ozone may be serving as a marker for other agents that are contributing to the short-term exposure effects on mortality). Even so, CASAC concluded that the evidence was strong enough to support a quantitative risk assessment of the relationship between short-term exposure to ozone and premature mortality as part of the Staff Paper. EPA has asked the National Academy of Sciences[32] for their advice on how best to quantify the uncertainty about the relationship between ambient ozone exposure and premature mortality within the context of quantifying projected benefits of alternative control strategies. We expect to receive this advice later this spring.

Using the NMMAPS study that was used as the basis for the risk analysis presented in our Staff Paper, we estimate 71 avoided premature deaths annually in 2020 from reducing ozone levels to meet the selected standard of 0.075 ppm, which, when added to the other projected ozone related benefits, leads to an estimated total benefit of $620 million/yr. Using three studies that synthesize data across a large number of individual studies, we estimate between 230 and 320, with total monetized ozone benefits to be between $1.9 and $2.6 billion/yr. Alternatively, if there is no causal relationship between ozone and mortality, avoided premature deaths would be zero. For a

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[30] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[31] Clean Air Scientific Advisory Committee's Peer Review of the Agency's 2nd Draft Ozone Staff Paper, October 24, 2006. EPA-CASAC-07-001. Available at http://www.epa.gov/sab/pdf/casac-07-001.pdf

[32] National Academy of Sciences (2007) Project Scope. Estimating Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure. Division on Earth and Life Studies, Board on Environmental Studies and Toxicology. Available at http://www8.nationalacademies.org/cp/projectview.aspx?key=48768

standard of 0.079 ppm, using the NMMAPS ozone mortality study, we estimate 24 premature deaths avoided and total monetized benefits of $220 million/yr. Using the three synthesis studies, we estimate premature deaths avoided for the less stringent standard to be between 80 and 110, with total monetized ozone benefits to be between $640 and $890 million/yr. For a standard of 0.070 ppm, using the NMMAPS ozone mortality study, we estimate 250 premature deaths avoided and total monetized benefits of $2.2 billion/yr. Using the three synthesis studies, we estimate premature deaths avoided for the less stringent standard to be between 810 and 1,100 avoided premature deaths annually in 2020, leading to total monetized benefits of between $6.5 and $9 billion/yr. For a standard of 0.065 ppm, using the NMMAPS ozone mortality study, we estimated to result in 450 premature deaths avoided and total monetized benefits of $3.9 billion/yr. Using the three synthesis studies, estimated premature deaths avoided for the more stringent standard are between 1,500 and 2,100, with total monetized ozone benefits between $12 and $16 billion/yr. Including premature mortality in our estimates had the largest impact on the overall magnitude of benefits: Premature mortality benefits account for more than 95 percent of the total benefits we can monetize. We note that these estimates reflect EPA's interim approach to characterizing the benefits of reducing premature mortality associated with ozone exposure. As mentioned above, EPA has requested advice from the NAS on this issue.

6.5.3 Estimate of Full Attainment Benefits

Tables 6.38 through 6.41 below summarize the estimates of full attainment and $PM_{2.5}$ co-benefit estimate for each standard alternative. The presentation of ozone benefits and $PM_{2.5}$ co-benefits for each standard alternative is broken into two tables. The first table presents the national ozone benefits and $PM_{2.5}$ co-benefits. Tables 6.42 through 6.49 summarize the combined ozone and $PM_{2.5}$ co-benefits.

Table 7-6: Illustrative Strategy to Attain 0.065 ppm: Estimated Annual Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure in 2020 (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses) [B, C, D, E]

Model or Assumption[A]	*Reference*	*National Modeled Partial Attainment*	*National Rolled-Back Full Attainment*
NMMAPS	Bell et al. 2004	120 (43--210)	450 (170--730)
Meta-Analysis	Bell et al. 2005	400 (200--610)	1500 (760--2,200)
	Ito et al. 2005	550 (340--760)	2000 (1,300--2,700)
	Levy et al. 2005	560 (390--730)	2100 (1,500--2,600)
Assumption that association is not causal		0	0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-7: Illustrative Strategy to Attain 0.065 ppm: Estimated Annual Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses)[A,B]

Morbidity Endpoint	*National Modeled Partial Attainment*	*National Rolled Back Full Attainment*
Hospital Admissions (ages 0-1)	700 (310--1,100)	2,700 (1,300--4,000)
Hospital Admissions (ages 65-99)	420 (-190--1,100)	3,200 (74--6,200)
Emergency Department Visits, Asthma-Related[C]	550 (-57--1,500)	1900 (-130--5,500)
School Absences	300,000 (77,000--560,000)	1,100,000 (320,000--1,800,000)
Minor Restricted Activity Days	810,000 (350,000--1,300,000)	2,900,000 (1,300,000--4,400,000)

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[C] The negative 5th percentile incidence estimates for this health endpoint are a result of the weak statistical power of the study and should not be inferred to indicate that decreased ozone exposure may cause an increase in asthma-related emergency department visits.

Table 7-8: Illustrative 0.065 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit[C]

Mortality Endpoint	*National 2020 Benefits*
Mortality Impact Functions Derived from Epidemiology Literature	
ACS Study[A]	1,000
Harvard Six-City Study[B]	2,300
Woodruff et al 1997 (infant mortality)	2.9
Mortality Impact Functions Derived from Expert Elicitation	
Expert A	4,000
Expert B	3,100
Expert C	3,100
Expert D	2,100
Expert E	5,000
Expert F	2,800
Expert G	1,800
Expert H	2,300
Expert I	3,000
Expert J	2,400
Expert K	490
Expert L	2,100

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-9: Illustrative 0.065 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of Morbidity Associated with PM Co-benefit[A, B]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	970
Nonfatal myocardial infarction (age >17)	940
Hospital admissions--respiratory (all ages)	660,000
Hospital admissions-- cardiovascular (age >17)	17,000
Emergency room visits for asthma (age <19)	13,000
Acute bronchitis (age 8-12)	110,000
Lower respiratory symptoms (age 7-14)	2,600
Upper respiratory symptoms (asthmatic children age 9-18)	16,000
Asthma exacerbation (asthmatic children age 6-18)	270
Work loss days (age 18-65)	550
Minor restricted activity days (age 18-65)	2,300

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[B] Morbidity Impact Functions Derived from Epidemiology Literature

Table 7-10: Illustrative Strategy to Attain 0.070 ppm: Estimated Annual Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure in 2020 (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses) [B, C, D, E]

Model or Assumption[A]	*Reference*	*National Modeled Partial Attainment*	*National Rolled Back Full Attainment*
NMMAPS	Bell et al. 2004	120 (43--210)	250 (92--410)
Meta-Analysis	Bell et al. 2005	400 (200--610)	810 (410--1,200)
	Ito et al. 2005	550 (340--760)	1100 (690--1,500)
	Levy et al. 2005	560 (390--730)	1100 (800--1,500)
Assumption that association is not causal		0	0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-11: Illustrative Strategy to Attain 0.070 ppm: Estimated Annual Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses)[A,B]

Morbidity Endpoint	*National Modeled Partial Attainment*	*National Rolled Back Full Attainment*
Hospital Admissions (ages 0-1)	700 (310--1,100)	1,500 (720--2,400)
Hospital Admissions (ages 65-99)	420 (-190--1,100)	1,400 (-110--3,000)
Emergency Department Visits, Asthma-Related[C]	550 (-57--1,500)	1000 (-82--3,000)
School Absences	300,000 (77,000--560,000)	640,000 (180,000--1,000,000)
Minor Restricted Activity Days	810,000 (350,000--1,300,000)	1,700,000 (740,000--2,600,000)

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[C] The negative 5th percentile incidence estimates for this health endpoint are a result of the weak statistical power of the study and should not be inferred to indicate that decreased ozone exposure may cause an increase in asthma-related emergency department visits.

Table 7-12: Illustrative 0.070 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit[C]

Mortality Endpoint	*National 2020 Benefits*
Mortality Impact Functions Derived from Epidemiology Literature	
ACS Study[A]	650
Harvard Six-City Study[B]	1,500
Woodruff et al 1997 (infant mortality)	1.9
Mortality Impact Functions Derived from Expert Elicitation	
Expert A	2,600
Expert B	2,000
Expert C	2,000
Expert D	1,400
Expert E	3,200
Expert F	1,800
Expert G	1,100
Expert H	1,500
Expert I	1,900
Expert J	1,600
Expert K	310
Expert L	1,400

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-13: Illustrative 0.070 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of Morbidity Associated with PM Co-benefit[A, B]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	630
Nonfatal myocardial infarction (age >17)	610
Hospital admissions--respiratory (all ages)	430,000
Hospital admissions-- cardiovascular (age >17)	11,000
Emergency room visits for asthma (age <19)	8,100
Acute bronchitis (age 8-12)	72,000
Lower respiratory symptoms (age 7-14)	1,700
Upper respiratory symptoms (asthmatic children age 9-18)	10,000
Asthma exacerbation (asthmatic children age 6-18)	180
Work loss days (age 18-65)	350
Minor restricted activity days (age 18-65)	1,500

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[B] Morbidity Impact Functions Derived from Epidemiology Literature

Table 7-14: Illustrative Strategy to Attain 0.075 ppm: Estimated Annual Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure in 2020 (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses) [B, C, D, E]

Model or Assumption[A]	*Reference*	*National Full Attainment*
NMMAPS	Bell et al. 2004	71 (27--110)
Meta-Analysis	Bell et al. 2005	230 (120--340)
	Ito et al. 2005	310 (200--430)
	Levy et al. 2005	320 (230--420)
Assumption that association is not causal		0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-15: Illustrative Strategy to Attain 0.075 ppm: Estimated Annual Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses)[A,B]

Morbidity Endpoint	*National Full Attainment*
Hospital Admissions (ages 0-1)	480 (230--730)
Hospital Admissions (ages 65-99)	470 (-5.1--930)
Emergency Department Visits, Asthma-Related[C]	280 (-18--830)
School Absences	200,000 (58,000--320,000)
Minor Restricted Activity Days	500,000 (230,000--760,000)

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[C] The negative 5th percentile incidence estimates for this health endpoint are a result of the weak statistical power of the study and should not be inferred to indicate that decreased ozone exposure may cause an increase in asthma-related emergency department visits.

Table 7-16: Illustrative 0.075 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit[C]

Mortality Endpoint	*National 2020 Benefits*
Mortality Impact Functions Derived from Epidemiology Literature	
ACS Study[A]	390
Harvard Six-City Study[B]	880
Woodruff et al 1997 (infant mortality)	1.1
Mortality Impact Functions Derived from Expert Elicitation	
Expert A	1,600
Expert B	1,200
Expert C	1,200
Expert D	820
Expert E	2,000
Expert F	1,100
Expert G	690
Expert H	880
Expert I	1,200
Expert J	950
Expert K	190
Expert L	820

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-17: Illustrative 0.075 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of Morbidity Associated with PM Co-benefit[A, B]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	380
Nonfatal myocardial infarction (age >17)	370
Hospital admissions--respiratory (all ages)	260,000
Hospital admissions-- cardiovascular (age >17)	6,700
Emergency room visits for asthma (age <19)	4,900
Acute bronchitis (age 8-12)	43,000
Lower respiratory symptoms (age 7-14)	1,000
Upper respiratory symptoms (asthmatic children age 9-18)	6,100
Asthma exacerbation (asthmatic children age 6-18)	110
Work loss days (age 18-65)	210
Minor restricted activity days (age 18-65)	890

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[B] Morbidity Impact Functions Derived from Epidemiology Literature

Table 7-18: Illustrative Strategy to Attain 0.079 ppm: Estimated Annual Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure in 2020 (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses) [B, C, D, E]

Model or Assumption[A]	*Reference*	*National Full Attainment*
NMMAPS	Bell et al. 2004	24 (10--39)
Meta-Analysis	Bell et al. 2005	80 (42--120)
	Ito et al. 2005	110 (69--150)
	Levy et al. 2005	110 (80--140)
Assumption that association is not causal		0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-19: Illustrative Strategy to Attain 0.079 ppm: Estimated Annual Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses)[A,B]

Morbidity Endpoint	*National Full Attainment*
Hospital Admissions (ages 0-1)	190 (9.0--350)
Hospital Admissions (ages 65-99)	190 (90--280)
Emergency Department Visits, Asthma-Related[C]	87 (-5.2--250)
School Absences	72,000 (21,000--110,000)
Minor Restricted Activity Days	180,000 (83,000--270,000)

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[C] The negative 5th percentile incidence estimates for this health endpoint are a result of the weak statistical power of the study and should not be inferred to indicate that decreased ozone exposure may cause an increase in asthma-related emergency department visits.

Table 7-20: Illustrative 0.079 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit[C]

Mortality Endpoint	*National 2020 Benefits*
Mortality Impact Functions Derived from Epidemiology Literature	
ACS Study[A]	250
Harvard Six-City Study[B]	560
Woodruff et al 1997 (infant mortality)	0.71
Mortality Impact Functions Derived from Expert Elicitation	
Expert A	1,000
Expert B	760
Expert C	750
Expert D	530
Expert E	1,200
Expert F	690
Expert G	440
Expert H	560
Expert I	750
Expert J	600
Expert K	120
Expert L	530

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-21: Illustrative 0.079 ppm Full Attainment Scenario: Estimated Annual Reductions in the Incidence of Morbidity Associated with PM Co-benefit[A, B, C]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	240
Nonfatal myocardial infarction (age >17)	230
Hospital admissions--respiratory (all ages)	160,000
Hospital admissions-- cardiovascular (age >17)	4,200
Emergency room visits for asthma (age <19)	3,100
Acute bronchitis (age 8-12)	28,000
Lower respiratory symptoms (age 7-14)	640
Upper respiratory symptoms (asthmatic children age 9-18)	3,900
Asthma exacerbation (asthmatic children age 6-18)	67
Work loss days (age 18-65)	140
Minor restricted activity days (age 18-65)	570

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above.
[B] Morbidity Impact Functions Derived from Epidemiology Literature
[C] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-22: Illustrative Strategy to Attain 0.065 ppm: Estimated Annual Valuation of Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses, Millions of 2006$)[B,C,D,E]

Model or Assumption[A]	*Reference*	*National Modeled Partial Attainment*	*National Rolled Back Full Attainment*
NMMAPS	Bell et al. 2004	$960 ($140--$2,200)	$3,500 ($510--$7,800)
Meta-Analysis	Bell et al. 2005	$3,100 ($490--6,600)	$11,000 ($1,800--24,000)
	Ito et al. 2005	$4,200 (730--$8,600)	$15,000 (2,700--$31,000)
	Levy et al. 2005	$4,400 ($770--$8,500)	$16,000 ($2,800--$31,000)
Assumption that association is not causal		0	0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-23: Illustrative Strategy to Attain 0.065 ppm: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses, Millions of 2006$) [A,B]

Morbidity Endpoint	National Modeled Partial Attainment	National Rolled Back Full Attainment
Hospital Admissions (ages 0-1)	$6.9 ($3.4--10)	$26 ($14.0--39)
Hospital Admissions (ages 65-99)[C]	$9.9 (-$3.3--$24)	$74 ($8.40--$140)
Emergency Department Visits, Asthma-Related[C]	$0.20 ($0.0--$0.56)	$0.69 ($0.0--$2.0)
School Absences	$27 ($8.4--$48)	$99 ($34--$150)
Minor Restricted Activity Days	$48 ($18--$89)	$170 ($67--$310)
Worker Productivity	$6.8	$49

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[C] The negative 5th percentile incidence estimates for this health endpoint are a result of the weak statistical power of the study and should not be inferred to indicate that decreased ozone exposure may cause an increase in asthma-related emergency department visits.

Table 7-24: Illustrative 0.065 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit (Millions of 2006$)[C]

Mortality Endpoint	*National 2020 Benefits (3% discount rate)*	*National 2020 Benefits (7% discount rate)*
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[A]	$9,700	$8,800
Harvard Six-City Study[B]	$22,000	$20,000
Woodruff et al 1997 (infant mortality)	$20	$16
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$33,000	$30,000
Expert B	$25,000	$23,000
Expert C	$25,000	$22,000
Expert D	$17,000	$16,000
Expert E	$41,000	$37,000
Expert F	$23,000	$20,000
Expert G	$15,000	$13,000
Expert H	$19,000	$17,000
Expert I	$25,000	$22,000
Expert J	$20,000	$18,000
Expert K	$4,300	$3,900
Expert L	$18,000	$16,000

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-25: Illustrative 0.065 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with PM Co-benefit (Millions of 2006$)[A, B, C]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	$480
Nonfatal myocardial infarction (age >17)	
3% discount rate	$250
7% discount rate	$240
Hospital admissions--respiratory (all ages)	$5.8
Hospital admissions-- cardiovascular (age >17)	$15
Emergency room visits for asthma (age <19)	$0.35
Acute bronchitis (age 8-12)	$1.3
Lower respiratory symptoms (age 7-14)	$0.33
Upper respiratory symptoms (asthmatic children age 9-18)	$0.39
Asthma exacerbation (asthmatic children age 6-18)	$0.84
Work loss days (age 18-65)	$14
Minor restricted activity days (age 18-65)	$19

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above.
[B] Morbidity Impact Functions Derived from Epidemiology Literature
[C] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-26: Illustrative Strategy to Attain 0.070 ppm: Estimated Annual Valuation of Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses, Millions of 2006$)[B,C,D,E]

Model or Assumption[A]	*Reference*	*National Modeled Partial Attainment*	*National Rolled Back Full Attainment*
NMMAPS	Bell et al. 2004	$960 ($140--$2,200)	$1,900 ($280--$4,300)
Meta-Analysis	Bell et al. 2005	$3,100 ($490--6,600)	$6,200 ($1,000--13,000)
	Ito et al. 2005	$4,200 (730--$8,600)	$8,500 (1,500--$17,000)
	Levy et al. 2005	$4,400 ($770--$8,500)	$8,800 ($1,600--$17,000)
Assumption that association is not causal		0	0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-27: Illustrative Strategy to Attain 0.070 ppm: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses, Millions of 2006$) [A,B]

Morbidity Endpoint	National Modeled Partial Attainment	National Rolled Back Full Attainment
Hospital Admissions (ages 0-1)	$6.9 ($3.4--10)	$15 ($7.8--23)
Hospital Admissions (ages 65-99)	$9.9 (-$3.3--$24)	$34 ($0.59--$67)
Emergency Department Visits, Asthma-Related	$0.20 ($0.0--$0.56)	$0.37 ($0.0--$1.1)
School Absences	$27 ($8.4--$48)	$57 ($19--$88)
Minor Restricted Activity Days	$48 ($18--$89)	$98 ($38--$180)
Worker Productivity	$6.8	$27

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-28: Illustrative 0.070 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit (Millions of 2006$)[C]

Mortality Endpoint	*National 2020 Benefits (3% discount rate)*	*National 2020 Benefits (7% discount rate)*
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[A]	$6,000	$5,400
Harvard Six-City Study[B]	$13,000	$12,000
Woodruff et al 1997 (infant mortality)	$13	$11
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$21,000	$19,000
Expert B	$16,000	$15,000
Expert C	$16,000	$15,000
Expert D	$11,000	$10,000
Expert E	$27,000	$24,000
Expert F	$15,000	$13,000
Expert G	$9,500	$8,600
Expert H	$12,000	$11,000
Expert I	$16,000	$14,000
Expert J	$13,000	$12,000
Expert K	$2,700	$2,500
Expert L	$12,000	$10,000

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

[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[C] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-298: Illustrative 0.070 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with PM Co-benefit (Millions of 2006$)[A, B, C]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	$310
Nonfatal myocardial infarction (age >17)	
3% discount rate	$160
7% discount rate	$160
Hospital admissions--respiratory (all ages)	$3.7
Hospital admissions-- cardiovascular (age >17)	$9.8
Emergency room visits for asthma (age <19)	$0.22
Acute bronchitis (age 8-12)	$0.85
Lower respiratory symptoms (age 7-14)	$ 0.22
Upper respiratory symptoms (asthmatic children age 9-18)	$0.25
Asthma exacerbation (asthmatic children age 6-18)	$0.54
Work loss days (age 18-65)	$8.9
Minor restricted activity days (age 18-65)	$12

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above.
[B] Morbidity Impact Functions Derived from Epidemiology Literature
[C] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-30: Illustrative Strategy to Attain 0.075 ppm: Estimated Annual Valuation of Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses, Millions of 2006$)[B,C,D,E]

Model or Assumption[A]	*Reference*	*National Full Attainment*
NMMAPS	Bell et al. 2004	$550 ($81--$1,200)
Meta-Analysis	Bell et al. 2005	$1,800 ($290--3,800)
	Ito et al. 2005	$2,400 (420--$4,900)
	Levy et al. 2005	$2,500 ($450--$4,900)
Assumption that association is not causal		0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-31: Illustrative Strategy to Attain 0.075 ppm: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses, Millions of 2006$) [A,B]

Morbidity Endpoint	National Full Attainment
Hospital Admissions (ages 0-1)	$4.8 ($2.5--$7.1)
Hospital Admissions (ages 65-99)	$11 ($0.89--21)
Emergency Department Visits, Asthma-Related	$0.10 ($0.00--$0.3)
School Absences	$18 ($6.1--$27)
Minor Restricted Activity Days	$29 ($12--$54)
Worker Productivity	$10

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-32: Illustrative 0.075 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit (Millions of 2006$)[C]

Mortality Endpoint	*National 2020 Benefits (3% discount rate)*	*National 2020 Benefits (7% discount rate)*
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[A]	$3,300	$3,000
Harvard Six-City Study[B]	$7,400	$6,600
Woodruff et al 1997 (infant mortality)	$8	$6
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$13,000	$12,000
Expert B	$9,900	$8,900
Expert C	$9,800	$8,900
Expert D	$6,900	$6,200
Expert E	$16,000	$15,000
Expert F	$9,000	$8,100
Expert G	$5,800	$5,200
Expert H	$7,300	$6,600
Expert I	$9,700	$8,800
Expert J	$7,900	$7,100
Expert K	$1,600	$1,500
Expert L	$6,900	$6,200

[A] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.
[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.
[C] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-33: Illustrative 0.075 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with PM Co-benefit (Millions of 2006$)[A, B, C]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	$180
Nonfatal myocardial infarction (age >17)	
3% discount rate	$97
7% discount rate	$94
Hospital admissions--respiratory (all ages)	$2.3
Hospital admissions-- cardiovascular (age >17)	$5.9
Emergency room visits for asthma (age <19)	$0.13
Acute bronchitis (age 8-12)	$0.51
Lower respiratory symptoms (age 7-14)	$0.13
Upper respiratory symptoms (asthmatic children age 9-18)	$0.15
Asthma exacerbation (asthmatic children age 6-18)	$0.33
Work loss days (age 18-65)	$5.3
Minor restricted activity days (age 18-65)	$7.2

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above.
[B] Morbidity Impact Functions Derived from Epidemiology Literature
[C] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-34: Illustrative Strategy to Attain 0.079 ppm: Estimated Annual Valuation of Reductions in the Incidence of Premature Mortality Associated with Ozone Exposure (Incremental to Current Ozone Standard, Arithmetic Mean, 95% Confidence Intervals in Parentheses, Millions of 2006$)[B,C,D,E]

Model or Assumption[A]	*Reference*	*National Full Attainment*
NMMAPS	Bell et al. 2004	$190 ($28--$420)
Meta-Analysis	Bell et al. 2005	$620 ($100--1,300)
	Ito et al. 2005	$830 (140--$1,700)
	Levy et al. 2005	$860 ($160--$1,700)
Assumption that association is not causal		0

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] With the exception of the assumption of no causal relationship, the arithmetic mean and 95% credible interval around the mean estimates of the annual number of lives saved are based on an assumption of a normal distribution.

[C] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics.

[D] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[E] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-35: Illustrative Strategy to Attain 0.079 ppm: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with Ozone Exposure (Incremental to Current Ozone Standard, 95% Confidence Intervals in Parentheses, Millions of 2006$) [A,B]

Morbidity Endpoint	National Full Attainment
Hospital Admissions (ages 0-1)	$4.4 ($0.60--$7.9)
Hospital Admissions (ages 65-99)	$1.9 ($0.98--2.7)
Emergency Department Visits, Asthma-Related	$0.03 ($0.00--$0.09)
School Absences	$6.4 ($2.2--$9.5)
Minor Restricted Activity Days	$11 ($4.2--$19)
Worker Productivity	$4.7

[A] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical.

[B] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-36: Illustrative 0.079 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of PM Premature Mortality associated with PM co-benefit (Millions of 2006$)[C]

Mortality Endpoint	*National 2020 Benefits (3% discount rate)*	*National 2020 Benefits (7% discount rate)*
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[A]	$1,800	$1,600
Harvard Six-City Study[B]	$4,100	$3,700
Woodruff et al 1997 (infant mortality)	$5.0	$4.0
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$8,400	$7,600
Expert B	$6,400	$5,700
Expert C	$6,400	$5,700
Expert D	$4,400	$4,000
Expert E	$11,000	$9,500
Expert F	$5,800	$5,200
Expert G	$3,700	$3,400
Expert H	$4,700	$4,300
Expert I	$6,300	$5,700
Expert J	$5,100	$4,600
Expert K	$1,000	$910
Expert L	$4,400	$3,900

[A] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.
[B] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.
[C] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-37: Illustrative 0.079 ppm Full Attainment Scenario: Estimated Annual Valuation of Reductions in the Incidence of Morbidity Associated with PM Co-benefit (Millions of 2006$)[A, B, C]

Morbidity Endpoint	*National 2020 Benefits*
Chronic Bronchitis (age >25 and over)	$120
Nonfatal myocardial infarction (age >17)	
3% discount rate	$62
7% discount rate	$60
Hospital admissions--respiratory (all ages)	$1.4
Hospital admissions-- cardiovascular (age >17)	$3.8
Emergency room visits for asthma (age <19)	$0.086
Acute bronchitis (age 8-12)	$0.33
Lower respiratory symptoms (age 7-14)	$0.083
Upper respiratory symptoms (asthmatic children age 9-18)	$0.10
Asthma exacerbation (asthmatic children age 6-18)	$0.21
Work loss days (age 18-65)	$3.4
Minor restricted activity days (age 18-65)	$4.6

[A] All estimates rounded to two significant figures. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not include confidence intervals because they were derived through a scaling technique described above.
[B] Morbidity Impact Functions Derived from Epidemiology Literature
[C] This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-38: Estimate of Annual Ozone and $PM_{2.5}$ Combined Morbidity and Mortality (Millions of 2006$) for the 0.065 ppm Full Attainment

Ozone Mortality and Morbidity Benefits of Attaining 0.065 ppm		Total
NMMAPS	Bell (2004)	$3,900
Meta-Analysis	Bell (2005)	$12,000
	Ito (2005)	$16,000
	Levy (2005)	$16,000
No Causality		$420

$PM_{2.5}$ Mortality and Morbidity Benefits of Attaining 0.065 ppm	Total (3% Discount Rate)	Total (7% Discount Rate)
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[C]	$11,000	$9,600
Harvard Six-City Study[D]	$23,000	$20,000
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$34,000	$31,000
Expert B	$26,000	$24,000
Expert C	$26,000	$23,000
Expert D	$18,000	$17,000
Expert E	$42,000	$38,000
Expert F	$24,000	$21,000
Expert G	$15,000	$14,000
Expert H	$19,000	$18,000
Expert I	$25,000	$23,000
Expert J	$21,000	$19,000
Expert K	$5,100	$4,700
Expert L	$19,000	$17,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

[B] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics. Credible intervals for ozone estimates and confidence intervals for $PM_{2.5}$ estimates not provided because the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates.

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

[D] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[E] All estimates incremental to 2006 PM NAAQS RIA. Estimates derived using benefit per ton estimates discounted at 3% and 7%. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-39: Estimate of Annual Ozone and $PM_{2.5}$ Combined Morbidity and Mortality (Millions of 2006$) for the 0.070 ppm Full Attainment

Ozone Mortality and Morbidity Benefits of Attaining 0.070 ppm		Total
NMMAPS	Bell (2004)	$2,200
Meta-Analysis	Bell (2005)	$6,500
	Ito (2005)	$8,800
	Levy (2005)	$9,000
No Causality		$230

$PM_{2.5}$ Mortality and Morbidity Benefits of Attaining 0.070 ppm	Total (3% Discount Rate)	Total (7% Discount Rate)
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[C]	$6,500	$5,900
Harvard Six-City Study[D]	$14,000	$13,000
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$22,000	$20,000
Expert B	$17,000	$15,000
Expert C	$17,000	$15,000
Expert D	$12,000	$11,000
Expert E	$27,000	$24,000
Expert F	$15,000	$14,000
Expert G	$10,000	$9,100
Expert H	$13,000	$11,000
Expert I	$17,000	$15,000
Expert J	$13,000	$12,000
Expert K	$3,200	$3,000
Expert L	$12,000	$11,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).
[B] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics. Credible intervals for ozone estimates and confidence intervals for $PM_{2.5}$ estimates not provided because the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates.
[C] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[D] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.
[E] All estimates incremental to 2006 PM NAAQS RIA. Estimates derived using benefit per ton estimates discounted at 3% and 7%. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-40: Estimate of Annual Ozone and $PM_{2.5}$ Combined Morbidity and Mortality (Millions of 2006$) for the 0.075 ppm Full Attainment

Ozone Mortality and Morbidity Benefits of Attaining 0.075 ppm		**Total**
NMMAPS	Bell (2004)	$620
Meta-Analysis	Bell (2005)	$1,900
	Ito (2005)	$2,500
	Levy (2005)	$2,600
No Causality		$73

$PM_{2.5}$ Mortality and Morbidity Benefits of Attaining 0.075 ppm	**Total (3% Discount Rate)**	**Total (7% Discount Rate)**
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[C]	$3,600	$3,300
Harvard Six-City Study[D]	$7,700	$7,000
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$13,000	$12,000
Expert B	$10,000	$9,200
Expert C	$10,000	$9,200
Expert D	$7,200	$6,500
Expert E	$16,000	$15,000
Expert F	$9,300	$8,400
Expert G	$6,100	$5,500
Expert H	$7,600	$6,900
Expert I	$10,000	$9,100
Expert J	$8,200	$7,400
Expert K	$1,900	$1,800
Expert L	$7,200	$6,500

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).
[B] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics. Credible intervals for ozone estimates and confidence intervals for $PM_{2.5}$ estimates not provided because the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates.
[C] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[D] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.
[E] All estimates incremental to 2006 PM NAAQS RIA. Estimates derived using benefit per ton estimates discounted at 3% and 7%. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-41: Estimate of Annual Ozone and $PM_{2.5}$ Combined Morbidity and Mortality (Millions of 2006$) for the 0.079 ppm Full Attainment

Ozone Mortality and Morbidity Benefits of Attaining 0.079 ppm		Total
NMMAPS	Bell (2004)	$220
Meta-Analysis	Bell (2005)	$640
	Ito (2005)	$860
	Levy (2005)	$890
No Causality		$28

$PM_{2.5}$ Mortality and Morbidity Benefits of Attaining 0.079 ppm	Total (3% Discount Rate)	Total (7% Discount Rate)
Mortality Impact Functions Derived from Epidemiology Literature		
ACS Study[C]	$2,000	$1,800
Harvard Six-City Study[D]	$4,300	$3,900
Mortality Impact Functions Derived from Expert Elicitation		
Expert A	$8,600	$7,800
Expert B	$6,600	$5,900
Expert C	$6,600	$5,900
Expert D	$4,600	$4,200
Expert E	$11,000	$9,700
Expert F	$6,000	$5,400
Expert G	$3,900	$3,600
Expert H	$4,900	$4,500
Expert I	$6,500	$5,900
Expert J	$5,300	$4,800
Expert K	$1,200	$1,100
Expert L	$4,600	$4,100

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).
[B] A credible interval is a posterior probability interval used in Bayesian statistics, which is similar to a confidence interval used in frequentist statistics. Credible intervals for ozone estimates and confidence intervals for $PM_{2.5}$ estimates not provided because the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates.
[C] The estimate is based on the concentration-response (C-R) function developed from the study of the American Cancer Society cohort reported in Pope et al (2002), which has previously been reported as the primary estimate in recent RIAs.

[D] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.
[E] All estimates incremental to 2006 PM NAAQS RIA. Estimates derived using benefit per ton estimates discounted at 3% and 7%. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-42: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 3% Discount Rate) for the 0.065 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$14,000	$22,000	$26,000	$27,000	$11,000
Harvard Six-City Study[C]	$26,000	$34,000	$38,000	$39,000	$23,000
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$34,000	$38,000	$46,000	$50,000	$50,000
Expert B	$26,000	$30,000	$38,000	$42,000	$42,000
Expert C	$26,000	$30,000	$38,000	$42,000	$42,000
Expert D	$19,000	$22,000	$30,000	$34,000	$35,000
Expert E	$42,000	$46,000	$54,000	$58,000	$58,000
Expert F	$24,000	$27,000	$35,000	$39,000	$40,000
Expert G	$16,000	$19,000	$27,000	$31,000	$32,000
Expert H	$20,000	$23,000	$31,000	$35,000	$36,000
Expert I	$26,000	$29,000	$37,000	$41,000	$42,000
Expert J	$21,000	$25,000	$33,000	$37,000	$37,000
Expert K	$5,500	$9,000	$17,000	$21,000	$21,000
Expert L	$19,000	$23,000	$30,000	$35,000	$35,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-43: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 7% Discount Rate) for the 0.065 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$13,000	$21,000	$25,000	$26,000	$10,000
Harvard Six-City Study[C]	$24,000	$32,000	$36,000	$37,000	$21,000
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$34,000	$42,000	$46,000	$47,000	$31,000
Expert B	$27,000	$35,000	$39,000	$40,000	$24,000
Expert C	$27,000	$35,000	$39,000	$40,000	$24,000
Expert D	$20,000	$28,000	$32,000	$33,000	$17,000
Expert E	$42,000	$50,000	$54,000	$54,000	$38,000
Expert F	$25,000	$33,000	$37,000	$38,000	$22,000
Expert G	$18,000	$26,000	$30,000	$30,000	$14,000
Expert H	$21,000	$29,000	$33,000	$34,000	$18,000
Expert I	$27,000	$35,000	$39,000	$39,000	$23,000
Expert J	$23,000	$31,000	$35,000	$35,000	$19,000
Expert K	$8,600	$16,000	$21,000	$21,000	$5,100
Expert L	$21,000	$29,000	$33,000	$33,000	$17,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-44: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 3% Discount Rate) for the 0.070 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$8,700	$13,000	$15,000	$16,000	$6,700
Harvard Six-City Study[C]	$16,000	$20,000	$23,000	$23,000	$14,000
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$24,000	$28,000	$31,000	$31,000	$22,000
Expert B	$19,000	$23,000	$26,000	$26,000	$17,000
Expert C	$19,000	$23,000	$25,000	$26,000	$17,000
Expert D	$14,000	$18,000	$21,000	$21,000	$12,000
Expert E	$29,000	$34,000	$36,000	$36,000	$27,000
Expert F	$17,000	$22,000	$24,000	$24,000	$15,000
Expert G	$12,000	$16,000	$19,000	$19,000	$10,000
Expert H	$15,000	$19,000	$21,000	$22,000	$13,000
Expert I	$19,000	$23,000	$25,000	$26,000	$17,000
Expert J	$16,000	$20,000	$22,000	$22,000	$14,000
Expert K	$5,400	$9,700	$12,000	$12,000	$3,500
Expert L	$14,000	$19,000	$21,000	$21,000	$12,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-45: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 7% Discount Rate) for the 0.070 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$8,100	$12,000	$15,000	$15,000	$6,100
Harvard Six-City Study[C]	$15,000	$19,000	$21,000	$22,000	$13,000
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$22,000	$26,000	$29,000	$29,000	$20,000
Expert B	$17,000	$22,000	$24,000	$24,000	$15,000
Expert C	$17,000	$22,000	$24,000	$24,000	$15,000
Expert D	$13,000	$17,000	$19,000	$20,000	$11,000
Expert E	$27,000	$31,000	$33,000	$33,000	$25,000
Expert F	$16,000	$20,000	$23,000	$23,000	$14,000
Expert G	$11,000	$16,000	$18,000	$18,000	$9,300
Expert H	$14,000	$18,000	$20,000	$20,000	$12,000
Expert I	$17,000	$21,000	$24,000	$24,000	$15,000
Expert J	$14,000	$19,000	$21,000	$21,000	$12,000
Expert K	$5,100	$9,500	$12,000	$12,000	$3,200
Expert L	$13,000	$17,000	$20,000	$20,000	$11,000

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-46: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of \$2006, 3% Discount Rate) for the 0.075 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$4,200	$5,500	$6,100	$6,200	$3,700
Harvard Six-City Study[C]	$8,300	$9,500	$10,000	$10,000	$7,800
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$14,000	$15,000	$16,000	$16,000	$13,000
Expert B	$11,000	$12,000	$13,000	$13,000	$10,000
Expert C	$11,000	$12,000	$13,000	$13,000	$10,000
Expert D	$7,800	$9,000	$9,700	$9,800	$7,300
Expert E	$17,000	$18,000	$19,000	$19,000	$17,000
Expert F	$9,900	$11,000	$12,000	$12,000	$9,300
Expert G	$6,700	$7,900	$8,600	$8,700	$6,100
Expert H	$8,300	$9,500	$10,000	$10,000	$7,700
Expert I	$11,000	$12,000	$13,000	$13,000	$10,000
Expert J	$8,800	$10,000	$11,000	$11,000	$8,300
Expert K	$2,600	$3,800	$4,400	$4,500	$2,000
Expert L	$7,800	$9,000	$9,700	$9,800	$7,300

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-47: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 7% Discount Rate) for the 0.075 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$3,900	$5,100	$5,800	$5,900	$3,400
Harvard Six-City Study[C]	$7,600	$8,800	$9,500	$9,500	$7,000
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$13,000	$14,000	$15,000	$15,000	$12,000
Expert B	$9,800	$11,000	$12,000	$12,000	$9,300
Expert C	$9,800	$11,000	$12,000	$12,000	$9,200
Expert D	$7,100	$8,400	$9,000	$9,100	$6,600
Expert E	$16,000	$17,000	$17,000	$17,000	$15,000
Expert F	$9,000	$10,000	$11,000	$11,000	$8,500
Expert G	$6,100	$7,400	$8,000	$8,100	$5,600
Expert H	$7,500	$8,800	$9,400	$9,500	$7,000
Expert I	$9,700	$11,000	$12,000	$12,000	$9,100
Expert J	$8,000	$9,300	$9,900	$10,000	$7,500
Expert K	$2,400	$3,600	$4,300	$4,300	$1,800
Expert L	$7,100	$8,400	$9,000	$9,100	$6,600

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-48: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 3% Discount Rate) for the 0.079 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$2,200	$2,700	$2,900	$2,900	$2,100
Harvard Six-City Study[C]	$4,500	$4,900	$5,200	$5,200	$4,300
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$8,900	$9,300	$9,500	$9,500	$8,700
Expert B	$6,800	$7,200	$7,400	$7,400	$6,600
Expert C	$6,800	$7,200	$7,400	$7,500	$6,600
Expert D	$4,900	$5,300	$5,500	$5,500	$4,700
Expert E	$11,000	$11,000	$12,000	$12,000	$11,000
Expert F	$6,200	$6,700	$6,900	$6,900	$6,000
Expert G	$4,100	$4,600	$4,800	$4,800	$4,000
Expert H	$5,200	$5,600	$5,800	$5,800	$5,000
Expert I	$6,700	$7,200	$7,400	$7,400	$6,500
Expert J	$5,500	$5,900	$6,200	$6,200	$5,300
Expert K	$1,400	$1,900	$2,100	$2,100	$1,200
Expert L	$4,800	$5,200	$5,400	$5,400	$4,600

[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Table 7-49: Combined Estimate of Annual Ozone and $PM_{2.5}$ Benefits (Millions of $2006, 7% Discount Rate) for the 0.079 ppm Alternative Standard

	Alternative Standard and Model or Assumption[A]				
	Bell (2004)	*Bell (2005)*	*Ito (2005)*	*Levy (2005)*	*No Causality*
Mortality Impact Functions Derived from Epidemiology Literature					
ACS Study[B]	$2,100	$2,500	$2,700	$2,700	$1,900
Harvard Six-City Study[C]	$4,100	$4,500	$4,800	$4,800	$3,900
Mortality Impact Functions Derived from Expert Elicitation					
Expert A	$8,000	$8,400	$8,700	$8,700	$7,800
Expert B	$6,100	$6,600	$6,800	$6,800	$5,900
Expert C	$6,200	$6,600	$6,800	$6,800	$6,000
Expert D	$4,400	$4,800	$5,100	$5,100	$4,200
Expert E	$9,900	$10,000	$11,000	$11,000	$9,700
Expert F	$5,600	$6,100	$6,300	$6,300	$5,500
Expert G	$3,800	$4,200	$4,400	$4,400	$3,600
Expert H	$4,700	$5,100	$5,300	$5,400	$4,500
Expert I	$6,100	$6,500	$6,700	$6,800	$5,900
Expert J	$5,000	$5,400	$5,700	$5,700	$4,800
Expert K	$1,300	$1,800	$2,000	$2,000	$1,100
Expert L	$4,300	$4,800	$5,000	$5,000	$4,100

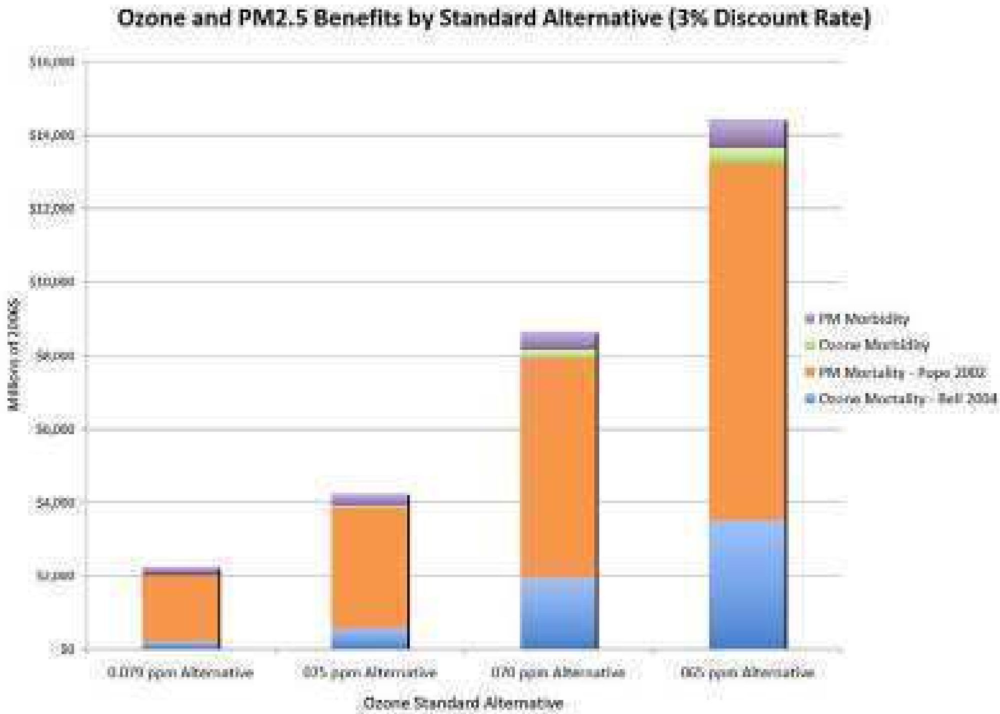
[A] Does not represent equal weighting among models or between assumption of causality vs. no causality (see text in section 6.3.2.1).

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

[C] Based on Laden et al (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[D] All estimates incremental to 2006 PM NAAQS RIA. Confidence intervals for $PM_{2.5}$ estimates not provided due to the fact that the valuation estimates were derived through a scaling technique (see above) that precluded us from generating such estimates. Estimates derived using a combination of modeling data and benefit per ton estimates. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

Figure 6.3: Ozone and $PM_{2.5}$ Benefits by Standard Alternative (3% and 7% Discount Rates)



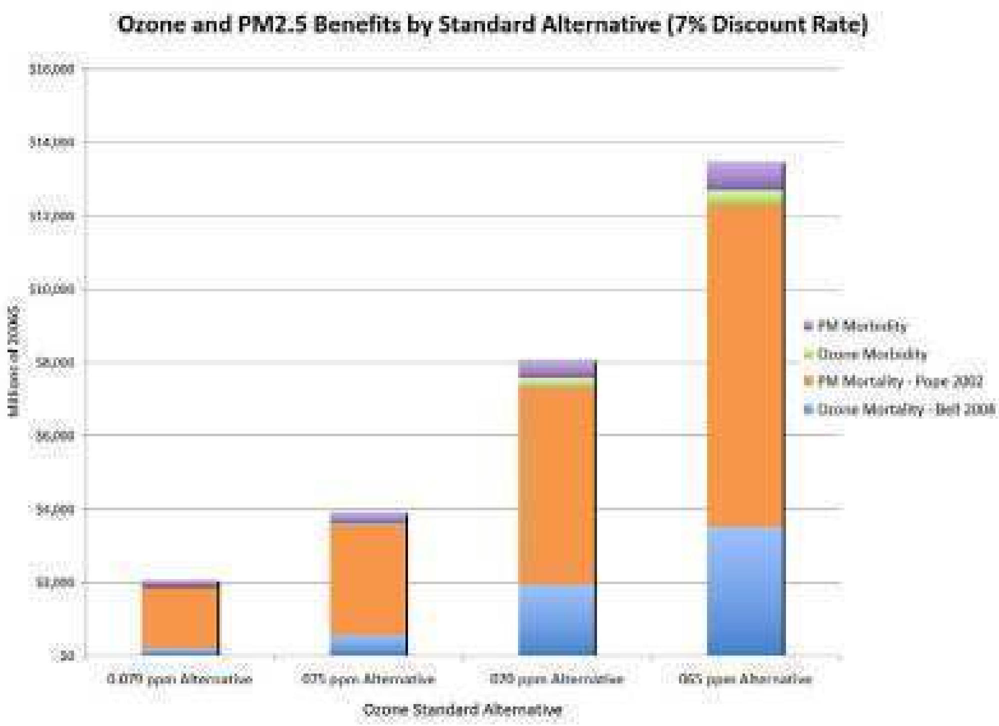
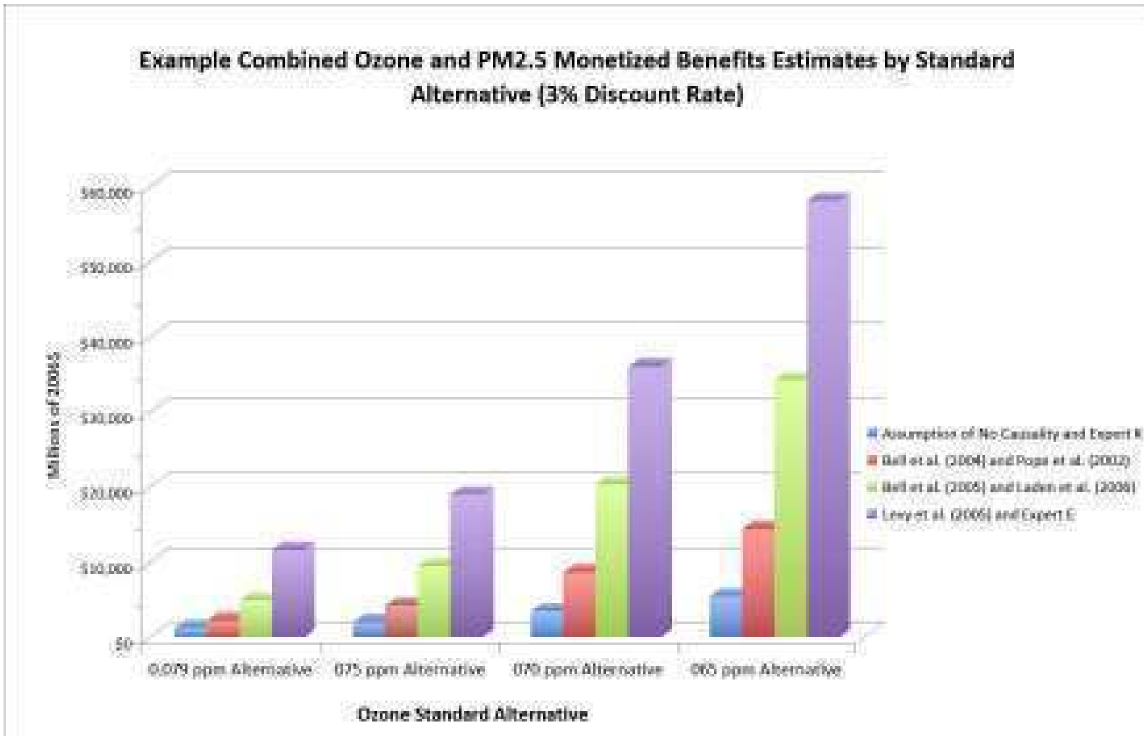


Figure 7.3 graphically shows the breakdown between ozone and PM morbidity and mortality monetized benefits for one example combination with PM benefits discounted at 3% and 7%, respectively. This example combination of Bell 2004 and Pope have been used in previous RIAs and Risk Assessments.

Figure 6.4: Example Combined Ozone and $PM_{2.5}$ Monetized Benefits Estimates by Standard Alternative (3% and 7% Discount Rates)*



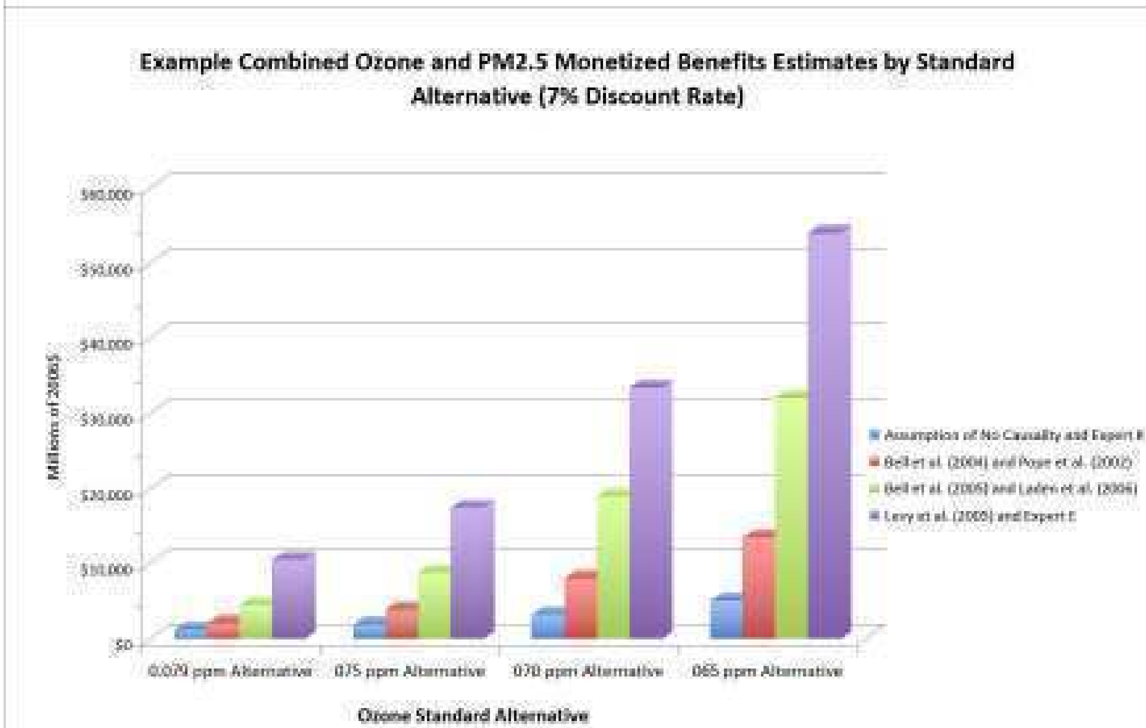
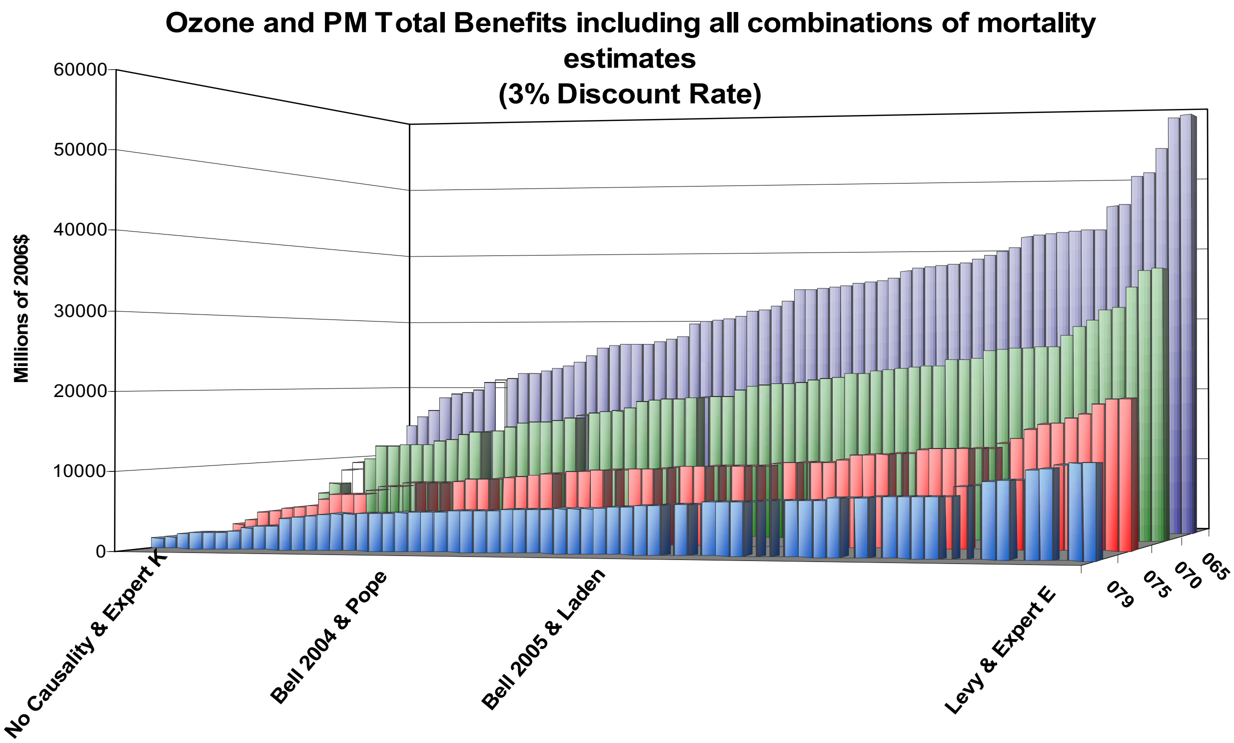


Figure 7.4 graphically shows four combinations of ozone and PM benefits estimates. These intermediate combinations represent reference points:

- Bell 2004 is the epidemiological study that underlies the ozone NAAQS risk assessment and Pope is the PM mortality function that was in several EPA RIAs, and
- Bell 2005 is one of three ozone meta-analyses and Laden is a more recent PM epidemiological study that was used as an alternative in the PM NAAQS RIA

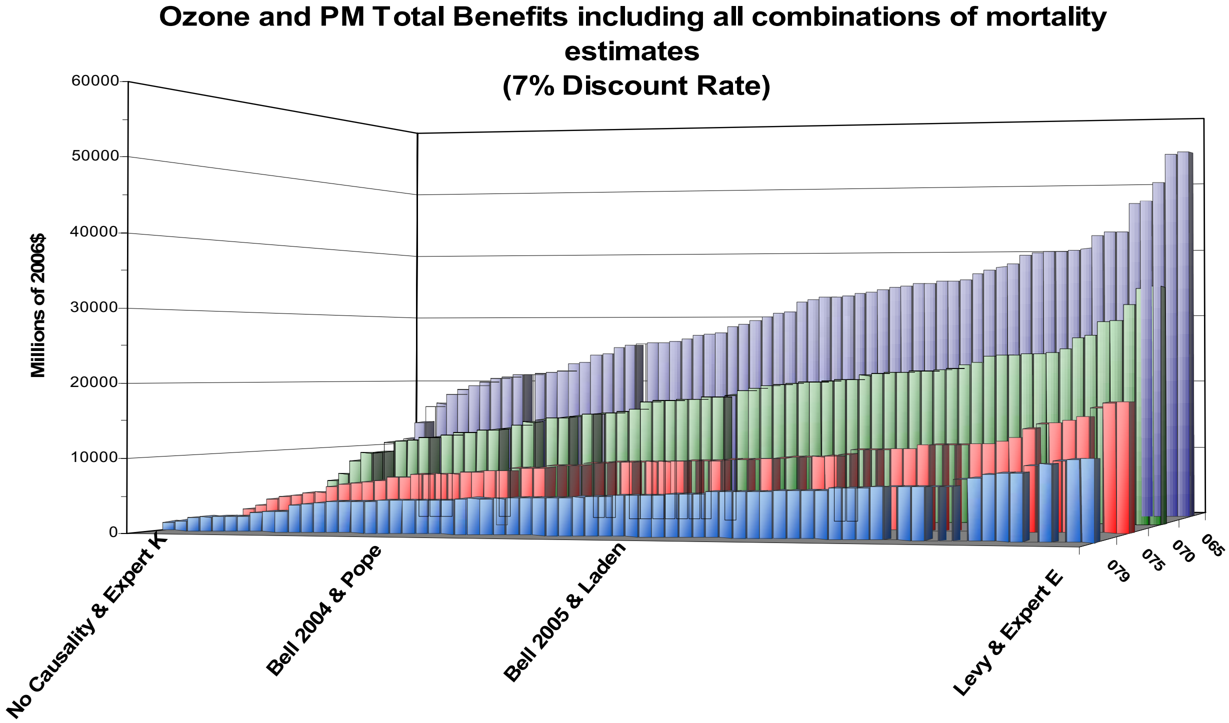
Figure 6.5 and Figure 6.6 show the complete range of combinations of ozone and PM mortality functions at 3 and 7 percent, respectively. These graphs display all possible combinations of benefits, utilizing the five different ozone functions and the fourteen different PM functions, for each standard alternative. Each of the 70 bars represents an independent and equally probably point estimate of benefits under a certain combination of ozone and PM functions. Thus it is not possible to infer the likelihood of any single benefit estimate.

Figure 6.5:*



* These figures reflect full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins. No causality, Bell, and Levy represent ozone estimates. Expert K, Pope, Laden, and Expert E represent PM estimates.

Figure 6.6*:



* These figures reflect full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins. No causality, Bell, and Levy represent ozone estimates. Expert K, Pope, Laden, and Expert E represent PM estimates.

6.5.4 Estimates of Visibility Benefits

Table 7-50 below summarizes the regional distribution of visibility benefits in Class I areas in 2020. Note that these estimates represent the monetized visibility benefits associated with the modeled ozone emission control strategy, and do not reflect the visibility benefits of fully attaining the 0.075 ppm selected alternative. For this reason, they are not added to the human health-based benefits estimates. The methodology we followed to generate these estimates may be found in the $PM_{2.5}$ RIA (EPA, 2006)

Table 7-50: Monetary Benefits Associated with Visibility Improvements from the 0.070 Simulated Ozone Attainment Strategy in Selected Federal Class I Areas in 2020 (in millions of 2006$)[A]

California	*Southwest*	*Southeast*	*Total*
$5	$95	$56	$160

[A] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns.

6.5.5 Discussion of Results and Uncertainties

The results of this analysis suggest there will be significant additional health and welfare benefits arising from reducing emissions from a variety of sources in and around projected nonattaining counties in 2020. While 2020 is the expected date that states would need to demonstrate attainment with the revised standard, it is expected that benefits (and costs) will begin occurring much earlier, as states begin implementing control measures to show reasonable progress towards attainment. Using the full range of benefits (including the results of the expert elicitation), we estimate that total ozone benefits and $PM_{2.5}$ co-benefits would be between $2.0 and $19 billion annually for the 0.075 ppm selected alternative when the emissions reductions from implementing the new standard are fully realized. The magnitude of these estimated benefits provide additional evidence of the important role that implementation of the standards plays in reducing the health risks associated with exceeding the standard.

There are several important factors to consider when evaluating the relative benefits of the attainment strategies for each of the alternative ozone standards:

1. *California (outside of San Joaquin Valley and South Coast) accounts for a substantial share of the total benefits for each of the evaluated standards.* Benefits are most uncertain for California due to the unique challenge of modeling attainment with the standards in this state. These challenges include high levels of ozone, difficulties in modeling the impacts of emissions controls on air quality, and the very large proportion of California benefits that were derived through extrapolation. On the one hand, these California benefits are likely to understate the actual benefits of attainment strategies, because we applied an estimation approach that reduced concentrations only at the specific violating monitors and not surrounding monitors that did not violate the

standards. The magnitude of this underestimate is unknown. On the other hand, it is possible that new technologies might not meet the specifications, development timelines, or cost estimates provided in this analysis, thereby increasing the uncertainty in when and if such benefits would be truly achieved.

2. *The extrapolation and interpolation techniques used to estimate the full attainment benefits of the selected and three alternate standards contributed some uncertainty to the analysis.* The great majority of benefits estimated for the 0.065 ppm standard alternative were derived through extrapolation. As noted previously in this chapter, these benefits are likely to be more uncertain than the modeled benefits. The 0.075 ppm and 0.079 ppm benefits were derived by interpolating the full attainment benefits of the 0.070 ppm alternative (a process which is described in Appendix 6a). This approach may under- or over-estimate benefits if the actual geographic distribution of air quality changes is different than that assumed in the interpolation.

3. *There are a variety of uncertainties associated with the health impact functions used in this modeling effort*. These include: within study variability, which is the precision with which a given study estimates the relationship between air quality changes and health effects; across study variation, which refers to the fact that 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, which 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, in which we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study; and, finally, there are various uncertainties in the C-R function, including causality, the correlation among multiple pollutants, the shape of the C-R function and the relative toxicity of PM component species, and the lag between exposure and the onset of the health effect.

4. *There are a variety of uncertainties associated with the economic valuation of the health endpoints estimated in this analysis*. Uncertainties specific to the valuation of premature mortality include across study variation; the assumption that WTP for mortality risk reduction is linear; assuming that voluntary and involuntary mortality risk will be valued equally; assuming that premature mortality from air pollution risk, which tend to involve longer periods of time, will be valued the same as short catastrophic events; the possibility for self-selection in avoiding risk, which may bias WTP estimates upward.

5. *This analysis includes estimates of $PM_{2.5}$ co-benefits that were derived through benefit per-ton estimates*. These benefit per-ton estimates represent regional averages. As such, they do not reflect any local variability in the incremental $PM_{2.5}$ benefits per ton of NOx abated. As discussed in the $PM_{2.5}$ NAAQS RIA (Table 5.5), there are a variety of uncertainties associated with these PM benefits.

6. *$PM_{2.5}$ co-benefits represent a substantial proportion of total benefits*. For the 0.075 ppm selected standard, we estimate co-benefits from PM to be between 42% and 99% of total benefits, depending on the $PM_{2.5}$ and ozone mortality functions used. When calculating $PM_{2.5}$ co-benefits we assume that states will pursue an ozone strategy that reduces NOx

emissions. As such, these estimates are strongly influenced by the assumption that all PM components are equally toxic. We also acknowledge that when implementing any new standard, states may elect to pursue a different ozone strategy, which would in turn affect the level of $PM_{2.5}$ co-benefits.

7. *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. In addition, data limitations prevent an overall quantitative estimate of the uncertainty associated with estimates of total economic benefits. If one is mindful of these limitations, the magnitude of the benefits estimates presented here can be useful information in expanding the understanding of the public health impacts of reducing ozone precursor emissions.

8. *This analysis omits certain unquantified effects due to lack of data, time and resources*. These unquantified endpoints include the direct effects of ozone on vegetation, the deposition of nitrogen to estuarine and coastal waters and agricultural and forested land, and the changes in the level of exposure to ultraviolet radiation from ground level ozone. EPA will continue to evaluate new methods and models and select those most appropriate for estimating the health benefits of reductions in air pollution. It is important to continue improving benefits transfer methods in terms of transferring economic values and transferring estimated impact functions. The development of both better models of current health outcomes and new models for additional health effects such as asthma, high blood pressure, and adverse birth outcomes (such as low birth weight) will be essential to future improvements in the accuracy and reliability of benefits analyses (Guo et al., 1999; Ibald-Mulli et al., 2001). Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, and economists should result in a more tightly integrated analytical framework for measuring health benefits of air pollution policies. Readers interested in a more extensive discussion of the sources of uncertainty in human health benefits analyses should consult the PM NAAQS RIA.

6.5.6 Summary of Total Benefits

Table 6.51 presents the total number of estimated ozone and $PM_{2.5}$-related premature mortalities and morbidities avoided nationwide in 2020. Ranges within the mortality section reflect variability in the studies upon which the estimates associated with premature mortality were derived. The lower end of the range reflects the Expert K derived mortality functions, and the upper end of the range reflects the Expert E derived mortality functions. Figure 6.7 graphically presents the total number of estimated ozone and $PM_{2.5}$-related premature mortalities avoided in 2020 by standard. Tables 6.52 through 6.56 show the overall ozone, PM, and combined results with regional breakdowns.

Table 6.51: Summary of Total Number of Annual Ozone and $PM_{2.5}$ -Related Premature Mortalities and Premature Morbidity Avoided in 2020[A]

Combined Estimate of Mortality

Model or Assumption		*Combined Range of Ozone Benefits and $PM_{2.5}$ Co-benefits by Standard Alternative[D]* 0.079 ppm	0.075 ppm	0.070 ppm	0.65 ppm
NMAPS	Bell (2004)	140 to 1,300	260 to 2,000	560 to 3,500	940 to 5,500
	Bell (2005)	200 to 1,300	420 to 2,200	1,100 to 4,100	2,000 to 6,500
Meta-analysis	Ito	230 to 1,400	500 to 2,300	1,400 to 4,300	2,500 to 7,000
	Levy	230 to 1,400	510 to 2,300	1,400 to 4,400	2,500 to 7,100
No Causality		120 to 1,200	190 to 2,000	310 to 3,200	490 to 5,000

Combined Estimate of Morbidity

	Combined Ozone Benefits and $PM_{2.5}$ Co-benefits by Standard Alternative			
Acute Myocardial Infarction[B]	570	890	1,500	2,300
Upper Respiratory Symptoms[B]	3,100	4,900	8,100	13,000
Lower Respiratory Symptoms[B]	4,200	6,700	11,000	17,000
Chronic Bronchitis[B]	240	380	630	970
Acute Bronchitis[B]	640	1,000	1,700	2,600
Asthma Exacerbation[B]	3,900	6,100	10,000	16,000
Work Loss Days[B]	28,000	43,000	72,000	110,000
School Loss Days[C]	72,000	200,000	640,000	1,100,000
Hospital and ER Visits	890	1,900	5,100	9,400
Minor Restricted Activity Days	340,000	750,000	2,100,000	3,500,000

[A] Does not reflect estimates for the San Joaquin and South Coast Air Basins

[B] PM-related benefits only

[C] Ozone-related benefits only

[D] Includes ozone benefits, and $PM_{2.5}$ co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the $PM_{2.5}$ premature mortality functions characterized in the expert elicitation.

Figure 6.7: Total Annual Ozone and $PM_{2.5}$-Related Premature Mortalities Avoided in 2020 by Standard Alternative

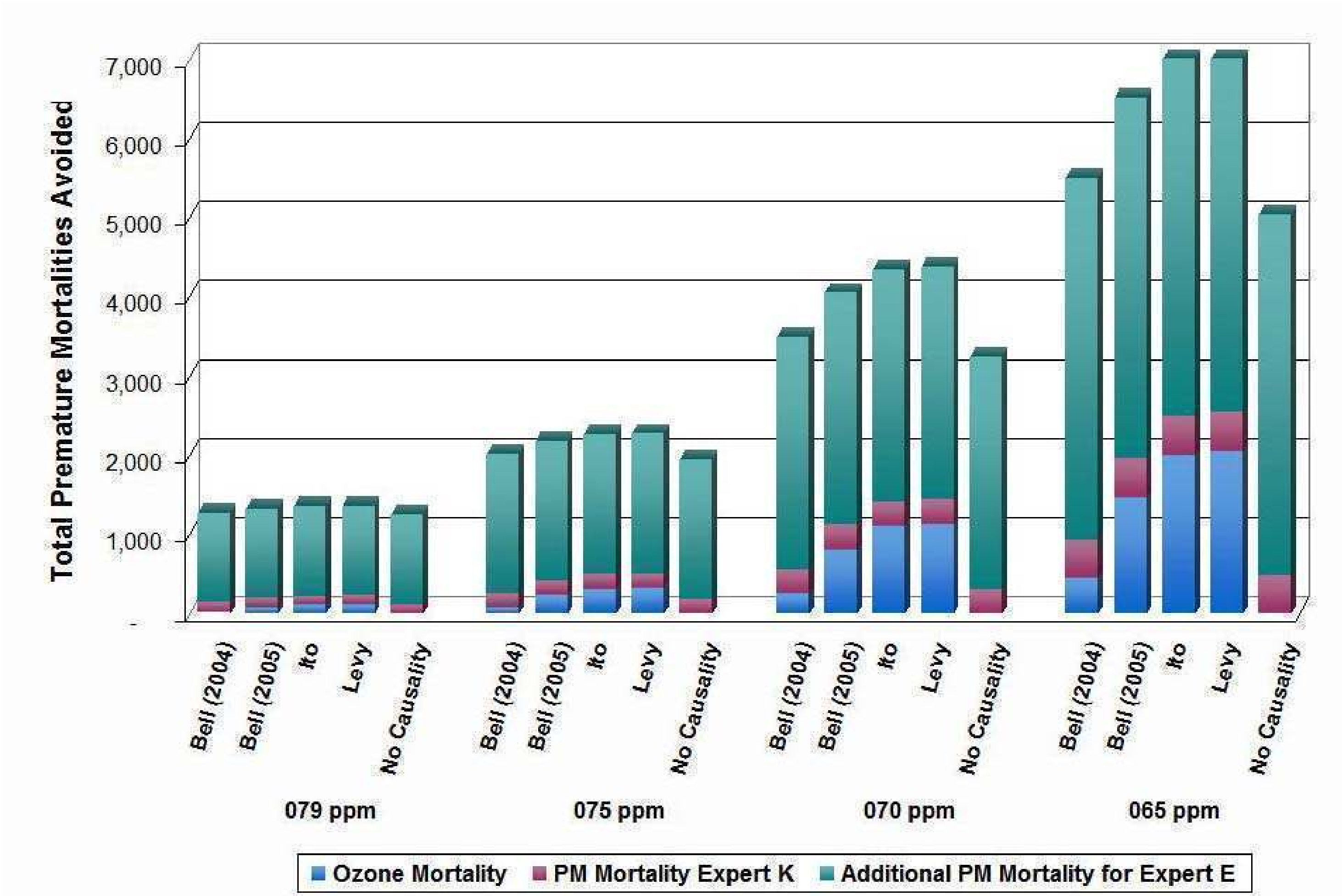


Table 6.52: Regional Breakdown of Annual Ozone Benefit Results by Health Endpoint in 2020 (thousands of 2006$)*

Region	Endpoint Group	Author	Year	079 Valuation	079 Incidence	075 Valuation	075 Incidence	070 Valuation	070 Incidence	065 Valuation	065 Incidence
East	Hospital Admissions, Respiratory (0-1)			$ 470	47	$ 2,200	220	$ 8,800	880	$ 15,000	1,500
	Hospital Admissions, Respiratory (65+)			$ 1,300	54	$ 5,200	220	$ 20,000	870	$ 50,000	2,100
	Emergency Room Visits, Respiratory			$ 13	35	$ 68	190	$ 290	770	$ 530	1,400
	School Loss Days			$ 1,700	19,000	$ 8,500	95,000	$ 35,000	390,000	$ 61,000	690,000
	Worker Productivity			$ 430	370,000	$ 2,100	1,800,000	$ 8,700	7,500,000	$ 16,000	14,000,000
	Acute Respiratory Symptoms			$ 2,800	47,000	$ 15,000	250,000	$ 61,000	1,000,000	$ 110,000	1,800,000
	Mortality	Bell et al.	2004	$ 50,000	7	$ 290,000	38	$ 1,300,000	170	$ 2,400,000	300
	Mortality	Bell et al.	2005	$ 160,000	21	$ 940,000	120	$ 4,100,000	530	$ 7,600,000	980
	Mortality	Ito et al.		$ 220,000	29	$ 1,300,000	170	$ 5,600,000	730	$ 10,000,000	1,300
	Mortality	Levy et al.		$ 230,000	30	$ 1,300,000	170	$ 5,800,000	750	$ 11,000,000	1,400
Rest of West	Hospital Admissions, Respiratory (0-1)			$ 10	1.0	$ 18	1.8	$ 820	83	$ 2,000	200
	Emergency Room Visits, Respiratory			$ 0.14	0.39	$ 0.27	0.74	$ 9.4	26	$ 27	74
	School Loss Days			$ 33	370	$ 60	670	$ 2,600	29,000	$ 6,500	72,000
	Worker Productivity			$ 6.3	5,500	$ 11	9,900	$ 360	310,000	$ 1,900	1,600,000
	Acute Respiratory Symptoms			$ 61	1,000	$ 110	1,800	$ 4,500	76,000	$ 11,000	180,000
	Hospital Admissions, Respiratory (65+)			$ 30	1.3	$ 58	2.5	$ (39)	(1.6)	$ 3,200	140
	Mortality	Bell et al.	2004	$ 1,500	0.20	$ 2,700	0.35	$ 69,000	9.0	$ 200,000	26
	Mortality	Bell et al.	2005	$ 5,100	0.65	$ 8,900	1.2	$ 230,000	30	$ 670,000	87
	Mortality	Ito et al.		$ 6,800	0.88	$ 12,000	1.6	$ 310,000	40	$ 900,000	120
	Mortality	Levy et al.		$ 7,100	0.92	$ 13,000	1.6	$ 320,000	42	$ 950,000	120
California	Hospital Admissions, Respiratory (0-1)			$ 1,400	140	$ 2,600	260	$ 5,800	580	$ 9,100	910
	Emergency Room Visits, Respiratory			$ 19	51	$ 36	97	$ 79	220	$ 130	340
	School Loss Days			$ 4,700	53,000	$ 9,000	100,000	$ 20,000	220,000	$ 31,000	350,000
	Worker Productivity			$ 4,300	3,800,000	$ 8,000	7,100,000	$ 18,000	16,000,000	$ 31,000	26,000,000
	Acute Respiratory Symptoms			$ 7,800	130,000	$ 15,000	250,000	$ 33,000	550,000	$ 52,000	880,000
	Hospital Admissions, Respiratory (65+)			$ 3,100	130	$ 5,800	240	$ 13,000	560	$ 22,000	910
	Mortality	Bell et al.	2004	$ 140,000	18	$ 260,000	33	$ 580,000	75	$ 940,000	120
	Mortality	Bell et al.	2005	$ 450,000	58	$ 840,000	110	$ 1,900,000	250	$ 3,100,000	400
	Mortality	Ito et al.		$ 610,000	78	$ 1,100,000	150	$ 2,600,000	330	$ 4,200,000	540
	Mortality	Levy et al.		$ 630,000	81	$ 1,200,000	150	$ 2,700,000	340	$ 4,300,000	560
National Total	Hospital Admissions, Respiratory (0-1)			$ 1,900	190	$ 4,800	480	$ 15,000	1,500	$ 26,000	2,700
	Hospital Admissions, Respiratory (65+)			$ 4,400	190	$ 11,000	470	$ 34,000	1,400	$ 74,000	3,200
	Emergency Room Visits, Respiratory			$ 32	87	$ 100	280	$ 370	1,000	$ 690	1,900
	School Loss Days			$ 6,400	72,000	$ 18,000	200,000	$ 57,000	640,000	$ 99,000	1,100,000
	Worker Productivity			$ 4,700	4,200,000	$ 10,000	9,000,000	$ 27,000	23,000,000	$ 49,000	42,000,000
	Acute Respiratory Symptoms			$ 11,000	180,000	$ 29,000	500,000	$ 98,000	1,700,000	$ 170,000	2,900,000
	Mortality	Bell et al.	2004	$ 190,000	24	$ 550,000	71	$ 1,900,000	250	$ 3,500,000	450
	Mortality	Bell et al.	2005	$ 620,000	80	$ 1,800,000	230	$ 6,200,000	810	$ 11,000,000	1,500
	Mortality	Ito et al.		$ 830,000	110	$ 2,400,000	310	$ 8,500,000	1,100	$ 15,000,000	2,000
	Mortality	Levy et al.		$ 860,000	110	$ 2,500,000	320	$ 8,800,000	1,100	$ 16,000,000	2,100

* National Total does not reflect benefits for the South Coast and San Joaquin Air Basins. Confidence intervals not available for PM estimates. All estimates rounded to two significant figures. Valuation results for mortality and nonfatal myocardial infarctions are shown at a 3% discount rate. Does not include visibility benefits.

Table 6.53: Regional Breakdown of Annual PM Benefit Results by Health Endpoint in 2020 (thousands of 2006$) at 3%*

	Endpoint Group	Author	079 Valuation	079 Incidence	075 Valuation	075 Incidence	070 Valuation	070 Incidence	065 Valuation	065 Incidence
East	Chronic Bronchitis		$ 31,000	64	$ 91,000	190	$ 190,000	390	$ 300,000	620
East	Emergency Room Visits, Respiratory		$ 23	62	$ 66	180	$ 140	380	$ 220	600
East	Acute Respiratory Symptoms		$ 1,200	43,000	$ 3,600	130,000	$ 7,500	260,000	$ 12,000	420,000
East	Upper+Lower Respiratory Symptoms		$ 47	1,900	$ 140	5,700	$ 290	12,000	$ 460	19,000
East	Work Loss Days		$ 910	7,300	$ 2,600	21,000	$ 5,500	45,000	$ 8,800	71,000
East	Acute Bronchitis		$ 87	170	$ 250	490	$ 530	1,000	$ 840	1,600
East	Asthma Exacerbation		$ 55	1,000	$ 160	3,000	$ 340	6,300	$ 530	10,000
East	Hospital Admissions		$ 1,400	54	$ 4,000	160	$ 8,400	330	$ 13,000	520
East	Non-fatal myocardial infarction		$ 16,000	150	$ 48,000	440	$ 100,000	920	$ 160,000	1,500
East	Infant Mortality	Woodruff	$ 1,300	0.19	$ 3,900	0.55	$ 8,100	1.20	$ 13,000	1.80
East	Mortality	Pope	$ 480,000	66	$ 1,600,000	190	$ 3,700,000	400	$ 6,200,000	640
East	Mortality	Laden	$ 1,100,000	150	$ 3,600,000	430	$ 8,300,000	900	$ 14,000,000	1,400
East	Mortality	Expert E	$ 2,800,000	330	$ 8,000,000	960	$ 16,000,000	2,000	$ 26,000,000	3,200
East	Mortality	Expert K	$ 270,000	32	$ 800,000	93	$ 1,700,000	190	$ 2,700,000	310
Rest of West	Chronic Bronchitis		$ 740	1.5	$ 740	1.5	$ 10,000	21	$ 27,000	55
Rest of West	Emergency Room Visits, Respiratory		$ 0.54	1.5	$ 0.54	1.5	$ 7.4	20	$ 20	53
Rest of West	Acute Respiratory Symptoms		$ 29	1,000	$ 29	1,000	$ 400	14,000	$ 1,100	37,000
Rest of West	Upper+Lower Respiratory Symptoms		$ 1.1	46	$ 1.1	46	$ 15	630	$ 40	1,700
Rest of West	Work Loss Days		$ 21	170	$ 21	170	$ 290	2,400	$ 780	6,300
Rest of West	Acute Bronchitis		$ 2.0	4.0	$ 2.0	4.0	$ 28	55	$ 74	140
Rest of West	Asthma Exacerbation		$ 1.3	24	$ 1.3	24	$ 18	330	$ 47	890
Rest of West	Hospital Admissions		$ 32	1.3	$ 32	1.3	$ 450	17	$ 1,200	46
Rest of West	Non-fatal myocardial infarction		$ 390	3.5	$ 390	3.5	$ 5,300	49	$ 14,000	130
Rest of West	Infant Mortality	Woodruff	$ 31	0.00	$ 31	0.00	$ 430	0.06	$ 1,100	0.16
Rest of West	Mortality	Pope	$ 11,000	1.5	$ 13,000	1.5	$ 200,000	21	$ 550,000	56
Rest of West	Mortality	Laden	$ 26,000	3.5	$ 29,000	3.5	$ 440,000	48	$ 1,200,000	130
Rest of West	Mortality	Expert E	$ 66,000	7.8	$ 65,000	7.8	$ 880,000	110	$ 2,300,000	280
Rest of West	Mortality	Expert K	$ 6,300	0.8	$ 6,500	0.8	$ 90,000	10	$ 240,000	27
California	Chronic Bronchitis		$ 86,000	180	$ 93,000	190	$ 110,000	220	$ 150,000	300
California	Emergency Room Visits, Respiratory		$ 63	170	$ 68	180	$ 78	210	$ 110	290
California	Acute Respiratory Symptoms		$ 3,400	120,000	$ 3,600	130,000	$ 4,200	150,000	$ 5,800	200,000
California	Upper+Lower Respiratory Symptoms		$ 130	5,300	$ 140	5,800	$ 160	6,700	$ 220	9,200
California	Work Loss Days		$ 2,500	20,000	$ 2,700	22,000	$ 3,100	25,000	$ 4,300	35,000
California	Acute Bronchitis		$ 240	460	$ 260	500	$ 300	580	$ 410	800
California	Asthma Exacerbation		$ 150	2,800	$ 160	3,100	$ 190	3,500	$ 260	4,900
California	Hospital Admissions		$ 3,800	150	$ 4,100	160	$ 4,700	180	$ 6,500	250
California	Non-fatal myocardial infarction		$ 45,000	410	$ 49,000	450	$ 56,000	510	$ 77,000	710
California	Infant Mortality	Woodruff	$ 3,600	0.52	$ 3,900	0.56	$ 4,500	0.65	$ 6,200	0.89
California	Mortality	Pope	$ 1,300,000	180	$ 1,700,000	200	$ 2,100,000	220	$ 3,000,000	310
California	Mortality	Laden	$ 3,000,000	410	$ 3,700,000	440	$ 4,700,000	510	$ 6,700,000	700
California	Mortality	Expert E	$ 7,600,000	910	$ 8,100,000	980	$ 9,200,000	1,100	$ 13,000,000	1,600
California	Mortality	Expert K	$ 740,000	88	$ 810,000	95	$ 950,000	110	$ 1,300,000	150
National Total	Chronic Bronchitis		$ 120,000	240	$ 180,000	380	$ 310,000	630	$ 480,000	970
National Total	Emergency Room Visits, Respiratory		$ 86	230	$ 130	370	$ 220	610	$ 350	940
National Total	Acute Respiratory Symptoms		$ 4,600	160,000	$ 7,200	260,000	$ 12,000	430,000	$ 19,000	660,000
National Total	Upper+Lower Respiratory Symptoms		$ 180	7,300	$ 280	12,000	$ 460	19,000	$ 720	30,000
National Total	Work Loss Days		$ 3,400	28,000	$ 5,300	43,000	$ 8,900	72,000	$ 14,000	110,000
National Total	Acute Bronchitis		$ 330	640	$ 510	1,000	$ 850	1,700	$ 1,300	2,600
National Total	Asthma Exacerbation		$ 210	3,900	$ 330	6,100	$ 540	10,000	$ 840	16,000
National Total	Hospital Admissions		$ 5,200	200	$ 8,100	320	$ 14,000	530	$ 21,000	820
National Total	Non-fatal myocardial infarction		$ 62,000	570	$ 97,000	890	$ 160,000	1,500	$ 250,000	2,300
National Total	Infant Mortality	Woodruff	$ 5,000	0.71	$ 7,800	1.10	$ 13,000	1.90	$ 20,000	2.90
National Total	Mortality	Pope	$ 1,800,000	250	$ 3,300,000	390	$ 6,000,000	650	$ 9,700,000	1,000
National Total	Mortality	Laden	$ 4,100,000	560	$ 7,400,000	880	$ 13,000,000	1,500	$ 22,000,000	2,300
National Total	Mortality	Expert E	$ 11,000,000	1,200	$ 16,000,000	2,000	$ 27,000,000	3,200	$ 41,000,000	5,000
National Total	Mortality	Expert K	$ 1,000,000	120	$ 1,600,000	190	$ 2,700,000	310	$ 4,300,000	490

* National Total does not reflect benefits for the South Coast and San Joaquin Air Basins. Confidence intervals not available for PM estimates. All estimates rounded to two significant figures. Valuation results for mortality and nonfatal myocardial infarctions are shown at a 3% discount rate. PM incidence and other PM morbidity incidence and valuation estimates are identical to Table 6.54 because these are not discounted. Does not include visibility benefits.

Table 6.54: Regional Breakdown of Annual PM Benefit Results by Health Endpoint in 2020 (thousands of 2006$) at 7%*

	Endpoint Group	Author	079 Valuation	079 Incidence	075 Valuation	075 Incidence	070 Valuation	070 Incidence	065 Valuation	065 Incidence
East	Chronic Bronchitis		$ 31,000	64	$ 91,000	190	$ 190,000	390	$ 300,000	620
East	Emergency Room Visits, Respiratory		$ 23	62	$ 66	180	$ 140	380	$ 220	600
East	Acute Respiratory Symptoms		$ 1,200	43,000	$ 3,600	130,000	$ 7,500	260,000	$ 12,000	420,000
East	Upper+Lower Respiratory Symptoms		$ 47	1,900	$ 140	5,700	$ 290	12,000	$ 460	19,000
East	Work Loss Days		$ 910	7,300	$ 2,600	21,000	$ 5,500	45,000	$ 8,800	71,000
East	Acute Bronchitis		$ 87	170	$ 250	490	$ 530	1,000	$ 840	1,600
East	Asthma Exacerbation		$ 55	1,000	$ 160	3,000	$ 340	6,300	$ 530	10,000
East	Hospital Admissions		$ 1,400	54	$ 4,000	160	$ 8,400	330	$ 13,000	520
East	Non-fatal myocardial infarction		$ 16,000	150	$ 46,000	440	$ 97,000	920	$ 150,000	1,500
East	Infant Mortality	Woodruff	$ 1,100	0.17	$ 3,100	0.50	$ 6,500	1.00	$ 10,000	1.60
East	Mortality	Pope	$ 440,000	66	$ 1,500,000	190	$ 3,300,000	400	$ 5,600,000	640
East	Mortality	Laden	$ 980,000	150	$ 3,300,000	430	$ 7,500,000	900	$ 12,000,000	1,400
East	Mortality	Expert E	$ 2,500,000	330	$ 7,200,000	960	$ 15,000,000	2,000	$ 23,000,000	3,200
East	Mortality	Expert K	$ 240,000	32	$ 720,000	93	$ 1,500,000	190	$ 2,500,000	310
Rest of West	Chronic Bronchitis		$ 740	1.5	$ 740	1.5	$ 10,000	21	$ 27,000	55
Rest of West	Emergency Room Visits, Respiratory		$ 0.54	1.5	$ 0.54	1.5	$ 7.4	20	$ 20	53
Rest of West	Acute Respiratory Symptoms		$ 29	1,000	$ 29	1,000	$ 400	14,000	$ 1,100	37,000
Rest of West	Upper+Lower Respiratory Symptoms		$ 1.1	46	$ 1.1	46	$ 15	630	$ 40	1,700
Rest of West	Work Loss Days		$ 21	170	$ 21	170	$ 290	2,400	$ 780	6,300
Rest of West	Acute Bronchitis		$ 2.0	4.0	$ 2.0	4.0	$ 28	55	$ 74	140
Rest of West	Asthma Exacerbation		$ 1.3	24	$ 1.3	24	$ 18	330	$ 47	890
Rest of West	Hospital Admissions		$ 32	1.3	$ 32	1.3	$ 450	17	$ 1,200	46
Rest of West	Non-fatal myocardial infarction		$ 370	3.5	$ 370	3.5	$ 5,100	49	$ 14,000	130
Rest of West	Infant Mortality	Woodruff	$ 25	0.00	$ 25	0.00	$ 350	0.06	$ 920	0.15
Rest of West	Mortality	Pope	$ 10,000	1.5	$ 12,000	1.5	$ 180,000	21	$ 490,000	56
Rest of West	Mortality	Laden	$ 23,000	3.5	$ 27,000	3.5	$ 400,000	48	$ 1,100,000	130
Rest of West	Mortality	Expert E	$ 59,000	7.8	$ 58,000	7.8	$ 790,000	110	$ 2,100,000	280
Rest of West	Mortality	Expert K	$ 5,700	0.8	$ 5,800	0.8	$ 81,000	10	$ 220,000	27
California	Chronic Bronchitis		$ 86,000	180	$ 93,000	190	$ 110,000	220	$ 150,000	300
California	Emergency Room Visits, Respiratory		$ 63	170	$ 68	180	$ 78	210	$ 110	290
California	Acute Respiratory Symptoms		$ 3,400	120,000	$ 3,600	130,000	$ 4,200	150,000	$ 5,800	200,000
California	Upper+Lower Respiratory Symptoms		$ 130	5,300	$ 140	5,800	$ 160	6,700	$ 220	9,200
California	Work Loss Days		$ 2,500	20,000	$ 2,700	22,000	$ 3,100	25,000	$ 4,300	35,000
California	Acute Bronchitis		$ 240	460	$ 260	500	$ 300	580	$ 410	800
California	Asthma Exacerbation		$ 150	2,800	$ 160	3,100	$ 190	3,500	$ 260	4,900
California	Hospital Admissions		$ 3,800	150	$ 4,100	160	$ 4,700	180	$ 6,500	250
California	Non-fatal myocardial infarction		$ 44,000	410	$ 47,000	450	$ 54,000	510	$ 75,000	710
California	Infant Mortality	Woodruff	$ 2,900	0.47	$ 3,200	0.51	$ 3,700	0.58	$ 5,100	0.80
California	Mortality	Pope	$ 1,200,000	180	$ 1,500,000	200	$ 1,900,000	220	$ 2,700,000	310
California	Mortality	Laden	$ 2,700,000	410	$ 3,300,000	440	$ 4,200,000	510	$ 6,000,000	700
California	Mortality	Expert E	$ 6,900,000	910	$ 7,300,000	980	$ 8,300,000	1,100	$ 11,000,000	1,600
California	Mortality	Expert K	$ 670,000	88	$ 740,000	95	$ 860,000	110	$ 1,200,000	150
National Total	Chronic Bronchitis		$ 120,000	240	$ 180,000	380	$ 310,000	630	$ 480,000	970
National Total	Emergency Room Visits, Respiratory		$ 86	230	$ 130	370	$ 220	610	$ 350	940
National Total	Acute Respiratory Symptoms		$ 4,600	160,000	$ 7,200	260,000	$ 12,000	430,000	$ 19,000	660,000
National Total	Upper+Lower Respiratory Symptoms		$ 180	7,300	$ 280	12,000	$ 460	19,000	$ 720	30,000
National Total	Work Loss Days		$ 3,400	28,000	$ 5,300	43,000	$ 8,900	72,000	$ 14,000	110,000
National Total	Acute Bronchitis		$ 330	640	$ 510	1,000	$ 850	1,700	$ 1,300	2,600
National Total	Asthma Exacerbation		$ 210	3,900	$ 330	6,100	$ 540	10,000	$ 840	16,000
National Total	Hospital Admissions		$ 5,200	200	$ 8,100	320	$ 14,000	530	$ 21,000	820
National Total	Non-fatal myocardial infarction		$ 60,000	570	$ 94,000	890	$ 160,000	1,500	$ 240,000	2,300
National Total	Infant Mortality	Woodruff	$ 4,000	0.64	$ 6,300	1.00	$ 11,000	1.70	$ 16,000	2.60
National Total	Mortality	Pope	$ 1,600,000	250	$ 3,000,000	390	$ 5,400,000	650	$ 8,800,000	1,000
National Total	Mortality	Laden	$ 3,700,000	560	$ 6,600,000	880	$ 12,000,000	1,500	$ 20,000,000	2,300
National Total	Mortality	Expert E	$ 9,500,000	1,200	$ 15,000,000	2,000	$ 24,000,000	3,200	$ 37,000,000	5,000
National Total	Mortality	Expert K	$ 910,000	120	$ 1,500,000	190	$ 2,500,000	310	$ 3,900,000	490

* National Total does not reflect benefits for the South Coast and San Joaquin Air Basins. Confidence intervals not available for PM estimates. All estimates rounded to two significant figures. Valuation results for mortality and nonfatal myocardial infarctions are shown at a 7% discount rate. PM incidence and other PM morbidity incidence and valuation estimates are identical to Table 6.53 because these are not discounted. Does not include visibility benefits.

Table 6.55: Regional Breakdown of Annual Ozone and PM Benefit Results by Health Endpoint in 2020 (3% discount rate, thousands of 2006$)*

	Endpoint Group	Author	Year	079 Valuation	075 Valuation	070 Valuation	065 Valuation
East	Ozone Morbidity (non-causal)			$6,600	$33,000	$130,000	$250,000
	Ozone Mortality	Bell	2004	$50,000	$290,000	$1,300,000	$2,400,000
	Ozone Mortality	Bell	2005	$160,000	$940,000	$4,100,000	$7,600,000
	Ozone Mortality	Ito	2005	$220,000	$1,300,000	$5,600,000	$10,000,000
	Ozone Mortality	Levy	2005	$230,000	$1,300,000	$5,800,000	$11,000,000
	PM Infant Mortality	Woodruff		$1,300	$3,900	$8,100	$13,000
	PM Morbidity			$51,000	$150,000	$310,000	$500,000
	PM Mortality	Pope		$480,000	$1,600,000	$3,700,000	$6,200,000
	PM Mortality	Laden		$1,100,000	$3,600,000	$8,300,000	$14,000,000
	PM Mortality	Expert E		$2,800,000	$8,000,000	$16,000,000	$26,000,000
	PM Mortality	Expert K		$270,000	$800,000	$1,700,000	$2,700,000
Rest of West	Ozone Morbidity (non-causal)			$140	$260	$8,200	$24,000
	Ozone Mortality	Bell	2004	$1,500	$2,700	$69,000	$200,000
	Ozone Mortality	Bell	2005	$5,100	$8,900	$230,000	$670,000
	Ozone Mortality	Ito	2005	$6,800	$12,000	$310,000	$900,000
	Ozone Mortality	Levy	2005	$7,100	$13,000	$320,000	$950,000
	PM Infant Mortality	Woodruff		$31	$31	$430	$1,100
	PM Morbidity			$1,200	$1,200	$17,000	$44,000
	PM Mortality	Pope		$11,000	$13,000	$200,000	$550,000
	PM Mortality	Laden		$26,000	$29,000	$440,000	$1,200,000
	PM Mortality	Expert E		$66,000	$65,000	$880,000	$2,300,000
	PM Mortality	Expert K		$6,300	$6,500	$90,000	$240,000
California	Ozone Morbidity (non-causal)			$21,000	$40,000	$90,000	$140,000
	Ozone Mortality	Bell	2004	$140,000	$260,000	$580,000	$940,000
	Ozone Mortality	Bell	2005	$450,000	$840,000	$1,900,000	$3,100,000
	Ozone Mortality	Ito	2005	$610,000	$1,100,000	$2,600,000	$4,200,000
	Ozone Mortality	Levy	2005	$630,000	$1,200,000	$2,700,000	$4,300,000
	PM Infant Mortality	Woodruff		$3,600	$3,900	$4,500	$6,200
	PM Morbidity			$140,000	$150,000	$180,000	$240,000
	PM Mortality	Pope		$1,300,000	$1,700,000	$2,100,000	$3,000,000
	PM Mortality	Laden		$3,000,000	$3,700,000	$4,700,000	$6,700,000
	PM Mortality	Expert E		$7,600,000	$8,100,000	$9,200,000	$13,000,000
	PM Mortality	Expert K		$740,000	$810,000	$950,000	$1,300,000
National Total	Ozone Morbidity (non-causal)			$28,000	$73,000	$230,000	$420,000
	Ozone Mortality	Bell	2004	$190,000	$550,000	$1,900,000	$3,500,000
	Ozone Mortality	Bell	2005	$620,000	$1,800,000	$6,200,000	$11,000,000
	Ozone Mortality	Ito	2005	$830,000	$2,400,000	$8,500,000	$15,000,000
	Ozone Mortality	Levy	2005	$860,000	$2,500,000	$8,800,000	$16,000,000
	PM Infant Mortality	Woodruff		$5,000	$7,800	$13,000	$20,000
	PM Morbidity			$190,000	$300,000	$500,000	$780,000
	PM Mortality	Pope		$1,800,000	$3,300,000	$6,000,000	$9,700,000
	PM Mortality	Laden		$4,100,000	$7,400,000	$13,000,000	$22,000,000
	PM Mortality	Expert E		$11,000,000	$16,000,000	$27,000,000	$41,000,000
	PM Mortality	Expert K		$1,000,000	$1,600,000	$2,700,000	$4,300,000

* Totals do not reflect benefits for the South Coast and San Joaquin Air Basins. Confidence intervals not available for PM estimates. All estimates rounded to two significant figures. Valuation results for mortality and nonfatal myocardial infarctions are shown at a 3% discount rate. Does not include visibility benefits.

Table 6.56: Regional Breakdown of Annual Ozone and PM Benefit Results by Health Endpoint in 2020 (7% discount rate, thousands of 2006$)*

	Endpoint Group	Author	Year	079 Valuation	075 Valuation	070 Valuation	065 Valuation
East	Ozone Morbidity (non-causal)			$6,600	$33,000	$130,000	$250,000
	Ozone Mortality	Bell	2004	$50,000	$290,000	$1,300,000	$2,400,000
	Ozone Mortality	Bell	2005	$160,000	$940,000	$4,100,000	$7,600,000
	Ozone Mortality	Ito	2005	$220,000	$1,300,000	$5,600,000	$10,000,000
	Ozone Mortality	Levy	2005	$230,000	$1,300,000	$5,800,000	$11,000,000
	PM Infant Mortality	Woodruff		$1,100	$3,100	$6,500	$10,000
	PM Morbidity			$51,000	$150,000	$310,000	$490,000
	PM Mortality	Pope		$440,000	$1,500,000	$3,300,000	$5,600,000
	PM Mortality	Laden		$980,000	$3,300,000	$7,500,000	$12,000,000
	PM Mortality	Expert E		$2,500,000	$7,200,000	$15,000,000	$23,000,000
	PM Mortality	Expert K		$240,000	$720,000	$1,500,000	$2,500,000
Rest of West	Ozone Morbidity (non-causal)			$140	$260	$8,200	$24,000
	Ozone Mortality	Bell	2004	$1,500	$2,700	$69,000	$200,000
	Ozone Mortality	Bell	2005	$5,100	$8,900	$230,000	$670,000
	Ozone Mortality	Ito	2005	$6,800	$12,000	$310,000	$900,000
	Ozone Mortality	Levy	2005	$7,100	$13,000	$320,000	$950,000
	PM Infant Mortality	Woodruff		$25	$25	$350	$920
	PM Morbidity			$1,200	$1,200	$16,000	$44,000
	PM Mortality	Pope		$10,000	$12,000	$180,000	$490,000
	PM Mortality	Laden		$23,000	$27,000	$400,000	$1,100,000
	PM Mortality	Expert E		$59,000	$58,000	$790,000	$2,100,000
	PM Mortality	Expert K		$5,700	$5,800	$81,000	$220,000
California	Ozone Morbidity (non-causal)			$21,000	$40,000	$90,000	$140,000
	Ozone Mortality	Bell	2004	$140,000	$260,000	$580,000	$940,000
	Ozone Mortality	Bell	2005	$450,000	$840,000	$1,900,000	$3,100,000
	Ozone Mortality	Ito	2005	$610,000	$1,100,000	$2,600,000	$4,200,000
	Ozone Mortality	Levy	2005	$630,000	$1,200,000	$2,700,000	$4,300,000
	PM Infant Mortality	Woodruff		$2,900	$3,200	$3,700	$5,100
	PM Morbidity			$140,000	$150,000	$180,000	$240,000
	PM Mortality	Pope		$1,200,000	$1,500,000	$1,900,000	$2,700,000
	PM Mortality	Laden		$2,700,000	$3,300,000	$4,200,000	$6,000,000
	PM Mortality	Expert E		$6,900,000	$7,300,000	$8,300,000	$11,000,000
	PM Mortality	Expert K		$670,000	$740,000	$860,000	$1,200,000
National Total	Ozone Morbidity (non-causal)			$28,000	$73,000	$230,000	$420,000
	Ozone Mortality	Bell	2004	$190,000	$550,000	$1,900,000	$3,500,000
	Ozone Mortality	Bell	2005	$620,000	$1,800,000	$6,200,000	$11,000,000
	Ozone Mortality	Ito	2005	$830,000	$2,400,000	$8,500,000	$15,000,000
	Ozone Mortality	Levy	2005	$860,000	$2,500,000	$8,800,000	$16,000,000
	PM Infant Mortality	Woodruff		$4,000	$6,300	$11,000	$16,000
	PM Morbidity			$190,000	$300,000	$500,000	$780,000
	PM Mortality	Pope		$1,600,000	$3,000,000	$5,400,000	$8,800,000
	PM Mortality	Laden		$3,700,000	$6,600,000	$12,000,000	$20,000,000
	PM Mortality	Expert E		$9,500,000	$15,000,000	$24,000,000	$37,000,000
	PM Mortality	Expert K		$910,000	$1,500,000	$2,500,000	$3,900,000

* Totals do not reflect benefits for the South Coast and San Joaquin Air Basins. Confidence intervals not available for PM estimates. All estimates rounded to two significant figures. Valuation results for mortality and nonfatal myocardial infarctions are shown at a 7% discount rate. Does not include visibility benefits.

6.6 References:

Abt Associates, Inc. October 2005. *Methodology for County-level Mortality Rate Projections.* Memorandum to Bryan Hubbell and Zachary Pekar, U.S. EPA.

Adams PF, Hendershot GE, Marano MA. 1999. Current Estimates from the National Health Interview Survey, 1996. Vital Health Stat 10(200):1-212.

Agency for Healthcare Research and Quality. 2000. HCUPnet, Healthcare Cost and Utilization Project. Rockville, Maryland. Available: http://www.ahrq.gov/HCUPnet/ [accessed 29 September 2004].

Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. 2004. Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3): Report of a WHO task group. Copenhagen, Denmark: World Health Organization.

Bell, M.L., et al. Ozone and short-term mortality in 95 US urban communities, 1987-2000. Jama, 2004. 292(19): p. 2372-8.

Bell, M.L., F. Dominici, and J.M. Samet. A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. Epidemiology, 2005. 16(4): p. 436-45.

Berger MC, Blomquist GC, Kenkel D, Tolley GS. 1987. Valuing Changes in Health Risks: A Comparison of Alternative Measures. The Southern Economic Journal 53:977-984.

Burnett RT, Smith-Doiron M, Stieb D, Raizenne ME, Brook JR, Dales RE, et al. 2001. Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. Am J Epidemiol 153(5):444-452.

Chen L, Jennison BL, Yang W, Omaye ST. 2000. Elementary school absenteeism and air pollution. Inhal Toxicol 12(11):997-1016.

Crocker, T.D. and R.L. Horst, Jr. Hours of Work, Labor Productivity, and Environmental Conditions: A Case Study. The Review of Economics and Statistics, 1981. 63: p. 361-368.

Freeman(III), AM. 1993. The Measurement of Environmental and Resource Values: Theory and Methods. Washington, DC: Resources for the Future.

Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, et al. 2001. The effects of ambient air pollution on school absenteeism due to respiratory illnesses. Epidemiology 12(1):43-54.

GeoLytics Inc. 2002. Geolytics CensusCD® 2000 Short Form Blocks. CD-ROM Release 1.0. GeoLytics, Inc. East Brunswick, NJ. Available: http://www.geolytics.com/ [accessed 29 September 2004].

Hall JV, Brajer V, Lurmann FW. 2003. Economic Valuation of Ozone-related School Absences in the South Coast Air Basin of California. Contemporary Economic Policy 21(4):407-417.

Harrington W, Portney PR. 1987. Valuing the Benefits of Health and Safety Regulation. Journal of Urban Economics 22:101-112.

Industrial Economics Incorporated (IEc). 1993. Memorandum to Jim DeMocker, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy Analysis and Review. September 30. Washington, D.C.

International Classification of Diseases, Ninth Revision. 1979. Hyattsville, MD: National Center for Health Statistics. Available: http://www.cdc.gov/nchs/about/major/dvs/icd9des.htm [accessed 29 September 2004].

Ito, K., S.F. De Leon, and M. Lippmann. Associations between ozone and daily mortality: analysis and meta-analysis. Epidemiology, 2005. 16(4): p. 446-57.

Jaffe DH, Singer ME, Rimm AA. 2003. Air pollution and emergency department visits for asthma among Ohio Medicaid recipients, 1991-1996. Environ Res 91(1):21-28.

Köchy, Martin and Scott D. Wilson, "Nitrogen deposition and forest expansion in the northern Great Plains Journal of Ecology *Journal of Ecology* 89 (5), 807–817

Kunzli, N., S. Medina, R. Kaiser, P. Quenel, F. Horak Jr, and M. Studnicka. 2001. "Assessment of Deaths Attributable to Air Pollution: Should We Use Risk Estimates Based on Time Series or on Cohort Studies?" *American Journal of Epidemiol*ogy 153(11):1050-55.

Levy JI, Carrothers TJ, Tuomisto JT, Hammitt JK, Evans JS. 2001. Assessing the Public Health Benefits of Reduced Ozone Concentrations. Environ Health Perspect 109(12):1215-1226

Levy, J.I., S.M. Chemerynski, and J.A. Sarnat. Ozone exposure and mortality: an empiric bayes metaregression analysis. Epidemiology, 2005. 16(4): p. 458-68.

Moolgavkar SH, Luebeck EG, Anderson EL. 1997. Air pollution and hospital admissions for respiratory causes in Minneapolis St. Paul and Birmingham. Epidemiology 8(4):364-370.

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

Ostro BD, Rothschild S. 1989. Air Pollution and Acute Respiratory Morbidity—an Observational Study of Multiple Pollutants. Environ Res 50(2):238-247.

Ostro, B., M. Lipsett, J. Mann, H. Braxton-Owens, and M. White. 2001. "Air Pollution and Exacerbation of Asthma in African-American Children in Los Angeles." *Epidemiology* 12(2):200-208.

Nadelhoffer, Knute J. et. al., "Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests" *Nature* 398, 145-148 (11 March 1999)

Peel, J. L., P. E. Tolbert, M. Klein, et al. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology. Vol. 16 (2): 164-74.

Schwartz J. 1994a. PM(10) Ozone, and Hospital Admissions For the Elderly in Minneapolis St Paul, Minnesota*.* Arch Environ Health 49(5):366-374.

Schwartz J. 1994b. Air Pollution and Hospital Admissions For the Elderly in Detroit, Michigan. Am J Respir Crit Care Med 150(3):648-655.

Schwartz J. 1995. Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. Thorax 50(5):531-538.

Smith DH, Malone DC, Lawson KA, Okamoto LJ, Battista C, Saunders WB. 1997. A national estimate of the economic costs of asthma. Am J Respir Crit Care Med. 156(3 Pt 1):787-793.

Stanford R, McLaughlin T, Okamoto LJ. 1999. The cost of asthma in the emergency department and hospital. Am J Respir Crit Care Med 160(1):211-215.

Thurston GD, Ito K. 2001. Epidemiological studies of acute ozone exposures and mortality. *J* Expo Anal Environ Epidemiol 11(4):286-294.

Tolley GS, Babcock L, Berger M, Bilotti A, Blomquist G, Brien M, et al. 1986. Valuation of Reductions in Human Health Symptoms and Risks. Prepared for U.S. Environmental Protection Agency. January. Washington, D.C.

U.S. Bureau of the Census. 2001. Statistical Abstract of the United States, 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 521. Washington, DC.

U.S. Department of Education. 1996. The Condition of Education 1996, Indicator 42: Student Absenteeism and Tardiness. National Center for Education Statistics. Washington DC.

U.S. EPA. 1970. Clean Air Act. 40CFR50.

U.S. Environmental Protection Agency. 1999. The Benefits and Costs of the Clean Air Act, 1990-2010. Prepared for U.S. Congress by U.S. EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC, November; EPA report no. EPA-410-R-99-001.

U.S. Environmental Protection Agency, 2004. Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines. EPA420-R-04-007. Prepared by Office of Air and Radiation. Available: http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf [accessed 29 September 2004].

U.S. Environmental Protection Agency, 2006. Final Regulatory Impact Analysis: $PM_{2.5}$ NAAQS. Prepared by Office of Air and Radiation. Available: http://www.epa.gov/ttn/ecas/ria.html [accessed 10 March 2008].

Vedal, S., J. Petkau, R. White, and J. Blair. 1998. "Acute Effects of Ambient Inhalable Particles in Asthmatic and Nonasthmatic Children." *American Journal of Respiratory and Critical Care Medicine* 157(4):1034-1043.

Vitousek, Peter M. et. al., "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences" *Issues in Ecology* No. 1 (Spring) 1997.

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

Woods & Poole Economics Inc. 2001. Population by Single Year of Age CD. CD-ROM. Woods & Poole Economics, Inc. Washington, D.C.

World Health Organization (WHO). 2003. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide: Report on a WHO Working Group. World Health Organization. Bonn, Germany. EUR/03/5042688.

Appendix 6a: Additional Benefits Information

Summary

This appendix provides additional information regarding the benefits analysis, including (1) methods for developing estimate of full attainment air quality; (2) the process for interpolating the 0.075 ppm and 0.079 ppm benefits estimates; (3) the partial attainment PM2.5 incidence and valuation estimates.

6a.1 Developing an Air Quality Estimate of Full Attainment with the Alternative Ozone Standards

As discussed in chapter 3, the modeled attainment scenarios were not sufficient to simulate full attainment with each of the three alternative ozone standards analyzed. To meet our analytical goal of estimating the human health benefits of full simulated attainment with each of these standard alternatives, it became necessary to derive an estimate of the full attainment air quality increment through a simple monitor rollback approach.

We rolled back the values at each monitor such that no monitor in the U.S. exceeded the alternative standard in question. This approach makes the bounding assumption that ozone concentrations can be reduced only at monitors projected to exceed the alternative standards. From a benefits perspective, this approach leads to a downward bias in the estimates because populations are assumed to be exposed at a distance weighted average of surrounding monitors. Thus, any individual's reduction in exposure from a change at a given monitor will be weighted less if there are other attaining monitors in close proximity.

We determined projected attainment status of each monitor by calculating design values. However, to estimate changes in ozone-related health effects resulting from improvement in air quality, the BenMAP model requires a series of metrics. When performing a benefits assessment with air quality modeling data, BenMAP calculates these metrics based on the distribution of CMAQ-modeled hourly ozone concentrations for the ozone season. However, because we were performing a benefits assessment based on monitor values that have been rolled-back, it was necessary to derive each of these metrics outside of the BenMAP model. Thus, we first developed a scaling ratio that related the calculated design value to each of the ozone metrics.

A summary of this procedure is as follows:

1. Import partial attainment 0.08 ppm calculated design values into the BenMAP model

2. Perform a spatial interpolation of these design values using the Voronoi Neighborhood Averaging algorithm. Design values are then interpolated to the CMAQ grid cell.

3. Import distribution of air quality modeled daily and hourly ozone concentrations into BenMAP. Create air quality grid in BenMAP using spatial and temporal scaling

technique.[1] This procedure creates grid cell level summer season ozone metrics (1 hour maximum, 5 hour average, 8 hour maximum, 8 hour average and 24 hour average).

4. Calculate grid cell-level ratio of each ozone metric to calculated design value. The result of this calculation is a grid cell-level ratio of metric to design value that can then be subsequently used to scale the calculated design value and thus derive each of the metrics.

After having calculated these scaling ratios we then performed the monitor rollback as follows:

1. Roll back the calculated 0.08 ppm partial attainment design value to just equal the 0.08 ppm standard. This process creates a new baseline design value grid.

2. Scale the design value grid cell values to ozone metric grid cell values by using ratios described above.

3. Create new 0.084 ppm baseline air quality grid from grid cell-level ozone metrics.

4. Roll back the calculated 0.070 ppm and 0.065 ppm partial attainment design values at each monitor to just reach the 0.070 ppm and 0.065 ppm standards, respectively.

5. Scale the calculated full attainment design value to grid cell-level ozone metric using ratios described above.

6. Create new 0.070 ppm and 0.065 ppm air quality grids from grid cell-level ozone metrics.

7. Perform benefits analysis with baseline and control grids.

To develop the full attainment air quality grids for 0.075 ppm and 0.079 ppm, we performed an interpolation of the 0.070 ppm full attainment air quality grid, rather than a monitor rollback. We used this technique because air quality modeling incorporating control strategies was only available for 0.070 ppm. This interpolation for 0.075 ppm entailed the following steps:

1. We identified any monitors that were projected to not attain 0.075 ppm alternative in the 0.084 ppm base case air quality grid.

2. For these monitors we calculated an adjustment factor that would scale down the air quality improvement at that monitor. The purpose of this adjustment was to ensure that the improvement in air quality at that monitor reflected the attainment of the 0.075 ppm standard. This ratio was calculated by dividing the improvement in the design value necessary to attain 0.075 ppm by the improvement in the design value necessary to attain 0.070 ppm. For example, a monitor whose baseline is 0.084 would receive 2/3 of the air quality improvement from attaining 0.075 ppm than they would from attaining 0.070 ppm.

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[1] BenMAP Technical Appendices, Abt Associates: May 2005. Page C-12.

3. We then interpolated these monitor-specific ratios to the grid cell-level in BenMAP, constraining the interpolation to within 200 km of the control buffer.

4. Finally, we used these grid cell-level ratios as the basis for scaling down the grid cell-level estimates of incidence and valuation from the 0.070 ppm analysis.

5. Next, we followed the same process for the 0.079 ppm interpolation.

6a.2 Partial Attainment $PM_{2.5}$ Incidence and Valuation Estimates

Tables 6a.1 through 6a.5 below summarize the estimates of $PM_{2.5}$ incidence and valuation resulting from the 0.070 ppm partial attainment scenario. These estimates provided the basis for the full attainment $PM_{2.5}$ co-benefit estimates found in Chapter 6 of this RIA. Details about the methodology for this approach can also be found in Chapter 6.

Table 6a.1: Illustrative 0.070 ppm Partial Attainment Scenario: Estimated Reductions in PM Premature Mortality associate with PM Co-Benefit (95th percentile confidence intervals provided in parentheses)[c]

	Eastern U.S.	Western U.S. Excluding California	California	National PM Co-Benefits
Mortality Impact Functions Derived from Epidemiology Literature				
ACS Study[a]	420 (110--730)	6.3 (2--10)	5.4 (2--9)	430 (110--750)
Harvard Six-City Study[b]	950 (420--1,500)	14 (7--21)	12 (6--18)	980 (440--1,500)
Woodruff et al. 1997 (infant mortality)	1.1 (0.34--1.8)	0.15 (0.07--0.23)	0.02 (0.01--0.04)	1.3 (0.42--2.1)
Mortality Impact Functions Derived from Expert Elicitation				
Expert A	1,600 (-92--3,200)	150 (0.90--310)	32 (3.4--60)	1,800 (-87--3,600)
Expert B	1,200 (-100--2,900)	110 (-4.3--270)	24 (2.3--53)	1,300 (-100--3,200)
Expert C	1,200 (-100--2,900)	120 (-0.89--280)	24 (2.7--54)	1,300 (-99--3,200)
Expert D	830 (42--1,500)	81 (5.7--140)	17 (1.7--28)	920 (49--1,700)
Expert E	2,000 (690--3,300)	190 (76--310)	39 (18--62)	2,200 (790--3,600)
Expert F	1,100 (660--1,700)	110 (66--160)	22 (15--32)	1,200 (740--1,900)
Expert G	690 (0.00--1,400)	68 (0.00--130)	14 (0.00--27)	770 (0.00--1,500)
Expert H	880 (-250--2,300)	86 (-17--220)	18 (-0.93--43)	990 (-270--2,600)
Expert I	1,200 (-14--2,400)	120 (1.5--220)	24 (1.2--44)	1,300 (-11--2,600)
Expert J	950 (44--2,400)	93 (11--230)	19 (5--45)	1,100 (60--2,700)
Expert K	190 (0.00--1,000)	18 (0.00--98)	3.8 (0.00--20)	210 (0.00--1,100)
Expert L	840 (25--1,800)	70 (1.5--170)	16 (1.2--33)	920 (28--2,000)

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

[b] Based on Laden et al. (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[c] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not reflect benefits for the San Joaquin Valley or South Coast Air Basins. Negative values indicate that an increase in incidence could occur.

Table 6a.2: Illustrative 0.070 ppm Partial Attainment Scenario: Estimated Reductions in Morbidity Associated with PM Co-Benefit (95th percentile confidence intervals provided in parentheses)[a]

	Eastern U.S.	Western U.S. Excluding California	California	National PM Co-Benefits
Morbidity Impact Functions Derived from Epidemiology Literature				
Chronic Bronchitis (age >25 and over)	380 (-11--760)	38 (4--72)	8.7 (1--17)	420 (-6--850)
Nonfatal myocardial infarction (age >17)	970 (440--1,500)	12 (6--18)	11 (5--16)	1,000 (450--1,500)
Hospital admissions—respiratory (all ages)	120 (46--184)	1.3 (1--2)	1.1 (1--2)	120 (46--186)
Hospital admissions—cardiovascular (age >17)	230 (127--340)	2.8 (2--4)	2.3 (1--3)	240 (130--340)
Emergency room visits for asthma (age <19)	400 (200--610)	3.6 (2--5)	2.4 (1--4)	410 (200--620)
Acute bronchitis (age 8–12)	980 (-310--2,300)	120 (-16--250)	23 (-3--50)	1,100 (-320--2,600)
Lower respiratory symptoms (age 7–14)	7,100 (2,600--12,000)	150 (63--230)	130 (57--210)	7,400 (2,800--12,000)
Upper respiratory symptoms (asthmatic children age 9–18)	5,200 (880--9,500)	110 (27--190)	95 (24--170)	5,400 (930--9,900)
Asthma exacerbation (asthmatic children age 6–18)	6,500 (-78--21,000)	130 (10--420)	120 (9--380)	6,800 (-60--22,000)
Work loss days (age 18–65)	47,000 (39,000--54,000)	830 (710--950)	800 (680--910)	48,000 (41,000--56,000)
Minor restricted activity days (age 18–65)	280,000 (220,000--330,000)	4,800 (4,000--5,700)	4,700 (3,900--5,500)	290,000 (230,000--340,000)

[a] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not reflect benefits for the San Joaquin Valley or South Coast Air Basins. Negative values indicate that an increase in incidence could occur.

Table 6a.3: Illustrative Strategy to Partially Attain 0.070 ppm: Estimated Partial Attainment Value of Reductions in PM2.5-Related Premature Mortality Associated with PM Co-Benefit (3 percent discount rate, in millions of 2006$) 95th Percentile Confidence Intervals Provided in Parentheses[c]

	Eastern U.S.	Western U.S. Excluding California	California	National PM Co-Benefits
Mortality Impact Functions Derived from Epidemiology Literature				
ACS Study[a]	$3,000 ($380--$7,000)	$44 ($6.8--$110)	$38 ($5.8--$95)	$3,000 ($440--$7,200)
Harvard Six-City Study[b]	$6,700 ($1,000--$14,000)	$99 ($16--$210)	$85 ($14--$180)	$6,900 ($1,000--$15,000)
Woodruff et al., 1997 (infant mortality)	$7.5 ($1.0--$17)	$1.0 ($0.16--$2.3)	$0.17 ($0.03--$0.36)	$8.8 ($1.2--$20)
Mortality Impact Functions Derived from Expert Elicitation				
Expert A	$11,000 ($200--$30,000)	$1,100 ($55--$2,800)	$220 ($20--$560)	$12,000 ($280--$33,000)
Expert B	$8,400 (-$600--$28,000)	$790 (-$23--$2,700)	$170 ($9.0--$520)	$9,300 (-$620--$31,000)
Expert C	$8,300 (-$33--$27,000)	$810 ($32--$2,600)	$170 ($15--$500)	$9,300 ($13--$30,000)
Expert D	$5,800 ($480--$15,000)	$570 ($53--$1,400)	$120 ($13--$280)	$6,500 ($540--$16,000)
Expert E	$14,000 ($2,000--$32,000)	$1,300 ($200--$3,000)	$280 ($43--$600)	$15,000 ($2,300--$35,000)
Expert F	$7,600 ($1,400--$17,000)	$740 ($130--$1,600)	$150 ($27--$330)	$8,500 ($1,400--$19,000)
Expert G	$4,900 ($0.00--$13,000)	$480 ($0.00--$1,300)	$98 ($0.00--$260)	$5,400 ($0.00--$14,000)
Expert H	$6,200 (-$1,700--$21,000)	$610 (-$100--$2,000)	$120 ($0.26--$390)	$6,900 (-$1,700--$23,000)
Expert I	$8,200 ($430--$22,000)	$810 ($53--$2,100)	$170 ($14--$420)	$9,200 ($500--$24,000)
Expert J	$6,700 ($430--$22,000)	$650 ($61--$2,100)	$130 ($17--$410)	$7,400 ($520--$24,000)
Expert K	$1,300 ($0.00--$8,200)	$130 ($0.00--$800)	$27 ($0.00--$160)	$1,500 ($0.00--$9,200)
Expert L	$5,900 ($240-$17,000)	$490 ($7.2--$1,600)	$110 ($5.7--$330)	$6,500 ($260--$19,000)

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

[b] Based on Laden et al. (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[c] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not reflect benefits for the San Joaquin Valley or South Coast Air Basins. Negative values indicate that an increase in incidence could occur.

Table 6a.4: Illustrative Strategy to Partially Attain 0.070 ppm: Estimated Partial Attainment Value of Reductions in $PM_{2.5}$-Related Premature Mortality Associated with PM Co-Benefit (7 percent discount rate, in millions of 2006$) 95th Percentile Confidence Intervals Provided in Parentheses[c]

	Eastern U.S.	Western U.S. Excluding California	California	National PM Co-Benefits
Mortality Impact Functions Derived from Epidemiology Literature				
ACS Study[a]	$2,700 ($340--$6,300)	$40 ($6.8--$110)	$34 ($5.8--$95)	$2,700 ($360--$6,400)
Harvard Six-City Study[b]	$6,000 ($920--$13,000)	$89 ($14--$190)	$77 ($12--$160)	$6,200 ($940--$13,000)
Woodruff et al., 1997 (infant mortality)	$6.8 ($0.90--$16)	$0.94 ($0.14--$2.0)	$0.15 ($0.02--$0.33)	$7.9 ($1.1--$18)
Mortality Impact Functions Derived from Expert Elicitation				
Expert A	$9,900 ($180--$27,000)	$970 ($50--$2,500)	$200 ($18--$510)	$11,000 ($250--$30,000)
Expert B	$7,500 (-$550--$25,000)	$720 (-$20--$2,400)	$150 ($8.1--$470)	$8,400 (-$560--$28,000)
Expert C	$7,500 (-$30--$24,000)	$730 ($28--$2,300)	$150 ($14--$450)	$8,400 ($12--$27,000)
Expert D	$5,200 ($430--$13,000)	$510 ($47--$1,300)	$110 ($11--$250)	$5,800 ($490--$15,000)
Expert E	$12,000 ($1,800--$29,000)	$1,200 ($180--$2,700)	$250 ($39--$540)	$14,000 ($2,000--$32,000)
Expert F	$6,800 ($1,200--$16,000)	$660 ($110--$1,500)	$140 ($24--$300)	$7,600 ($1,300--$17,000)
Expert G	$4,400 ($0.00--$12,000)	$430 ($0.00--$1,200)	$88 ($0.00--$240)	$4,900 ($0.00--$13,000)
Expert H	$5,600 (-$1,500--$19,000)	$550 (-$90--$1,800)	$110 ($0.24--$350)	$6,200 (-$1,600--$21,000)
Expert I	$7,400 ($380--$20,000)	$730 ($48--$1,900)	$150 ($12--$380)	$8,300 ($450--$22,000)
Expert J	$6,000 ($390--$19,000)	$590 ($55--$1,900)	$120 ($16--$370)	$6,700 ($470--$22,000)
Expert K	$1,200 ($0.00--$7,400)	$110 ($0.00--$720)	$24 ($0.00--$150)	$1,300 ($0.00--$8,200)
Expert L	$5,300 ($220--$16,000)	$440 ($6.5--$1,500)	$99 ($5.1--$300)	$5,800 ($230--$17,000)

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

[b] Based on Laden et al. (2006) reporting of the extended Six-cities study; to be reviewed by the EPA-SAB for advice on the appropriate method for incorporating what has previously been a sensitivity estimate.

[c] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS RIA. Estimates do not reflect benefits for the San Joaquin Valley or South Coast Air Basins. Negative values indicate that an increase in incidence could occur.

Table 6a.5: Illustrative Strategy to Partially Attain 0.070 ppm: Estimated Partial Attainment Monetary Value of Reductions in Risk of $PM_{2.5}$-Related Morbidity Reductions Associated with PM Co-Benefit (in millions of 2006$) 95th Percentile Confidence Intervals Provided in Parentheses[a]

	Eastern U.S.	Western U.S. Excluding California	California	National PM Co-Benefits
Morbidity Impact Functions Derived from Epidemiology Literature				
Chronic Bronchitis (age >25 and over)	$180 ($4.0--$870)	$19 ($1.0--$86)	$4.3 ($0.24--$20)	$210 ($5.2--$980)
Nonfatal myocardial infarction (age >17)	$210 ($50--$480)	$2.6 ($0.65--$5.8)	$2.3 ($0.61--$5.2)	$210 ($50--$490)
Hospital admissions—respiratory (all ages)	$2.5 ($1.10--$3.80)	$0.03 ($0.01--$0.04)	$0.02 ($0.01--$0.04)	$ 2.5 ($1.1--$3.8)
Hospital admissions—cardiovascular (age >17)	$6.5 ($3.80--$9.10)	$0.08 ($0.05--$0.11)	$0.06 ($0.04--$0.09)	$6.6 ($3.9--$9.3)
Emergency room visits for asthma (age <19)	$0.15 ($0.07--$0.25)	$0.00 ($0.00--$0.00)	$0.00 ($0.00--$0.00)	$0.15 ($0.07--$0.25)
Acute bronchitis (age 8–12)	$0.50 (-$0.14--$1.50)	$0.06 ($0.00--$0.17)	$0.01 ($0.00--$0.03)	$0.57 (-$0.14--$1.7)
Lower respiratory symptoms (age 7–14)	$ 0.14 ($0.04--$0.29)	$0.00 ($0.00--$0.01)	$0.00 ($0.00--$0.01)	$0.14 ($0.04--$0.30)
Upper respiratory symptoms (asthmatic children age 9–18)	$0.16 ($0.03--$0.41)	$0.00 ($0.00--$0.01)	$0.00 ($0.00--$0.01)	$0.17 ($0.03--$0.42)
Asthma exacerbation (asthmatic children age 6–18)	$0.35 ($0.01--$1.30)	$0.01 ($0.00--$0.03)	$0.01 ($0.00--$0.02)	$0.36 ($0.01--$1.4)
Work loss days (age 18–65)	$5.7 ($4.9--$6.6)	$0.10 ($0.09--$0.11)	$0.12 ($0.10--$0.13)	$6.0 ($5.1--$6.8)
Minor restricted activity days (age 18–65)	$7.8 ($0.39--$16)	$0.14 ($0.01--$0)	$0.13 ($0.01--$0)	$8.1 ($0.40--$17)

[a] All estimates rounded to two significant figures. As such, confidence intervals may not be symmetrical and totals will not sum across columns. All estimates incremental to 2006 PM NAAQS. Estimates do not reflect benefits for the San Joaquin Valley or South Coast Air Basins.

Health-Based Cost-Effectiveness of Reductions in Ambient O_3 and $PM_{2.5}$ Associated with Illustrative O_3 NAAQS Attainment Strategies

Draft Report

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March 11, 2008

Appendix Chapter 7b: Health-Based Cost-Effectiveness of Reductions in Ambient O_3 and $PM_{2.5}$ Associated with Illustrative O_3 NAAQS Attainment Strategies

7b.1 Summary

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. Analyses of environmental regulations have typically used benefit-cost analysis to characterize impacts on social welfare. Benefit-cost analyses allow for aggregation of the benefits of reducing mortality risks with other monetized benefits of reducing air pollution, including reduced risk of acute and chronic morbidity, and non-health benefits. One of the great advantages of the benefit-cost paradigm is that a wide range of quantifiable benefits can be compared to costs to evaluate the economic efficiency of particular actions. However, alternative paradigms such as CEA and CUA analyses may also provide useful insights. CEA involves estimation of the costs per unit of benefit (e.g., lives or life years saved). CUA is a special type of CEA using preference-based measures of effectiveness, such as quality-adjusted life years (QALYs). QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA for environmental regulations.

In this CEA, we estimated statistical lives saved, statistical life years saved, and QALYs gained. In addition, where relevant, we used an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILYs), to address some of the concerns about aggregation of life extension and quality-of-life impacts. MILYs represent the sum of life years gained due to reductions in premature mortality and the QALYs gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy.

Following the methodology used in the CEA for the PM NAAQS RIA, we did not assign QALY weights to the life years saved – i.e., we calculated life years saved, rather than QALYs gained from mortality avoided. Put another way, we assumed weights of 1.0 for all life years saved. Life years saved in the future, however, were discounted to reflect people's time preference (i.e., a benefit received now is worth more than the same benefit received in the future). We used discount rates of 3 percent and 7 percent.

For each illustrative O_3 NAAQS attainment strategy, we present several metrics: lives saved, life years saved, and cost of the regulation per life saved and per life year saved. Where possible, benefits that could not be quantified in the denominator of our cost-effectiveness ratios were monetized and subtracted from the cost of the regulation in the numerator.

Although there are indirect $PM_{2.5}$-related co-benefits associated with all the illustrative O_3 NAAQS attainment strategies considered, we were able to model the changes in $PM_{2.5}$ occurring as a result of only one illustrative O_3 NAAQS attainment strategy[1]. Therefore $PM_{2.5}$-related co-benefits are included in the cost effectiveness metrics presented only for that one strategy. The cost effectiveness metrics presented for all of the other illustrative O_3 NAAQS attainment strategies omit the $PM_{2.5}$-related co-benefits and are therefore likely to understate the cost effectiveness of those strategies.

For the illustrative O_3 NAAQS attainment strategy for which we were able to include both direct O_3-related health benefits and indirect $PM_{2.5}$-related co-benefits, in addition to the cost effectiveness metrics listed above we also calculated MILYs and the cost of the regulation (net of the monetized benefits not included in the denominator) per MILY gained.

The results of the analysis are summarized as follows:

- Estimates of O_3-related lives saved were substantially affected by the underlying O_3-mortality study used and, to a greater extent, by the attainment scenario considered. Because all O_3-related mortality was assumed to occur in 2020, we did not discount O_3-related lives saved. Non-zero estimates of O_3-related lives saved based on Bell et al. (2004) ranged from 36 (95% CI: 12 – 60), under full attainment of an alternative standard of 0.079 ppm, to 520 (95% CI: 170 – 880), under full attainment of an alternative standard of 0.065 ppm. Estimates of O_3-related lives saved based on Levy et al. (2005) ranged from 160 (95% CI: 110 – 210) to 2,400 (95% CI: 1,600 – 3,100), under full attainment of the 0.079 ppm and 0.065 ppm alternative standards, respectively.

- Non-zero estimates of O_3-related life years saved also depended substantially on the underlying mortality study used and the attainment scenario considered. In addition, we hypothesized several alternative possible sets of life expectancies associated with age-specific O_3-related deaths avoided, and the choice of life expectancies had a large impact on the estimates of O_3-related life years saved. Using a 3 percent discount rate, the smallest non-zero estimate of O_3-related life years saved was 160 (95% CI: 54 – 270), under full attainment of the alternative standard of 0.079 ppm, based on Bell et al. (2004), and assuming that O_3-related mortality occurs only in the subpopulation with severe preexisting conditions (and thus the shortest life expectancies). The largest estimate of O_3-related life years saved was 26,000 (95% CI: 18,000 – 34,000), under full attainment of the alternative standard of 0.065 ppm, based on Levy et al. (2004), and assuming that O_3-related mortality occurs in the general population.

- Using a 7 percent discount rate, the smallest non-zero estimate of O_3-related life years saved was 140 (95% CI: 46 – 230), under full attainment of the alternative standard of 0.079 ppm, based on Bell et al. (2004), and assuming that O_3-related mortality occurs only in the subpopulation with severe preexisting conditions (and thus the shortest life expectancies). The largest estimate of O_3-related life years saved was 19,000 (95% CI: 13,000 – 25,000), under full attainment of the alternative standard of 0.065 ppm, based

[1] This illustrative attainment strategy has a baseline of partial attainment of the current standard of 0.084 ppm and a control scenario of partial attainment of an alternative standard of 0.070 ppm.

on Levy et al. (2004), and assuming that O_3-related mortality occurs in the general population.

- The estimate of $PM_{2.5}$-related lives saved under the single illustrative attainment strategy for which we were able to model the indirect changes in $PM_{2.5}$ concentrations and thus include $PM_{2.5}$ co-benefits, was 440 (95% CI: 170 – 700), based on Pope et al. (2002), and 2,400 (95% CI: 540 – 1,400), based on Laden et al. (2006). Unlike O_3-related mortality, $PM_{2.5}$-related mortality was not all assumed to occur in the year of exposure. Estimates of $PM_{2.5}$-related life years saved were thus discounted twice – first life years saved were discounted back to the year of avoided death, and then were further discounted back to 2020. Using a 3 percent discount rate, $PM_{2.5}$-related life years saved was estimated to be 4,400 (95% CI: 1,700 – 7000), based on Pope et al. (2002), and 9,900 (95% CI: 5,400 – 14,000), based on Laden et al. (2006). Using a 7 percent discount rate, the corresponding estimates using Pope et al. (2002) and Laden et al. (2006) were 3,000 (95% CI: 1,200 – 4,800) and 6,700 (95% CI: 3,700 – 9,800), respectively.

- Under the single scenario for which we were able to model the indirect changes in $PM_{2.5}$ concentrations and thus include $PM_{2.5}$ co-benefits, we estimated $PM_{2.5}$-related reductions in chronic bronchitis (CB) and non-fatal acute myocardial infarction (AMI) and the corresponding improvements in quality of life as QALYs gained. QALYs gained from $PM_{2.5}$-related reductions in CB were estimated to be 1,970 (95% CI: 270 – 4,700), using a 3 percent discount rate, and 1,300 (95% CI: 180 – 3,000) using a 7 percent discount rate. QALYs gained from $PM_{2.5}$-related reductions in AMI were estimated to be 870 (95% CI: 220 – 1,800) and 680 (95% CI: 180 – 1,400), using 3 percent and 7 percent discount rates, respectively.

- Because both costs (in the numerator) and benefits (in the denominator) increased with the stringency of the alternative regulations considered, the cost effectiveness ratios would not necessarily be expected to show a monotonic pattern across the regulations. Net cost per O_3-related life saved (in 2006 $) (in those illustrative attainment strategies for which we incorporated only O_3-related benefits) were greatest in the illustrative attainment strategy of full attainment of a 0.075 ppm standard. Even under this one strategy, however, cost effectiveness estimates varied substantially, depending on the underlying mortality study used and the discount rate (for cost) assumed – from a low estimate of $18 million per life saved (95% CI: $13 million – $25 million), based on Levy et al. (2005) and using a lower bound estimate of the 7 percent discounted cost, to a high estimate of $110 million (95% CI: $55 million – $280 million), based on Bell et al. (2004) and using an upper bound estimate of the 7 percent discounted cost. Note, however, that all of the cost effectiveness ratios for illustrative attainment strategies for which we incorporated only O_3-related benefits would tend to overstate the cost per life saved – i.e., understate cost effectiveness – because $PM_{2.5}$ co-benefits were not included in the denominator.

- Net cost per life saved tended to be substantially lower for the single scenario for which both O_3-related and $PM_{2.5}$-related lives saved were included, ranging from $1.8 million (95% CI: $1.3 million – $2.6 million), using Levy et al. (2005) and Laden et al. (2006), to $5.4 million (95% CI: $3.2 million – $9.9 million), using Bell et al. (2004) and Pope et al. (2002).

- The pattern seen for cost per life year saved was similar to that seen for cost per life saved. Net costs per O_3-related life year saved were greatest in the illustrative attainment strategy of full attainment of a 0.075 ppm standard. However, there was substantial variability in cost effectiveness estimates across these illustrative attainment strategies. The lowest cost per life year saved was estimated to be $1.6 million (95% CI: $1.2 million – $2.3 million), under full attainment of a 0.079 ppm standard, using Levy et al. (2005) and a 3 percent discount rate, and assuming life expectancies of the general population. The highest cost per life year saved was estimated to be $29 million (95% CI: $15 million – $75 million), under full attainment of a 0.075 ppm standard, using Bell et al. (2004) and a 7 percent discount rate, and assuming life expectancies of a subpopulation with severe preexisting conditions.

- Net costs per life year saved in the single illustrative strategy for which we included both O_3-related and $PM_{2.5}$-related benefits were substantially smaller than for the other scenarios. This is not surprising, since the cost effectiveness of those other scenarios was understated – and thus the cost per life year saved was overstated – because of the omission of $PM_{2.5}$-related live years saved. The lowest estimate of net cost per life year saved for this illustrative strategy was $0.14 million (95% CI: $0.1 million – $0.2 million), based on Levy et al. (2005) and Laden et al. (2006), and, for O_3-related mortality avoided, assuming life expectancies of the general population, and using a 3 percent discount rate. The highest estimate was $0.79 million (95% CI: $0.44 million – $1.6 million), based on Bell et al. (2004) and Pope et al. (2002), and, for O_3-related mortality avoided, assuming life expectancies of a subpopulation with severe preexisting conditions, and using a 7 percent discount rate.

- Finally, under the single illustrative strategy for which we included both O_3-related and $PM_{2.5}$-related benefits, the lowest estimate of net costs per MILY gained, using a 3 percent discount rate, was $0.12 million (95% CI: $0.09 million – $0.17 million), based on Levy et al. (2005) and Laden et al. (2006) and, for O_3-related mortality avoided, assuming life expectancies of the general population; the highest estimate was $0.30 million (95% CI: $0.19 million – $0.53 million), based on Bell et al. (2004) and Pope et al. (2002) and, for O_3-related mortality avoided, assuming life expectancies of a subpopulation with severe preexisting conditions.

- Using a 7 percent discount rate, the lowest estimate of net costs per MILY gained was $0.18 million (95% CI: $0.14 million – $0.26 million), based on Levy et al. (2005) and Laden et al. (2006) and, for O_3-related mortality avoided, assuming life expectancies of the general population; the highest estimate was $0.48 million (95% CI: $0.29 million – $0.86 million), based on Bell et al. (2004) and Pope et al. (2002) and, for O_3-related mortality avoided, assuming life expectancies of a subpopulation with severe preexisting conditions.

7b.2 Introduction

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. Analyses of environmental regulations have typically used benefit-cost analysis to characterize impacts on social welfare. Benefit-cost analyses allow for aggregation of the benefits of reducing mortality risks with other monetized benefits of reducing air pollution, including reduced risk of acute and chronic morbidity, and non-health benefits. One of the great advantages of the benefit-cost paradigm is that a wide range of quantifiable benefits can be compared to costs to evaluate the economic efficiency of particular actions. However, alternative paradigms such as CEA and CUA analyses may also provide useful insights. CEA involves estimation of the costs per unit of benefit (e.g., lives or life years saved). CUA is a special type of CEA using preference-based measures of effectiveness, such as quality-adjusted life years (QALYs).

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA for environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for non-health benefits.

The Office of Management and Budget (OMB) recently issued Circular A-4 guidance on regulatory analyses, requiring federal agencies to "prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes." Environmental quality improvements may have multiple health and ecological benefits, however, making application of CEA more difficult and less straightforward.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled "Valuing Health for Regulatory Cost-Effectiveness Analysis" which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006). They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses.

CEA and CUA are most useful for comparing programs that have similar goals, for example, alternative medical interventions or treatments that can save a life or cure a disease. They are less readily applicable to programs with multiple categories of benefits, such as those reducing ambient air pollution, because the cost-effectiveness calculation is based on the quantity of a single benefit category. In other words, we cannot readily convert non-health benefits, such as visibility improvements associated with reductions in $PM_{2.5}$ or increases in worker productivity associated with reductions in O_3, to a health metric such as life years saved. For these reasons, environmental economists prefer to present results in terms of monetary benefits and net benefits.

However, QALY-based CUA has been widely adopted within the health economics literature (Neumann, 2003; Gold et al., 1996) and in the analysis of public health interventions (US FDA, 2004). QALY-based analyses have not been as accepted in the environmental economics literature because of concerns about the theoretical consistency of QALYs with individual preferences (Hammitt, 2002), treatment of nonhuman health benefits, and a number of other factors (Freeman, Hammitt, and De Civita, 2002). For environmental regulations, benefit-cost analysis has been the preferred method of choosing among regulatory alternatives in terms of economic efficiency. Recently several academic analyses have proposed the use of life years-based benefit-cost or CEAs of air pollution regulations (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003; Rabl, 2003; Carrothers, Evans, and Graham, 2002). In addition, the World Health Organization has adopted the use of disability-adjusted life years, a variant on QALYs, to assess the global burden of disease due to different causes, including environmental pollution (Murray et al., 2002; de Hollander et al., 1999).

One of the ongoing controversies in health impact assessment regards whether reductions in mortality risk should be reported and valued in terms of statistical lives saved or in terms of statistical life years saved. Life years saved measures differentiate among premature mortalities based on the remaining life expectancy of affected individuals. In general, under the life years approach, older individuals will gain fewer life years than younger individuals for the same reduction in mortality risk during a given time period, making interventions that benefit older individuals seem less beneficial relative to similar interventions benefiting younger individuals. A further complication in the debate is whether to apply quality adjustments to life years lost. Under this approach, individuals with preexisting health conditions would have fewer QALYs lost relative to healthy individuals for the same loss in life expectancy, making interventions that primarily benefit individuals with poor health seem less beneficial than similar interventions affecting primarily healthy individuals.

In this CEA, we calculated both life years saved and statistical lives saved. Following the methodology used in the CEA for the PM NAAQS RIA, we did not assign QALY weights to the life years saved – i.e., we calculated life years saved, rather than QALYs gained from mortality avoided. Put another way, we assumed weights of 1.0 for all life years saved. Life years saved in the future, however, were discounted to reflect people's time preference (i.e., a benefit received now is worth more than the same benefit received in the future). We used discount rates of 3 percent and 7 percent.

Where possible, benefits that could not be quantified in the denominator of our cost-effectiveness ratios were monetized and subtracted from the cost of the regulation in the numerator. For example, developing QALYs for acute health effects is problematic (Bala and Zarkin, 2000). Therefore, rather than try to derive QALYs for the acute morbidity endpoints, we instead applied valuation estimates and subtracted the total monetized value of all avoided acute morbidity effects from the cost of the regulation, in the numerator of the cost-effectiveness ratios. The monetized benefits of non-health improvements, where they were estimated, were similarly subtracted from the cost of the regulation. Finally, although QALY estimates were derived for the ($PM_{2.5}$-related) chronic morbidity endpoints, the medical and opportunity costs associated with these chronic illnesses were also subtracted from the cost of the regulation.

Although there are indirect $PM_{2.5}$-related co-benefits associated with all the illustrative O_3 NAAQS attainment strategies, we were able to model the changes in $PM_{2.5}$ occurring as a result of only one illustrative O_3 NAAQS attainment strategy (see Chapter 7 for a full discussion of this issue). Therefore $PM_{2.5}$-related co-benefits are included in the cost effectiveness metrics presented only for that one strategy. The cost effectiveness metrics presented for all of the other illustrative O_3 NAAQS attainment strategies omit the $PM_{2.5}$-related co-benefits and are therefore likely to understate the cost effectiveness of those strategies.

The indirect $PM_{2.5}$-related co-benefits derive not only from avoided cases of premature mortality and acute morbidity, but from avoided cases of chronic morbidity (chronic bronchitis and non-fatal myocardial infarction) as well. In the CEA for the PM NAAQS RIA, EPA derived QALYs for these two chronic morbidity endpoints (see Appendix G of the PM NAAQS RIA, http://www.epa.gov/ttn/ecas/regdata/RIAs/Appendix%20G--Health%20Based%20Cost%20Effectiveness%20Analysis.pdf) and used an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILYs), to address some of the concerns about aggregation of life extension and quality-of-life impacts. MILYs represent the sum of life years gained due to reductions in premature mortality and the QALYs gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy.

For each illustrative O_3 NAAQS attainment strategy, we present several metrics: lives saved, life years saved, and cost of the regulation (net of the monetized benefits not included in the denominator) per life saved and per life year saved.

For the illustrative O_3 NAAQS attainment strategy for which we were able to include both direct O_3-related health benefits and indirect $PM_{2.5}$-related co-benefits, in addition to the cost effectiveness metrics listed above we also calculated MILYs and the cost of the regulation (net of the monetized benefits not included in the denominator) per MILY gained.

Note that, like future life years saved, future QALYs gained from avoided cases of chronic bronchitis and myocardial infarction are discounted. All costs and monetized benefits are in 2006 dollars.

Monte Carlo simulation methods as implemented in the Crystal Ball™ software program were used to propagate uncertainty in several of the model parameters throughout the analysis. In particular, we incorporated uncertainty surrounding the coefficients in the concentration-response (C-R) functions, the unit values for the various morbidity endpoints included in the analysis, and the quality of life weights for the two chronic morbidity endpoints for which we developed QALYs.

We characterized overall uncertainty in the results with 95 percent credible or confidence intervals based on the Monte Carlo simulations. In addition, we examined the impacts on the cost effectiveness metrics of changing key parameters and/or assumptions, including

- the discount rate (for the cost of the regulation in the numerator and future lives or life years saved and QALYs gained in the denominator);
- the C-R functions for O_3-related and $PM_{2.5}$-related mortality ; and
- the life expectancies (and therefore years of potential life lost) of individuals who die as a result of exposure to O_3 (as explained in Section 7b.5 below).

The methodology presented in this appendix is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations where it may be inappropriate. It is intended solely to demonstrate one particular approach to estimating the cost-effectiveness of direct reductions in ambient O_3 (and indirect reductions in $PM_{2.5}$, where possible) in achieving improvements in public health. Reductions in ambient O_3 and $PM_{2.5}$ are estimated to have other health and environmental benefits that will not be reflected in this CEA. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar health-based CEAs. A number of additional methodological issues must be considered when conducting CEAs for environmental policies, including treatment of non-health effects, aggregation of acute and long-term health impacts, and aggregation of life extensions and quality-of-life improvements in different populations. The appropriateness of health-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models, among other factors.

The remainder of this appendix provides an overview of the methods used to derive the cost effectiveness metrics developed for this CEA and presents the resulting metrics. Section 7b.3 provides an overview of effectiveness measures. Section 7b.4 discusses general issues in constructing cost-effectiveness ratios. Section 7b.5 presents the methods and results for those illustrative O_3 NAAQS attainment strategies for which we were able to incorporate only the O_3-related benefits; and Section 7b.6 presents the methods and results for the single illustrative O_3 NAAQS attainment strategy for which we were able to include both the O_3-related benefits and $PM_{2.5}$-related co-benefits. Finally, Section 7b.7 presents concluding remarks.

7b.3 Effectiveness Measures

For the purposes of CEA, we focus the effectiveness measures on the quantifiable health impacts of the reductions in O_3 and, where possible, $PM_{2.5}$, estimated to result from each illustrative O_3 NAAQS attainment strategy considered. If the main impact of interest is reductions in mortality risk from air pollution, the effectiveness measures are relatively straightforward to develop. Mortality impacts can be characterized similar to the benefits analysis, by counting the number of premature deaths avoided, or can be characterized in terms of increases in life expectancy or life years.[2] Estimates of premature mortality have the benefit of being relatively simple to calculate, are consistent with the benefit-cost analysis, and do not impose additional assumptions on the degree of life shortening. However, some have argued that counts of premature deaths avoided are problematic because a gain in life of only a few months would be considered equivalent to a gain of many life years, and the true effectiveness of an intervention is the gain in life expectancy or life years (Rabl, 2003; Miller and Hurley, 2003).

Calculations of changes in life years and life expectancy can be accomplished using standard life table methods (Miller and Hurley, 2003). However, the calculations require assumptions about the baseline mortality risks for each age cohort affected by air pollution. A general assumption may be that air pollution mortality risks affect the general mortality risk of the population in a proportional manner. However, some concerns have been raised that air pollution affects mainly those individuals with preexisting cardiovascular and respiratory disease, who may have reduced life expectancy relative to the general population. This issue is explored in more detail below.

Air pollution is also associated with a number of significant chronic and acute morbidity endpoints. Failure to consider these morbidity effects may understate the cost-effectiveness of air pollution regulations or give too little weight to reductions in particular pollutants that have large morbidity impacts but no effect on life expectancy. The QALY approach explicitly incorporates morbidity impacts into measures of life years gained and is often used in health economics to assess the cost-effectiveness of medical spending programs (Gold et al., 1996). Using a QALY rating system, health quality ranges from 0 to 1, where 1 may represent full health, 0 death, and some number in between (e.g., 0.8) an impaired condition. QALYs thus measure morbidity as a reduction in quality of life over a period of life. QALYs assume that duration and quality of life are equivalent, so that 1 year spent in perfect health is equivalent to 2 years spent with quality of life half that of perfect health. QALYs can be used to evaluate environmental rules under certain circumstances, although some very strong assumptions (detailed below) are associated with QALYs. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommended using QALYs when evaluating medical and public health programs that primarily reduce both mortality and morbidity (Gold et al., 1996). Although there are significant non-health benefits associated with air pollution regulations, over 90 percent of quantifiable monetized benefits are health-related. Thus, it can be argued that QALYs are more applicable for these types of regulations than for other environmental policies. However, the value of non-health benefits should not be ignored. As discussed below, we have chosen to subtract the value of non-health benefits from the costs in the numerator of the cost-effectiveness ratio.

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[2] Life expectancy is an *ex ante* concept, indicating the impact on an entire population's expectation of the number of life years they have remaining, before knowing which individuals will be affected. Life expectancy thus incorporates both the probability of an effect and the impact of the effect if realized. Life years is an *ex post* concept, indicating the impact on individuals who actually die from exposure to air pollution. Changes in population life expectancy will always be substantially smaller than changes in life years per premature mortality avoided, although the total life years gained in the population will be the same. This is because life expectancy gains average expected life years gained over the entire population, while life years gained measures life years gained only for those experiencing the life extension.

The use of QALYs is predicated on the assumptions embedded in the QALY analytical framework. As noted in the QALY literature, QALYs are consistent with the utility theory that underlies most of economics only if one imposes several restrictive assumptions, including independence between longevity and quality of life in the utility function, risk neutrality with respect to years of life (which implies that the utility function is linear), and constant proportionality in trade-offs between quality and quantity of life (Pliskin, Shepard, and Weinstein, 1980; Bleichrodt, Wakker, and Johannesson, 1996). To the extent that these assumptions do not represent actual preferences, the QALY approach will not provide results that are consistent with a benefit-cost analysis based on the Kaldor-Hicks criterion.[3] Even if the assumptions are reasonably consistent with reality, because QALYs represent an average valuation of health states rather than the sum of societal WTP, there are no guarantees that the option with the highest QALY per dollar of cost will satisfy the Kaldor-Hicks criterion (i.e., generate a potential Pareto improvement [Garber and Phelps, 1997]).

Benefit-cost analysis based on WTP is not without potentially troubling underlying structures as well, incorporating ability to pay (and thus the potential for equity concerns) and the notion of consumer sovereignty (which emphasizes wealth effects). Table 7b-1 compares the two approaches across a number of parameters. For the most part, WTP allows parameters to be determined empirically, while the QALY approach imposes some conditions *a priori*.

Table 7b-1. Comparison of QALY and WTP Approaches

Parameter	*QALY*	*WTP*
Risk aversion	Risk neutral	Empirically determined
Relation of duration and quality	Independent	Empirically determined
Proportionality of duration/ quality trade-off	Constant	Variable
Treatment of time/age in utility function	Utility linear in time	Empirically determined
Preferences	Community/Individual	Individual
Source of preference data	Stated	Revealed and stated
Treatment of income and prices	Not explicitly considered	Constrains choices

7b.4 Construction of Cost-Effectiveness Ratios: General Issues

7b.4.1 Dealing with Morbidity Health Effects and Non-health Effects

Health effects from exposure to O_3 and $PM_{2.5}$ air pollution encompass a wide array of chronic and acute conditions in addition to premature mortality. EPA's Ozone and PM Criteria Documents outline numerous health effects known or suspected to be linked to exposure to ambient ozone and PM (US EPA, 2006; US EPA, 2005; Anderson et al., 2004). Although chronic conditions and premature mortality generally account for the majority of monetized

[3] The Kaldor-Hicks efficiency criterion requires that the "winners" in a particular case be potentially able to compensate the "losers" such that total societal welfare improves. In this case, it is sufficient that total benefits exceed total costs of the regulation. This is also known as a potential Pareto improvement, because gains could be allocated such that at least one person in society would be better off while no one would be worse off.

benefits, acute symptoms can affect a broad population or sensitive populations (e.g., asthma-related emergency room visits among asthmatics). In addition, reductions in air pollution may result in a broad set of non-health environmental benefits, including improved worker productivity, improved visibility in national parks, increased agricultural and forestry yields, reduced acid damage to buildings, and a host of other impacts. Lives saved, life years saved, and QALYs gained address only health impacts, and the OMB guidance notes that "where regulation may yield several different beneficial outcomes, a cost-effectiveness comparison becomes more difficult to interpret because there is more than one measure of effectiveness to incorporate in the analysis."

With regard to acute health impacts, Bala and Zarkin (2000) suggest that QALYs are not appropriate for valuing acute symptoms, because of problems with both measuring utility for acute health states and applying QALYs in a linear fashion to very short duration health states. Johnson and Lievense (2000) suggest using conjoint analysis to get healthy-utility time equivalences that can be compared across acute effects, but it is not clear how these can be combined with QALYs for chronic effects and loss of life expectancy. There is also a class of effects that EPA has traditionally treated as acute, such as hospital admissions, which may also result in a loss of quality of life for a period of time following the effect. For example, life after asthma hospitalization has been estimated with a utility weight of 0.93 (Bell et al., 2001; Kerridge, Glasziou, and Hillman, 1995).

How should these effects be combined with QALYs for chronic and mortality effects? One method would be to convert the acute effects to QALYs; however, as noted above, there are problems with the linearity assumption (i.e., if a year with asthma symptoms is equivalent to 0.7 year without asthma symptoms, then 1 day without asthma symptoms is equivalent to 0.0019 QALY gained). This is troubling from both a conceptual basis and a presentation basis. An alternative approach is simply to treat acute health effects like non-health benefits and subtract the dollar value (based on WTP or COI) from compliance costs in the CEA.

To address the issues of incorporating acute morbidity and non-health benefits, OMB suggests that agencies "subtract the monetary estimate of the ancillary benefits from the gross cost estimate to yield an estimated net cost." As with benefit-cost analysis, any unquantified benefits and/or costs should be noted and an indication of how they might affect the cost-effectiveness ratio should be described. We followed this recommended "net cost" approach, specifically in netting out the benefits of health improvements other than reduced mortality and improved quality of life from avoided chronic illness – in particular, the monetized benefits of acute morbidity avoided, the medical and opportunity costs ("cost of illness") of avoided chronic illness, and the benefits of non-health improvements, including increases in worker productivity associated with reductions in O_3 and visibility improvements at national parks associated with reductions in $PM_{2.5}$ (see Chapter 7 for more details on these benefit categories).

7b.4.2 Should Life Years Gained Be Adjusted for Initial Health Status?

The methods outlined below in Sections 7b.5 and 7b.6 provide estimates of the total number of life years gained in a population, regardless of the quality of those life years, or equivalently, assuming that all life years gained are in perfect health. In some CEAs (Cohen, Hammitt, and Levy, 2003; Coyle et al., 2003), analysts have adjusted the number of life years gained to reflect the fact that 1) the general public is not in perfect health and thus "healthy" life years are less than total life years gained and 2) those affected by air pollution may be in a worse health state than the general population and therefore will not gain as many "healthy" life years adjusted for quality, from an air pollution reduction. This adjustment, which converts life years gained into QALYs, raises a number of serious ethical issues. Proponents of QALYs have promoted the nondiscriminatory nature of QALYs in evaluating improvements in quality of life (e.g., an improvement from a score of 0.2 to 0.4 is equivalent to an improvement from 0.8 to 1.0), so the starting health status does not affect the evaluation of interventions that improve quality of life. However, for life-extending interventions, the gains in QALYs will be directly proportional to the baseline health state (e.g., an individual with a 30-year life expectancy and a starting health status of 0.5 will gain exactly half the QALYs of an individual with the same life expectancy and a starting health status of 1.0 for a similar life-extending intervention). This is troubling because it imposes an additional penalty for those already suffering from disabling conditions. Brock (2002) notes that "the problem of disability discrimination represents a deep and unresolved problem for resource prioritization."

OMB (2003) has recognized this issue in their Circular A-4 guidance, which includes the following statement:

> *When CEA is performed in specific rulemaking contexts, you should be prepared to make appropriate adjustments to ensure fair treatment of all segments of the population. Fairness is important in the choice and execution of effectiveness measures. For example, if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves the lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimated number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts. More generally, when numeric adjustments are made for life expectancy or quality of life, analysts should prefer use of population averages rather than information derived from subgroups dominated by a particular demographic or income group. (p. 13)*

This suggests two adjustments to the standard QALY methodology: one adjusting the relevant life expectancy of the affected population, and the other affecting the baseline quality of life for the affected population.

In addition to the issue of fairness, potential measurement issues are specific to the air pollution context that might argue for caution in applying quality-of-life adjustments to life years gained due to air pollution reductions. A number of epidemiological and toxicological studies link exposure to air pollution with chronic diseases, such as CB and atherosclerosis (Abbey et al., 1995; Schwartz, 1993; Suwa et al., 2002). If these same individuals with chronic disease caused by exposure to air pollution are then at increased risk of premature death from air pollution, there is an important dimension of "double jeopardy" involved in determining the correct baseline for assessing QALYs lost to air pollution (see Singer et al. [1995] for a broader discussion of the double-jeopardy argument).

Analyses estimating mortality from acute exposures that ignore the effects of long-term exposure on morbidity may understate the health impacts of reducing air pollution. Individuals exposed to chronically elevated levels of air pollution may realize an increased risk of death and chronic disease throughout life. If at some age they contract heart (or some other chronic) disease as a result of the exposure to air pollution, they will from that point forward have both reduced life expectancy and reduced quality of life. The benefit to that individual from reducing lifetime exposure to air pollution would be the increase in life expectancy plus the increase in quality of life over the full period of increased life expectancy. If the QALY loss is determined based on the underlying chronic condition and life expectancy without regard to the fact that the person would never have been in that state without long-term exposure to elevated air pollution, then the person is placed in double jeopardy. In other words, air pollution has placed more people in the susceptible pool, but then we penalize those people in evaluating policies by treating their subsequent deaths as less valuable, adding insult to injury, and potentially downplaying the importance of life expectancy losses due to air pollution. If the risk of chronic disease and risk of death are considered together, then there is no conceptual problem with measuring QALYs, but this has not been the case in recent applications of QALYs to air pollution (Carrothers, Evans, and Graham, 2002; Coyle et al., 2003). The use of QALYs thus highlights the need for a better understanding of the relationship between chronic disease and long-term exposure and suggests that analyses need to consider morbidity and mortality jointly, rather than treating each as a separate endpoint (this is an issue for current benefit-cost approaches as well).

Because of the fairness and measurement concerns discussed above, for the purposes of this analysis, we do not reduce the number of life years gained to reflect any differences in underlying health status that might reduce quality of life in remaining years. Thus, we maintain the assumption that all direct gains in life years resulting from mortality risk reductions will be assigned a weight of 1.0. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that "since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY" (Gold et al., 1996). However, for the purposes of this analysis, we propose an alternative to the traditional aggregate QALY metric that keeps separate quality adjustments to life expectancy and gains in life expectancy. As such, we do not make any adjustments to life years gained to reflect the less than perfect health of the general population. Gains in quality of life will be addressed as they accrue because of reductions in the incidence of chronic diseases. This is an explicit equity choice in the treatment of issues associated with quality-of-life adjustments for increases in life expectancy that still capitalizes on the ability of QALYs to capture both morbidity and mortality impacts in a single effectiveness measure.

7b.4.3 Constructing Cost-Effectiveness Ratios

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. The estimate of costs in the numerator should include both the direct costs of the controls necessary to achieve the reduction in ambient concentrations of the air pollutant and the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). In general, because reductions in air pollution do not require direct actions by the affected populations, there are no specific costs to affected individuals (aside from the overall increases in prices that might be expected to occur as control costs are passed on by affected industries). Likewise, because individuals do not engage in any specific actions to realize the health benefit of the pollution reduction, there are no decreases in utility (as might occur from a medical intervention) that need to be adjusted for in the denominator. Thus, the elements of the numerator are direct costs of controls minus the avoided costs of illness (COI) associated with chronic illnesses. In addition, as noted above, to account for the value of reductions in acute health impacts and non-health benefits, we netted out the monetized value of these benefits from the numerator to yield a “net cost” estimate.

The denominators of the cost-effectiveness ratios we calculated are either lives saved, life years saved, or, for the single scenario in which we were able to include both O_3-related and $PM_{2.5}$-related benefits, MILYs gained. For the MILY aggregate effectiveness measure, the denominator is simply the sum of life years gained from increased life expectancy and QALYs gained from the reductions in incidence of chronic illnesses associated with $PM_{2.5}$ – chronic bronchitis (CB) and nonfatal acute myocardial infarction (AMI).

7b.5 Cost Effectiveness Metrics Incorporating Only O_3-Related Benefits

In this section we describe the development of cost effectiveness metrics for those illustrative O_3 NAAQS attainment strategies for which we were able to incorporate only O_3-related benefits. This includes the scenarios in which the baseline is full attainment of the current O_3 standard of 0.084 ppm and the control scenarios are full attainment of the following four alternative standards: 0.079 ppm, 0.075 ppm, 0.070 ppm, and 0.065 ppm.

To generate health outcomes, we used the same framework as for the benefit-cost analysis described in Chapter 8. For convenience, we summarize the basic methodologies here. For more details, see Chapter 8 and the Environmental Benefits Mapping and Analysis Program (BenMAP) user’s manual (http://www.epa.gov/ttn/ecas/benmodels.html).

BenMAP uses health impact functions to generate changes in the incidence of health effects. Health impact functions are derived from the C-R functions reported in the epidemiology literature. A standard health impact function has four components: an effect estimate from a particular epidemiological study, a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics, such as CDC), the affected population, and the estimated change in the relevant pollutant summary measure.

A typical health impact function might look like this:

$$\Delta y \quad y_0 \cdot (e^{\beta \cdot \Delta x} - 1),$$

where y_0 is the baseline incidence, equal to the baseline incidence rate times the potentially affected population; β is the effect estimate; x is the estimated change in the pollutant (e.g., O_3 or $PM_{2.5}$) and y is the estimated change in incidence of the health effect (e.g., the number of deaths avoided) associated with the change in the pollutant, x. There are other functional forms, but the basic elements remain the same.

7b.5.1 Reductions in O_3-Related Premature Deaths

To calculate O_3-related life years saved under a given illustrative O_3 NAAQS attainment strategy, we first calculated the numbers of O_3-related statistical lives saved within 5-year age groups, using BenMAP. (For more details on the calculation of statistical lives saved using BenMAP, see Chapter 8 or the BenMAP user's manual (http://www.epa.gov/ttn/ecas/benmodels.html). We used two studies used in the benefit analysis for the O_3 NAAQS RIA – Bell et al. (2004) and Levy et al. (2005). Both studies report estimated C-R functions of the association between premature mortality and short-term exposures to ambient O_3. Bell et al. (2004) is a multi-city study of 95 cities, and as such may avoid the potential for publication bias that may be inherent in single-city studies or meta-analyses of single-city studies. This study provides the lowest estimate of O_3-related premature deaths among the mortality studies included in the O_3 NAAQS RIA benefit analysis. An upper bound estimate of O_3-related premature deaths in the O_3 NAAQS RIA benefit analysis was provided by Levy et al. (2005). More extensive discussions of these studies are given in Chapter 8.

We checked to confirm that, for each O_3 NAAQS attainment strategy, the total number of O_3-related statistical lives saved, summed across all age groups, equals the corresponding number calculated in the benefit analysis. Age group-specific O_3-related premature deaths avoided under the illustrative O_3 NAAQS attainment strategies for which we considered only O_3-related benefits are given in Table 7b-2.

Table 7b-2. Estimated Reduction in Incidence of O_3-Related Premature Mortality Associated with Illustrative O_3 NAAQS Attainment Strategies in 2020

	Reduction in O_3-Related Premature Mortality (95% CI)*							
	Bell et al. (2004)				Levy et al. (2005)			
Age Interval	Baseline of Full Attainment of Current (0.084 ppm) Standard to Control Scenario of Full Attainment of:							
	0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm	0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
0 - 4	0 (0 - 0)	0 (0 - 1)	1 (0 - 2)	2 (1 - 3)	1 (1 - 1)	2 (2 - 3)	7 (5 - 9)	12 (8 - 16)
5 - 9	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	1 (0 - 1)	0 (0 - 1)	1 (1 - 1)	3 (2 - 4)	5 (4 - 7)
10 - 14	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	1 (0 - 1)	0 (0 - 1)	1 (1 - 1)	3 (2 - 4)	5 (4 - 7)
15 - 19	0 (0 - 0)	0 (0 - 0)	0 (0 - 1)	1 (0 - 1)	1 (1 - 1)	2 (1 - 2)	5 (4 - 7)	9 (6 - 12)
20 - 24	0 (0 - 0)	0 (0 - 0)	0 (0 - 1)	1 (0 - 1)	1 (1 - 2)	3 (2 - 4)	9 (6 - 11)	15 (10 - 20)
25 - 29	0 (0 - 0)	0 (0 - 1)	1 (0 - 2)	3 (1 - 4)	2 (1 - 2)	4 (3 - 6)	12 (9 - 16)	22 (15 - 29)
30 - 34	0 (0 - 0)	0 (0 - 1)	1 (0 - 2)	2 (1 - 4)	2 (1 - 2)	4 (3 - 5)	12 (8 - 15)	21 (14 - 27)
35 - 39	0 (0 - 1)	1 (0 - 2)	3 (1 - 5)	5 (2 - 9)	3 (2 - 3)	6 (4 - 8)	18 (12 - 24)	32 (22 - 42)
40 - 44	0 (0 - 1)	1 (0 - 2)	3 (1 - 5)	5 (2 - 8)	2 (2 - 3)	6 (4 - 8)	17 (11 - 22)	29 (20 - 38)
45 - 49	1 (0 - 2)	2 (1 - 4)	7 (2 - 12)	12 (4 - 20)	5 (3 - 6)	12 (8 - 15)	34 (23 - 45)	60 (41 - 79)
50 - 54	1 (0 - 2)	2 (1 - 4)	7 (2 - 12)	13 (4 - 21)	5 (3 - 6)	12 (8 - 15)	35 (24 - 47)	62 (43 - 82)
55 - 59	3 (1 - 4)	7 (2 - 11)	20 (6 - 34)	35 (12 - 59)	12 (8 - 15)	30 (21 - 39)	91 (63 - 120)	160 (110 - 210)
60 - 64	2 (1 - 4)	6 (2 - 10)	19 (6 - 32)	33 (11 - 55)	11 (7 - 14)	27 (19 - 36)	85 (58 - 110)	150 (100 - 190)
65 - 69	4 (1 - 7)	11 (4 - 19)	36 (11 - 61)	63 (21 - 110)	19 (13 - 25)	50 (34 - 65)	160 (110 - 210)	280 (190 - 360)
70 - 74	3 (1 - 6)	9 (3 - 15)	28 (9 - 47)	49 (16 - 83)	15 (10 - 19)	38 (27 - 50)	120 (84 - 160)	220 (150 - 290)
75 - 79	5 (2 - 9)	14 (5 - 23)	45 (14 - 75)	80 (26 - 130)	23 (16 - 30)	61 (42 - 80)	200 (130 - 260)	350 (240 - 460)
80 - 84	3 (1 - 6)	9 (3 - 15)	29 (9 - 49)	51 (17 - 85)	15 (10 - 19)	39 (27 - 51)	130 (86 - 170)	220 (150 - 290)
85+	11 (4 - 19)	30 (10 - 50)	94 (30 - 160)	170 (54 - 280)	49 (34 - 64)	130 (90 - 170)	140 (280 - 540)	240 (500 - 960)
Total:	36 (12 - 60)	94 (31 - 160)	300 (93 - 500)	520 (170 - 880)	160 (110 - 210)	430 (300 - 560)	1,300 (920 - 1,800)	2,400 (1,600 - 3,100)

*95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

7b.5.2 Life Years Saved as a Result of Reductions in O_3-Related Mortality Risk

The number of life years saved depends not only on the number of statistical lives saved, but also on the life expectancies associated with those statistical lives. As was pointed out in the CEA for the PM NAAQS RIA, age-specific life expectancies for the general population are calculated from mortality rates for the general population, and these reflect the prevalence of chronic disease, which shortens life expectancies. The only reason one might use lower life expectancies than those for the general population in the CEA for the O_3 NAAQS RIA is if the population at risk from exposure to O_3 was limited solely or disproportionately to individuals with preexisting chronic illness, whose life expectancies were, on average, shorter than those of the general population (unless all of those individuals had preexisting chronic illness because of long-term exposure to O_3).

It is reasonable to assume that someone who dies from exposure to an air pollutant is already in a compromised state. However, there are both acute and chronic compromised states. If an individual has an acute illness (e.g., pneumonia) that puts him at risk of mortality when exposed to a high concentration of an air pollutant, then in the absence of that high concentration he could be expected to recover from the illness and go on to live the expected number of years for someone his age – i.e., he would have the age-specific life expectancy of the general population.

If an individual has a chronic illness that makes him vulnerable to a high concentration of an air pollutant, then an important question is whether or not he would have had that chronic illness if he had not been exposed over the long term to high levels of the air pollutant.

We can categorize individuals who are at risk of dying because of exposure to an air pollutant into three groups:

- those who are vulnerable because of a preexisting acute condition;
- those who are vulnerable because of a preexisting chronic condition that they would *not* have had, had they not been exposed over the long term to high levels of the air pollutant; and
- those who are vulnerable because of a preexisting chronic condition that they would have had even in the absence of long term exposure to high levels of the air pollutant.

The age-specific life expectancies of the general population should apply to the first two groups, and the age-specific life expectancies of the subpopulation with the relevant chronic condition(s) should apply to the third group. If we knew the proportions of people who die from exposure to O_3 who are in each group, and the life expectancies of people in the third group, we could calculate the number of life years saved as follows:

$$\textit{Total life years saved} \quad \sum_i M_i * (p_{1i} * LE_i + p_{2i} * LE_i + p_{3i} * LE_i^*)$$

where

M_i denotes the number of O_3-related deaths of individuals age *i,*

LE_i denotes the general population life expectancy for age *i,*

LE_i^* denotes the life expectancy for age i of the subpopulation with the relevant chronic condition(s) – i.e., the third group;

p_{1i} denotes the proportion of the M_i O_3-related deaths that are in the first group;

p_{2i} denotes the proportion of the M_i O_3-related deaths that are in the second group; and

p_{3i} denotes the proportion of the M_i O_3-related deaths that are in the third group.

Unlike for $PM_{2.5}$ (discussed below in Section 7b.6), we currently lack information that would allow us to estimate the relevant proportions necessary to estimate the set of life expectancies that would be appropriate to apply to O_3-related deaths. Although there is substantial evidence linking premature mortality to short-term exposures to O_3, there is currently not similar evidence for long-term exposures. We therefore do not know if the second group above is relevant in the case of O_3-related mortality. Nor do we know what proportion of O_3-related deaths can be attributed to preexisting acute conditions (the first group) versus preexisting chronic conditions that these individuals would have had even in the absence of long term exposure to O_3 (the third group).

Because we currently lack the necessary information to determine the appropriate set of life expectancies to use in calculating life years saved associated with O_3-related premature mortality avoided, we calculated life years saved based on four different underlying assumptions:

- A lower bound assumption of zero life years saved, based on the hypothesis that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship;
- An upper bound assumption that an O_3-related premature death of an individual of a given age will result in a loss of life years equal to the life expectancy in the general population of that age;
- Two intermediate assumptions: That the proportions of O_3-related premature deaths in the three groups delineated above (p_{1i}, p_{2i}, and p_{3i}) are such that, on average, the age-specific life expectancies among people who die O_3-related premature deaths are those of
    - people with severe preexisting chronic conditions, whose life expectancies are substantially shorter than those of the general population; and
    - people with preexisting chronic conditions of a range of severities, whose life expectancies are somewhat shorter than those of the general population.

Life years saved based on the upper bound assumption were calculated from age-specific mortality probabilities for the general population taken from the Centers for Disease Control (CDC) National Vital Statistics Reports, Vol. 56, No. 9, December 28, 2007, Table 1. Life table for the total population: United States, 2004.[4] We used a simplified method of calculating life expectancies from these age-specific mortality probabilities that yielded life expectancies that were close to the life expectancies derived using the more complicated method employed by the

[4] http://www.cdc.gov/nchs/data/nvsr/nvsr56/nvsr56_09.pdf

CDC.[5] In particular, starting with a cohort of size 1,000,000 at birth, we calculated the life-years lived between ages *x* and (*x*+1), for *x* = 0, 1, 2, …, 99, using the age-specific mortality probabilities taken from the CDC Vital Statistics Report (see above) and assuming that all deaths that occurred between ages *x* and (*x*+1) occurred midway through the year (i.e., we assigned 0.5 life-year to each year of death). The life expectancy at age *n* was then calculated as the sum of the life-years lived from age *n* through age 100 divided by the cohort size at age *n*. The life expectancy at age *n* is the number of life years lost due to an O_3-related premature mortality of an individual age *n*.

To estimate life years saved under the two intermediate assumptions about the life years lost as a result of O_3-related premature mortality, we turned to the epidemiological evidence of a statistically significant association between short-term exposures to O_3 and respiratory hospital admissions. This evidence suggests that these short-term exposures may exacerbate respiratory conditions that were preexisting. It is reasonable to suppose that some of these hospitalizations for respiratory illnesses on days of relatively high O_3 concentrations might result in death. It may also be the case that some individuals who did not go to the hospital might also die. We therefore looked for information on life expectancies of people with chronic respiratory conditions.

While there is information readily available in vital statistics sources on rates of death *from* chronic respiratory diseases, there is not similarly available information on rates of death *among that subpopulation who suffer from those diseases*. It is the latter rate – the rate of death among that subpopulation who suffers from those diseases – that is of interest.

A recent study of people with and without chronic obstructive pulmonary disease (COPD) provided data from which we were able to construct estimates of the mortality rates of interest. Mannino et al. (2006) followed a cohort of 15,440 subjects ages 43 to 66 for up to 11 years. The cohort subjects were selected from the larger cohort of the Atherosclerosis Risk in Communities (ARIC) study, which selected its subjects from the population of four U.S. communities by probability sampling.[6] The subjects in the Mannino study were limited to the ARIC participants who provided baseline information on respiratory symptoms and diagnoses, who underwent pulmonary function testing, and for whom follow-up data were available.

Using a modification of the criteria developed by the Global Initiative on Obstructive Lung Disease (GOLD), Mannino et al. (2006) classified the study subjects into COPD severity groups (or stages), with GOLD stage 0 (presence of respiratory symptoms in the absence of any lung function abnormality) being the least severe COPD group, and GOLD stages 3 and 4 being the most severe. The unadjusted death rates of the study participants (taken from Table 1 of Mannino et al., 2006), ratios of (unadjusted) death rates, and hazard ratios, based on Cox

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5 We calculated life expectancies from the mortality probabilities rather than using the life expectancies given in the CDC table because we were going to also calculate life expectancies for the subpopulations with severe COPD and with "average" COPD by adjusting the age-specific mortality probabilities and then calculating life expectancies using these adjusted probabilities.

6 In one of the four communities probability sampling was used to select African-Americans only.

proportional hazard regressions, which took into account several covariates (including, among others, age, sex, race, smoking status, and education level) are shown in the table below. In addition, the right-most column of the table below shows the proportion of COPD subjects in the study in each GOLD category.

Table 7b-3. Death Rates and Hazard Ratios for Subjects with Varying Degrees of Severity of COPD (from Mannino et al., 2006)

GOLD* Category	N	Deaths	(%)	Person-Years	Death Rate per 1,000 Person-Years	Ratio of Death Rate to Death Rate for Normal Population	Hazard Ratio**	Proportion of COPD Subjects in GOLD Category
GOLD 3 or 4	271	92	33.9%	2,143	42.9	7.97	5.7	4.77%
GOLD 2	1,484	232	15.6%	12,852	18.1	3.35	2.4	26.14%
GOLD 1	1,679	137	8.2%	15,031	9.1	1.69	1.4	29.57%
GOLD 0	2,244	204	9.1%	20,191	10.1	1.88	1.5	39.52%
Restricted	1,101	150	13.6%	9,644	15.6	2.89	2.3	
Normal	8,661	427	4.9%	79,317	5.4	1.00	1.0	
Total	15,440	1,242	8.0%	139,178	8.9			

*Global Inititative on Obstructive Lung Disease (GOLD) guidelines for the staging of COPD severity.
**See Mannino et al. (2006), p. 117.

The ratios of unadjusted death rates are somewhat larger than the corresponding hazard ratios because these ratios were not adjusted for age. COPD is a progressive disease, so it would be expected that the proportion of older individuals would increase as the stages (and severity) increased, and this was indeed the case in the Mannino study. The hazard ratios, being based on regressions that took age into account, avoid this problem. We therefore used the hazard ratios to derive age-specific mortality rates for individuals with (1) severe COPD and (2) COPD of "average" severity. In particular, to derive age-specific mortality probabilities for the subpopulation with severe COPD, we multiplied each age-specific mortality probability for the general population by 5.7 (the hazard ratio for GOLD 3 or 4); to derive age-specific mortality probabilities for the subpopulation with "average" COPD, we multiplied each age-specific mortality probability for the general population by a weighted average of the GOLD category-specific hazard ratios, where the weight for a GOLD category was the proportion of COPD subjects in that GOLD category (given in the right-most column of Table 1 above). The weighted average hazard ratio was 1.906. Age-specific life expectancies were then derived for the severe COPD and "average" COPD subpopulations using these adjusted mortality probabilities and the method for calculating life expectancies described above.

Once an appropriate set of life expectancies has been determined (e.g., life expectancies for the general population or life expectancies for a subpopulation with severe COPD), these then provide the number of life years lost for an individual who dies at a given age. This information can then be combined with the estimated number of O_3-related premature deaths at each age calculated with BenMAP (see previous subsection). Because BenMAP calculates numbers of premature deaths avoided within age intervals, we can either allocate the premature deaths avoided within an age interval uniformly to the ages within the interval or, alternatively, we can calculate average life expectancies for the age intervals. We illustrate the first approach in calculating O_3-related life years saved and the second approach in calculating $PM_{2.5}$-related life years saved (see Section 7b.6).

Total O_3-related life years gained was calculated as the sum of life years gained at each age:

$$\textit{Total life years gained} \quad \sum_{i \; 0}^{N} LE_i \times M_i$$

where LE_i is the remaining life expectancy for age i, M_i is the number of premature deaths avoided among individuals age i, and N is the oldest age considered.

For the purposes of determining cost effectiveness, it is also necessary to consider the time-dependent nature of the gains in life years. Standard economic theory suggests that benefits occurring in future years should be discounted relative to benefits occurring in the present. OMB and EPA guidance suggest discount rates of three and seven percent. Selection of a 3 percent discount rate is also consistent with recommendations from the U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine (Gold et al., 1996).

Discounted total life years gained is calculated as follows:

$$\textit{Discounted LY} \quad \int_0^{LE} e^{-rt}\,dt,$$

where r is the discount rate, t indicates time, and LE is the life expectancy at the time when the premature death would have occurred. Because O_3-related premature mortality is associated only with short-term exposures, all O_3-related premature deaths are assumed to occur in the year of exposure. We therefore did not discount O_3-related premature deaths avoided.

Undiscounted age-specific life expectancies, and age-specific life expectancies using discount rates of 3 percent and 7 percent are given for the general population, the subpopulation of individuals with severe COPD, and the subpopulation of individuals with COPD of average severity in Tables 7b-4, 7b-5, and 7b-6, respectively. The O_3-related (discounted) life years saved, based on each of the two O_3-mortality studies and each of the assumptions about relevant life expectancies, are given, using 3 percent and 7 percent discount rates, in Tables 7b-7 and 7b-8, respectively. The O_3-related (discounted) life years saved, under the first assumption – that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship – is zero in all cases (i.e., regardless of the mortality study used and the scenario considered), and is therefore not shown in these Tables.

Table 7b-4. Undiscounted and Discounted Age-Specific Life Expectancies for the General Population

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.006799	1,000,000	6,799	996,600	77.8	30.9	15.2
1	0.000483	993,201	480	992,961	77.3	30.8	15.2
2	0.000297	992,721	295	992,574	76.4	30.7	15.2
3	0.000224	992,427	222	992,315	75.4	30.6	15.2
4	0.000188	992,204	187	992,111	74.4	30.5	15.2
5	0.000171	992,017	170	991,932	73.4	30.4	15.2
6	0.000161	991,847	159	991,768	72.4	30.3	15.2
7	0.000151	991,688	149	991,613	71.4	30.2	15.2
8	0.000136	991,538	135	991,471	70.4	30.1	15.2
9	0.000119	991,403	118	991,345	69.5	29.9	15.1
10	0.000106	991,286	105	991,233	68.5	29.8	15.1
11	0.000112	991,180	111	991,125	67.5	29.7	15.1
12	0.000149	991,070	148	990,996	66.5	29.5	15.1
13	0.000227	990,922	225	990,809	65.5	29.4	15.1
14	0.000337	990,697	333	990,530	64.5	29.2	15.1
15	0.000460	990,363	456	990,135	63.5	29.1	15.1
16	0.000579	989,907	573	989,621	62.5	28.9	15.1
17	0.000684	989,334	677	988,996	61.6	28.8	15.0
18	0.000763	988,657	755	988,280	60.6	28.6	15.0
19	0.000819	987,902	809	987,498	59.7	28.4	15.0
20	0.000873	987,093	862	986,662	58.7	28.3	15.0
21	0.000926	986,231	913	985,775	57.8	28.1	15.0
22	0.000960	985,318	946	984,845	56.8	27.9	15.0
23	0.000972	984,372	957	983,893	55.9	27.8	14.9
24	0.000969	983,415	953	982,939	54.9	27.6	14.9
25	0.000960	982,462	943	981,991	54.0	27.4	14.9
26	0.000954	981,519	936	981,051	53.0	27.2	14.9
27	0.000952	980,583	933	980,117	52.1	27.0	14.8
28	0.000958	979,650	939	979,181	51.1	26.8	14.8
29	0.000973	978,712	952	978,235	50.2	26.5	14.8
30	0.000994	977,759	972	977,273	49.2	26.3	14.7
31	0.001023	976,787	999	976,287	48.3	26.1	14.7
32	0.001063	975,788	1,038	975,269	47.3	25.9	14.7
33	0.001119	974,750	1,091	974,205	46.4	25.6	14.6
34	0.001192	973,659	1,160	973,079	45.4	25.4	14.6
35	0.001275	972,499	1,240	971,879	44.5	25.1	14.5
36	0.001373	971,259	1,334	970,592	43.5	24.9	14.5
37	0.001493	969,925	1,448	969,201	42.6	24.6	14.4
38	0.001634	968,477	1,582	967,686	41.7	24.3	14.4
39	0.001788	966,895	1,729	966,031	40.7	24.0	14.3
40	0.001945	965,166	1,877	964,228	39.8	23.7	14.3
41	0.002107	963,290	2,029	962,275	38.9	23.5	14.2
42	0.002287	961,260	2,198	960,161	38.0	23.2	14.1
43	0.002494	959,062	2,392	957,866	37.0	22.8	14.0
44	0.002727	956,670	2,609	955,366	36.1	22.5	14.0
45	0.002982	954,061	2,845	952,639	35.2	22.2	13.9
46	0.003246	951,216	3,088	949,672	34.3	21.9	13.8

Table 7b-4. Undiscounted and Discounted Age-Specific Life Expectancies for the General Population (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.003520	948,129	3,337	946,460	33.5	21.6	13.7
48	0.003799	944,792	3,589	942,997	32.6	21.2	13.6
49	0.004088	941,203	3,848	939,279	31.7	20.9	13.5
50	0.004404	937,355	4,128	935,291	30.8	20.5	13.4
51	0.004750	933,227	4,433	931,010	30.0	20.2	13.3
52	0.005113	928,794	4,749	926,419	29.1	19.8	13.2
53	0.005488	924,045	5,071	921,510	28.2	19.4	13.0
54	0.005879	918,974	5,403	916,273	27.4	19.1	12.9
55	0.006295	913,571	5,751	910,696	26.6	18.7	12.7
56	0.006754	907,820	6,131	904,755	25.7	18.3	12.6
57	0.007280	901,689	6,564	898,407	24.9	17.9	12.4
58	0.007903	895,125	7,074	891,588	24.1	17.5	12.3
59	0.008633	888,051	7,667	884,217	23.3	17.1	12.1
60	0.009493	880,384	8,357	876,205	22.5	16.7	11.9
61	0.010449	872,027	9,112	867,471	21.7	16.2	11.8
62	0.011447	862,915	9,878	857,976	20.9	15.8	11.6
63	0.012428	853,037	10,601	847,736	20.1	15.4	11.4
64	0.013408	842,435	11,295	836,788	19.4	15.0	11.2
65	0.014473	831,140	12,029	825,126	18.6	14.5	11.0
66	0.015703	819,111	12,863	812,680	17.9	14.1	10.7
67	0.017081	806,249	13,771	799,363	17.2	13.7	10.5
68	0.018623	792,477	14,758	785,098	16.5	13.2	10.3
69	0.020322	777,719	15,805	769,817	15.8	12.8	10.0
70	0.022104	761,915	16,841	753,494	15.1	12.3	9.8
71	0.024023	745,073	17,899	736,124	14.4	11.9	9.5
72	0.026216	727,174	19,064	717,642	13.7	11.5	9.3
73	0.028745	708,110	20,355	697,933	13.1	11.0	9.0
74	0.031561	687,756	21,706	676,903	12.5	10.6	8.7
75	0.034427	666,050	22,930	654,585	11.9	10.2	8.4
76	0.037379	643,120	24,039	631,100	11.3	9.7	8.2
77	0.040756	619,080	25,231	606,465	10.7	9.3	7.9
78	0.044764	593,849	26,583	580,558	10.1	8.9	7.6
79	0.049395	567,266	28,020	553,256	9.6	8.5	7.3
80	0.054471	539,246	29,373	524,560	9.0	8.1	7.0
81	0.059772	509,873	30,476	494,635	8.5	7.7	6.7
82	0.065438	479,397	31,371	463,712	8.1	7.3	6.4
83	0.071598	448,026	32,078	431,987	7.6	6.9	6.1
84	0.078516	415,949	32,659	399,619	7.1	6.5	5.8
85	0.085898	383,290	32,924	366,828	6.7	6.2	5.6
86	0.093895	350,366	32,897	333,917	6.3	5.8	5.3
87	0.102542	317,468	32,554	301,192	5.9	5.5	5.0
88	0.111875	284,915	31,875	268,977	5.5	5.1	4.7
89	0.121928	253,040	30,853	237,613	5.1	4.8	4.5
90	0.132733	222,187	29,492	207,441	4.8	4.5	4.2
91	0.144318	192,695	27,809	178,791	4.4	4.2	3.9
92	0.156707	164,886	25,839	151,967	4.1	3.9	3.7
93	0.169922	139,047	23,627	127,234	3.7	3.6	3.4
94	0.183975	115,420	21,234	104,803	3.4	3.3	3.1
95	0.198875	94,186	18,731	84,820	3.0	3.0	2.8
96	0.214620	75,454	16,194	67,357	2.7	2.6	2.5
97	0.231201	59,260	13,701	52,410	2.3	2.2	2.2
98	0.248600	45,559	11,326	39,896	1.8	1.8	1.8
99	0.266786	34,233	9,133	29,667	1.2	1.2	1.2
100	1.000000	25,100	25,100	12,550	0.5	0.5	0.5

*Mortality probabilities for the general population taken from Table 1. Life table for the total population: United States, 2004. CDC National Vital Statistics Reports, Vol. 56, No. 9, December 28, 2007 http://www.cdc.gov/nchs/data/nvsr/nvsr56/nvsr56_09.pdf

Table 7b-5. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with Severe COPD

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.038755	1,000,000	38,755	980,622	54.5	27.5	14.9
1	0.002752	961,245	2,646	959,922	55.7	27.7	14.9
2	0.001692	958,599	1,622	957,788	54.9	27.5	14.9
3	0.001277	956,977	1,222	956,366	53.9	27.4	14.9
4	0.001074	955,755	1,026	955,242	53.0	27.2	14.9
5	0.000978	954,729	933	954,263	52.1	27.0	14.8
6	0.000916	953,796	873	953,359	51.1	26.8	14.8
7	0.000859	952,923	819	952,513	50.2	26.5	14.8
8	0.000777	952,104	739	951,734	49.2	26.3	14.7
9	0.000677	951,365	644	951,043	48.2	26.1	14.7
10	0.000606	950,721	576	950,433	47.3	25.8	14.7
11	0.000636	950,145	605	949,842	46.3	25.6	14.6
12	0.000850	949,540	807	949,137	45.3	25.3	14.6
13	0.001295	948,733	1,229	948,119	44.4	25.1	14.5
14	0.001918	947,505	1,818	946,596	43.4	24.8	14.5
15	0.002625	945,687	2,482	944,446	42.5	24.6	14.4
16	0.003301	943,205	3,113	941,648	41.6	24.3	14.4
17	0.003901	940,092	3,667	938,258	40.8	24.0	14.3
18	0.004351	936,424	4,075	934,387	39.9	23.8	14.3
19	0.004671	932,350	4,355	930,172	39.1	23.5	14.2
20	0.004976	927,995	4,618	925,686	38.3	23.3	14.1
21	0.005278	923,377	4,873	920,941	37.5	23.0	14.1
22	0.005472	918,504	5,026	915,991	36.7	22.7	14.0
23	0.005542	913,478	5,063	910,947	35.9	22.4	13.9
24	0.005522	908,415	5,016	905,907	35.1	22.2	13.9
25	0.005470	903,399	4,942	900,928	34.2	21.9	13.8
26	0.005436	898,458	4,884	896,016	33.4	21.6	13.7
27	0.005425	893,573	4,847	891,150	32.6	21.2	13.6
28	0.005461	888,726	4,853	886,300	31.8	20.9	13.5
29	0.005547	883,873	4,903	881,422	31.0	20.6	13.4
30	0.005668	878,970	4,982	876,479	30.1	20.2	13.3
31	0.005830	873,988	5,095	871,440	29.3	19.9	13.2
32	0.006061	868,893	5,266	866,260	28.5	19.5	13.1
33	0.006380	863,626	5,510	860,872	27.6	19.2	12.9
34	0.006792	858,117	5,828	855,203	26.8	18.8	12.8
35	0.007269	852,289	6,195	849,191	26.0	18.4	12.7
36	0.007827	846,094	6,622	842,783	25.2	18.0	12.5
37	0.008510	839,472	7,144	835,900	24.4	17.6	12.3
38	0.009312	832,328	7,750	828,452	23.6	17.2	12.2
39	0.010191	824,577	8,403	820,376	22.8	16.8	12.0
40	0.011084	816,174	9,047	811,651	22.0	16.4	11.8
41	0.012008	807,128	9,692	802,282	21.3	16.0	11.7
42	0.013035	797,436	10,395	792,238	20.5	15.6	11.5
43	0.014215	787,041	11,187	781,447	19.8	15.2	11.3
44	0.015546	775,854	12,061	769,823	19.1	14.8	11.1
45	0.016996	763,792	12,981	757,301	18.4	14.4	10.9
46	0.018503	750,811	13,892	743,865	17.7	14.0	10.7

Table 7b-5. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with Severe COPD (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.020061	736,919	14,784	729,527	17.0	13.6	10.4
48	0.021652	722,135	15,636	714,317	16.3	13.1	10.2
49	0.023303	706,500	16,464	698,268	15.7	12.7	10.0
50	0.025103	690,036	17,322	681,375	15.0	12.3	9.8
51	0.027075	672,714	18,214	663,607	14.4	11.9	9.5
52	0.029144	654,500	19,075	644,963	13.8	11.5	9.3
53	0.031280	635,425	19,876	625,487	13.2	11.1	9.0
54	0.033512	615,549	20,628	605,235	12.6	10.7	8.8
55	0.035880	594,921	21,346	584,248	12.0	10.3	8.5
56	0.038497	573,575	22,081	562,535	11.5	9.9	8.2
57	0.041497	551,494	22,885	540,052	10.9	9.5	8.0
58	0.045046	528,609	23,812	516,703	10.3	9.0	7.7
59	0.049211	504,797	24,842	492,376	9.8	8.6	7.4
60	0.054108	479,956	25,969	466,971	9.3	8.2	7.1
61	0.059560	453,986	27,040	440,467	8.8	7.9	6.9
62	0.065249	426,947	27,858	413,018	8.3	7.5	6.6
63	0.070839	399,089	28,271	384,953	7.9	7.1	6.3
64	0.076425	370,818	28,340	356,648	7.4	6.8	6.0
65	0.082495	342,478	28,253	328,352	7.0	6.4	5.8
66	0.089507	314,225	28,125	300,163	6.6	6.1	5.5
67	0.097361	286,100	27,855	272,173	6.2	5.7	5.2
68	0.106149	258,245	27,413	244,539	5.8	5.4	5.0
69	0.115833	230,833	26,738	217,463	5.4	5.1	4.7
70	0.125993	204,094	25,714	191,237	5.1	4.8	4.4
71	0.136933	178,380	24,426	166,167	4.7	4.5	4.2
72	0.149433	153,954	23,006	142,451	4.4	4.2	3.9
73	0.163847	130,948	21,455	120,220	4.1	3.9	3.7
74	0.179896	109,493	19,697	99,644	3.8	3.6	3.5
75	0.196231	89,795	17,621	80,985	3.5	3.4	3.2
76	0.213062	72,175	15,378	64,486	3.2	3.1	3.0
77	0.232309	56,797	13,194	50,200	3.0	2.9	2.8
78	0.255152	43,603	11,125	38,040	2.7	2.7	2.6
79	0.281552	32,477	9,144	27,905	2.5	2.4	2.4
80	0.310486	23,333	7,245	19,711	2.3	2.2	2.2
81	0.340699	16,089	5,481	13,348	2.1	2.0	2.0
82	0.372994	10,607	3,956	8,629	1.9	1.9	1.8
83	0.408108	6,651	2,714	5,294	1.7	1.7	1.7
84	0.447543	3,937	1,762	3,056	1.5	1.5	1.5
85	0.489619	2,175	1,065	1,642	1.4	1.4	1.4
86	0.535199	1,110	594	813	1.3	1.3	1.2
87	0.584489	516	302	365	1.1	1.1	1.1
88	0.637689	214	137	146	1.0	1.0	1.0
89	0.694992	78	54	51	0.9	0.9	0.9
90	0.756579	24	18	15	0.8	0.8	0.8
91	0.822612	6	5	3	0.6	0.6	0.6
92	0.893232	1	0	0	0.0	0.0	0.0

*Mortality probabilities derived from mortality probabilities for the general population by multiplying by the hazard ratio (5.7) for GOLD 3 or 4, from Mannino et al. (2006).

Table 7b-6. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with COPD of Average Severity

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
0	0.012960	1,000,000	12,960	993,520	69.6	29.9	15.1
1	0.000920	987,040	908	986,586	69.5	29.9	15.1
2	0.000566	986,132	558	985,853	68.6	29.8	15.1
3	0.000427	985,574	421	985,363	67.6	29.7	15.1
4	0.000359	985,153	354	984,976	66.7	29.5	15.1
5	0.000327	984,799	322	984,638	65.7	29.4	15.1
6	0.000306	984,477	301	984,326	64.7	29.3	15.1
7	0.000287	984,176	283	984,034	63.7	29.1	15.1
8	0.000260	983,893	256	983,765	62.7	29.0	15.1
9	0.000226	983,638	223	983,526	61.8	28.8	15.1
10	0.000203	983,415	199	983,315	60.8	28.6	15.0
11	0.000213	983,216	209	983,111	59.8	28.5	15.0
12	0.000284	983,006	279	982,867	58.8	28.3	15.0
13	0.000433	982,727	426	982,514	57.8	28.1	15.0
14	0.000642	982,302	630	981,986	56.8	27.9	15.0
15	0.000878	981,671	862	981,241	55.9	27.8	14.9
16	0.001104	980,810	1,083	980,268	54.9	27.6	14.9
17	0.001304	979,727	1,278	979,088	54.0	27.4	14.9
18	0.001455	978,449	1,424	977,737	53.1	27.2	14.9
19	0.001562	977,025	1,526	976,262	52.1	27.0	14.8
20	0.001664	975,499	1,623	974,688	51.2	26.8	14.8
21	0.001765	973,876	1,719	973,017	50.3	26.6	14.8
22	0.001830	972,157	1,779	971,268	49.4	26.4	14.7
23	0.001853	970,378	1,798	969,479	48.5	26.1	14.7
24	0.001846	968,580	1,788	967,686	47.6	25.9	14.7
25	0.001829	966,792	1,769	965,907	46.7	25.7	14.6
26	0.001818	965,023	1,754	964,146	45.7	25.5	14.6
27	0.001814	963,269	1,747	962,395	44.8	25.2	14.5
28	0.001826	961,521	1,756	960,643	43.9	25.0	14.5
29	0.001855	959,766	1,780	958,875	43.0	24.7	14.5
30	0.001896	957,985	1,816	957,077	42.1	24.4	14.4
31	0.001949	956,169	1,864	955,237	41.1	24.2	14.3
32	0.002027	954,305	1,934	953,338	40.2	23.9	14.3
33	0.002133	952,371	2,032	951,355	39.3	23.6	14.2
34	0.002271	950,339	2,158	949,260	38.4	23.3	14.1
35	0.002431	948,181	2,305	947,028	37.5	23.0	14.1
36	0.002617	945,876	2,476	944,638	36.6	22.7	14.0
37	0.002846	943,400	2,685	942,058	35.7	22.4	13.9
38	0.003114	940,716	2,929	939,251	34.8	22.0	13.8
39	0.003408	937,786	3,196	936,189	33.9	21.7	13.7
40	0.003707	934,591	3,464	932,859	33.0	21.4	13.6
41	0.004016	931,127	3,739	929,257	32.1	21.0	13.5
42	0.004359	927,388	4,042	925,366	31.2	20.7	13.4
43	0.004753	923,345	4,389	921,151	30.4	20.3	13.3
44	0.005199	918,956	4,777	916,567	29.5	20.0	13.2
45	0.005683	914,179	5,196	911,581	28.7	19.6	13.1
46	0.006187	908,983	5,624	906,171	27.8	19.2	13.0

Table 7b-6. Undiscounted and Discounted Age-Specific Life Expectancies for the Subpopulation with COPD of Average Severity (cont'd)

Age at Beginning of Year	Mortality Probability*	Cohort Size	Deaths in Year	Life-Years in Year	Age-Specific Life Expectancy	3% Discounted Remaining Life Expectancy	7% Discounted Remaining Life Expectancy
47	0.006709	903,359	6,060	900,329	27.0	18.9	12.8
48	0.007241	897,298	6,497	894,050	26.2	18.5	12.7
49	0.007793	890,801	6,942	887,331	25.3	18.1	12.5
50	0.008395	883,860	7,420	880,150	24.5	17.7	12.4
51	0.009054	876,440	7,935	872,472	23.7	17.3	12.2
52	0.009746	868,505	8,464	864,273	23.0	16.9	12.1
53	0.010460	860,040	8,996	855,542	22.2	16.5	11.9
54	0.011207	851,044	9,537	846,276	21.4	16.1	11.7
55	0.011999	841,507	10,097	836,458	20.6	15.7	11.5
56	0.012874	831,410	10,703	826,058	19.9	15.3	11.3
57	0.013877	820,707	11,389	815,012	19.1	14.8	11.1
58	0.015064	809,318	12,191	803,222	18.4	14.4	10.9
59	0.016456	797,127	13,118	790,568	17.7	14.0	10.7
60	0.018094	784,009	14,186	776,916	17.0	13.5	10.4
61	0.019917	769,823	15,333	762,157	16.3	13.1	10.2
62	0.021820	754,490	16,463	746,259	15.6	12.7	10.0
63	0.023689	738,028	17,483	729,286	14.9	12.3	9.7
64	0.025557	720,545	18,415	711,337	14.3	11.8	9.5
65	0.027587	702,130	19,370	692,445	13.6	11.4	9.2
66	0.029932	682,760	20,436	672,542	13.0	11.0	8.9
67	0.032558	662,324	21,564	651,542	12.4	10.5	8.7
68	0.035497	640,760	22,745	629,388	11.8	10.1	8.4
69	0.038735	618,015	23,939	606,046	11.2	9.7	8.1
70	0.042133	594,076	25,030	581,561	10.6	9.3	7.8
71	0.045791	569,046	26,057	556,017	10.1	8.9	7.6
72	0.049971	542,989	27,134	529,422	9.6	8.4	7.3
73	0.054791	515,855	28,264	501,723	9.0	8.0	7.0
74	0.060158	487,591	29,333	472,924	8.5	7.6	6.7
75	0.065621	458,258	30,071	443,223	8.0	7.3	6.4
76	0.071249	428,187	30,508	412,933	7.6	6.9	6.1
77	0.077685	397,679	30,894	382,232	7.1	6.5	5.8
78	0.085324	366,785	31,296	351,137	6.7	6.1	5.6
79	0.094152	335,489	31,587	319,696	6.2	5.8	5.3
80	0.103828	303,902	31,554	288,125	5.8	5.4	5.0
81	0.113932	272,349	31,029	256,834	5.5	5.1	4.7
82	0.124731	241,319	30,100	226,269	5.1	4.8	4.5
83	0.136473	211,219	28,826	196,806	4.8	4.5	4.2
84	0.149661	182,394	27,297	168,745	4.4	4.2	4.0
85	0.163731	155,096	25,394	142,399	4.1	3.9	3.7
86	0.178974	129,702	23,213	118,096	3.8	3.7	3.5
87	0.195456	106,489	20,814	96,082	3.5	3.4	3.3
88	0.213247	85,675	18,270	76,540	3.3	3.2	3.1
89	0.232409	67,405	15,666	59,572	3.0	3.0	2.8
90	0.253004	51,740	13,090	45,194	2.8	2.7	2.7
91	0.275086	38,649	10,632	33,333	2.6	2.5	2.5
92	0.298702	28,017	8,369	23,833	2.4	2.4	2.3
93	0.323890	19,649	6,364	16,467	2.2	2.2	2.1
94	0.350677	13,285	4,659	10,955	2.0	2.0	2.0
95	0.379078	8,626	3,270	6,991	1.9	1.8	1.8
96	0.409089	5,356	2,191	4,261	1.7	1.7	1.6
97	0.440695	3,165	1,395	2,468	1.5	1.5	1.5
98	0.473858	1,770	839	1,351	1.3	1.3	1.3
99	0.508523	931	474	695	1.0	1.0	1.0
100	1.000000	458	458	229	0.5	0.5	0.5

*Mortality probabilities derived from mortality probabilities for the general population (see Table 2) by multiplying by the weighted average of hazard ratios for the GOLD severity categories (1.906) from Mannino et al. (2006).

Table 7b-7. Estimated Discounted O_3-Related Life Years Saved Under Alternative Illustrative O_3 NAAQS Attainment Strategies in 2020, Using a 3 Percent Discount Rate

Estimated O_3-Related Life Years Saved* (95% CI)**							
Bell et al. (2004)				Levy et al. (2005)			
Baseline: Full Attainment of Current (0.084 ppm) Standard; Control Scenario: Full Attainment of Alternative Standard of:							
0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm	0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
Assuming Life Expectancies of the General Population							
380 (130 - 630)	980 (320 - 1,600)	3,000 (960 - 5,100)	5,400 (1,700 - 9,000)	1,800 (1,300 - 2,400)	4,700 (3,300 - 6,200)	15,000 (10,000 - 19,000)	26,000 (18,000 - 34,000)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity							
290 (97 - 480)	750 (250 - 1,300)	2,300 (740 - 3,900)	4,100 (1,300 - 6,900)	1,400 (1,000 - 1,900)	3,700 (2,500 - 4,800)	11,000 (7,800 - 15,000)	20,000 (14,000 - 26,000)
Assuming Life Expectancies of the Sub-Population with Severe COPD							
160 (54 - 270)	420 (140 - 700)	1,300 (400 - 2,200)	2,300 (730 - 3,800)	840 (580 - 1,100)	2,100 (1,500 - 2,800)	6,500 (4,500 - 8,600)	11,000 (7,900 - 15,000)

*The O_3-related (discounted) life years saved, under the first assumption – that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship – is zero in all cases (i.e., regardless of the mortality study used and the scenario considered, and is therefore not shown.

**95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

Table 7b-8. Estimated Discounted O_3-Related Life Years Saved Under Alternative Illustrative O_3 NAAQS Attainment Strategies in 2020, Using a 7 Percent Discount Rate

Estimated O_3-Related Life Years Saved* (95% CI)**							
Bell et al. (2004)				Levy et al. (2005)			
Baseline: Full Attainment of Current (0.084 ppm) Standard; Control Scenario: Full Attainment of Alternative Standard of:							
0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm	0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
Assuming Life Expectancies of the General Population							
290 (96 - 480)	750 (250 - 1,200)	2,300 (740 - 3,900)	4,100 (1,300 - 6,900)	1,400 (940 - 1,800)	3,500 (2,400 - 4,600)	11,000 (7,500 - 14,000)	19,000 (13,000 - 25,000)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity							
230 (77 - 390)	600 (200 - 1,000)	1,900 (590 - 3,200)	3,300 (1,100 - 5,500)	1,100 (770 - 1,500)	2,900 (2,000 - 3,800)	8,900 (6,100 - 12,000)	16,000 (11,000 - 21,000)
Assuming Life Expectancies of the Sub-Population with Severe COPD							
140 (46 - 230)	350 (120 - 590)	1,100 (340 - 1,800)	1,900 (620 - 3,200)	690 (480 - 900)	1,800 (1,200 - 2,300)	5,400 (3,700 - 7,100)	9,500 (6,500 - 12,000)

*The O_3-related (discounted) life years saved, under the first assumption – that the observed statistical association between premature mortality and short-term exposures to O_3 is not actually a causal relationship – is zero in all cases (i.e., regardless of the mortality study used and the scenario considered, and is therefore not shown.

**95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

7b.5.3 Cost-Effectiveness Ratios

For each illustrative O_3 NAAQS attainment strategy for which we considered only O_3-related benefits, we calculated one set of cost-effectiveness ratios using total lives saved, based on the Bell study and the Levy study, as the denominator, and another set using total life years saved as the denominator. As discussed above in Section 7b.4, we netted out the monetized benefits of avoided cases of O_3-related acute morbidity (respiratory hospital admissions, asthma-related ER visits, school absence days, and minor restricted activity days) as well as avoided O_3-related worker productivity losses from the direct costs of the controls necessary to achieve the reductions in ambient concentrations of O_3 in the numerator. Incidences of avoided acute morbidity are given in Chapter 8.

We used Monte Carlo procedures to incorporate the uncertainty surrounding the O_3 coefficient in each of the C-R functions (including C-R functions for each of the acute morbidity endpoints as well as the C-R function for mortality) as well as the uncertainty surrounding the unit value (monetized benefit of an avoided case) of each acute morbidity endpoint. This procedure was repeated separately for each of the two mortality C-R functions used, and, for cost-effectiveness ratios using life years saved, for each combination of mortality C-R function and assumption about relevant life expectancies. The results are shown in Table 7b-9 for cost-effectiveness ratios using lives saved. As noted above, O_3-related premature mortality avoided (lives saved) are assumed to be related only to short-term exposures and are not discounted. The cost of the regulation, however, which occurs over a period of time, is discounted (using discount rates of 3 percent and 7 percent). Tables 7b-10 and 7b-11 show cost-effectiveness ratios using life years saved, using discount rates of 3 and 7 percent, respectively. Both the costs of the regulation and the lives saved are discounted.

As noted in Section 1, these cost-effectiveness ratios omit the $PM_{2.5}$-related co-benefits of these illustrative O_3 NAAQS strategies and are therefore likely to understate the cost effectiveness of these strategies. As can be seen in Tables 7b-9 through 7b-11, the direct costs of the controls necessary to achieve the reductions in ambient concentrations of O_3, in the numerators of the cost-effectiveness ratios, increase with the stringency of the alternative standards. The lives and life years saved, in the denominators of the cost-effectiveness ratios, similarly increase with the stringency of the alternative standards. It is therefore not surprising that we do not see a monotonic trend in these ratios across the increasingly more stringent alternative standards.

Table 7b-9. Estimated Net Cost (2006$) per O_3-Related Life Saved Under Alternative Illustrative O_3 NAAQS Attainment Strategies in 2020

Mortality Study	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Saved* (95% CI)**			
	Change From Full Attainment of the Current (0.084 ppm) Std. To Full Attainment of Alternative Std. of:			
	0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
*Estimated 3% discounted cost of the regulation (in Billion $):****	$2.9	$8.8	$25	$44
Bell et al. (2004)	$93 ($48 - $240)	$110 ($55 - $280)	$98 ($50 - $260)	$96 ($50 - $260)
Levy et al. (2005)	$18 ($13 - $25)	$21 ($15 - $29)	$19 ($14 - $27)	$19 ($14 - $27)
Using lower bound estimate of 7% discounted cost of the regulation (in Billion $):	$2.4	$7.6	$19	$32
Bell et al. (2004)	$76 ($40 - $200)	$92 ($48 - $240)	$74 ($38 - $200)	$70 ($36 - $190)
Levy et al. (2005)	$15 ($11 - $21)	$18 ($13 - $25)	$14 ($11 - $20)	$14 ($10 - $19)
Using upper bound estimate of 7% discounted cost of the regulation (in Billion $):	$2.9	$8.8	$25	$44
Bell et al. (2004)	$93 ($48 - $240)	$110 ($55 - $280)	$98 ($50 - $260)	$96 ($50 - $260)
Levy et al. (2005)	$18 ($13 - $25)	$21 ($15 - $29)	$19 ($14 - $27)	$19 ($14 - $27)

*Because $PM_{2.5}$-related benefits are not incorporated in these cost effectiveness ratios, the cost effectiveness of full attainment of each alternative O_3 standard shown in this table will tend to be understated.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 coefficients in the mortality and morbidity endpoints as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

***Uses the upper bound estimates of the 7% discounted costs of the regulations as proxies for the 3% discounted costs.

Table 7b-10. Estimated Net Cost (2006$) per O_3-Related Life Year Saved Under Alternative Illustrative O_3 NAAQS Attainment Strategies in 2020, Using a 3 Percent Discount Rate

Mortality Study	Life Expectancy Assumption	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Year Saved* (95% CI)**			
		Change From Full Attainment of the Current (0.084 ppm) Std. To Full Attainment of Alternative Std. of:			
		0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
*Estimated 3% discounted cost of the regulation (in Billion $):****		$2.9	$8.8	$25	$44
Bell et al. (2004)	General Population	$8.7 ($4.6 - $23)	$10 ($5.3 - $27)	$9.5 ($4.8 - $26)	$9.6 ($4.8 - $25)
Bell et al. (2004)	Subpopulation with Average COPD	$11 ($5.9 - $29)	$13 ($6.9 - $35)	$12 ($6.3 - $34)	$12 ($6.3 - $33)
Bell et al. (2004)	Subpopulation with Severe COPD	$20 ($11 - $53)	$24 ($13 - $63)	$22 ($11 - $61)	$22 ($12 - $59)
Levy et al. (2005)	General Population	$1.6 ($1.2 - $2.3)	$1.9 ($1.4 - $2.7)	$1.7 ($1.3 - $2.5)	$1.7 ($1.3 - $2.5)
Levy et al. (2005)	Subpopulation with Average COPD	$2.0 ($1.5 - $2.9)	$2.4 ($1.8 - $3.4)	$2.2 ($1.7 - $3.2)	$2.2 ($1.7 - $3.2)
Levy et al. (2005)	Subpopulation with Severe COPD	$3.5 ($2.6 - $4.9)	$4.2 ($3.1 - $5.9)	$3.9 ($2.9 - $5.5)	$3.9 ($2.9 - $5.5)

*Because $PM_{2.5}$-related benefits are not incorporated in these cost effectiveness ratios, the cost effectiveness of full attainment of each alternative O_3 standard shown in this table will tend to be understated.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

***Uses the upper bound estimates of the 7% discounted costs of the regulations as proxies for the 3% discounted costs.

Table 7b-11. Estimated Net Cost (2006$) per O_3-Related Life Year Saved Under Alternative Illustrative O_3 NAAQS Attainment Strategies in 2020, Using a 7 Percent Discount Rate

Mortality Study	Life Expectancy Assumption	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Year Saved* (95% CI)**			
		Change From Full Attainment of the Current (0.084 ppm) Std. To Full Attainment of Alternative Std. of:			
		0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
Using lower bound estimate of 7% discounted cost of the regulation (in Billion $):		$2.4	$7.6	$19	$32
Bell et al. (2004)	General Population	$9.4 ($4.9 - $25)	$12 ($6 - $30)	$9.5 ($4.8 - $25)	$8.8 ($4.6 - $24)
Bell et al. (2004)	Subpopulation with Average COPD	$12 ($6.1 - $31)	$14 ($7.5 - $38)	$12 ($5.9 - $32)	$11 ($5.7 - $29)
Bell et al. (2004)	Subpopulation with Severe COPD	$20 ($10 - $52)	$25 ($13 - $64)	$20 ($10 - $55)	$19 ($9.8 - $50)
Levy et al. (2005)	General Population	$1.8 ($1.3 - $2.5)	$2.2 ($1.6 - $3.1)	$1.7 ($1.3 - $2.5)	$1.7 ($1.2 - $2.4)
Levy et al. (2005)	Subpopulation with Average COPD	$2.2 ($1.6 - $3.1)	$2.7 ($2 - $3.8)	$2.2 ($1.6 - $3.1)	$2.1 ($1.5 - $2.9)
Levy et al. (2005)	Subpopulation with Severe COPD	$3.5 ($2.6 - $5)	$4.4 ($3.3 - $6.2)	$3.6 ($2.6 - $5.1)	$3.4 ($2.5 - $4.8)
Using upper bound estimate of 7% discounted cost of the regulation (in Billion $):		$2.9	$8.8	$25	$44
Bell et al. (2004)	General Population	$11 ($6 - $30)	$14 ($7 - $35)	$13 ($6.3 - $34)	$12 ($6.3 - $32)
Bell et al. (2004)	Subpopulation with Average COPD	$14 ($7.4 - $37)	$17 ($8.7 - $44)	$16 ($7.8 - $42)	$15 ($7.9 - $41)
Bell et al. (2004)	Subpopulation with Severe COPD	$24 ($13 - $63)	$29 ($15 - $75)	$27 ($13 - $72)	$26 ($14 - $70)
Levy et al. (2005)	General Population	$2.2 ($1.6 - $3)	$2.5 ($1.9 - $3.6)	$2.3 ($1.7 - $3.3)	$2.3 ($1.7 - $3.3)
Levy et al. (2005)	Subpopulation with Average COPD	$2.6 ($2 - $3.7)	$3.1 ($2.3 - $4.4)	$2.9 ($2.1 - $4.1)	$2.8 ($2.1 - $4)
Levy et al. (2005)	Subpopulation with Severe COPD	$4.3 ($3.2 - $6)	$5.1 ($3.8 - $7.2)	$4.7 ($3.5 - $6.7)	$4.7 ($3.5 - $6.7)

*Because $PM_{2.5}$-related benefits are not incorporated in these cost effectiveness ratios, the cost effectiveness of full attainment of each alternative O_3 standard shown in this table will tend to be understated.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O3 coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

7b.6 Cost-Effectiveness Metrics Incorporating Both O_3-Related and $PM_{2.5}$-Related Benefits

In this section we describe the development of cost-effectiveness metrics for the single illustrative O_3 NAAQS attainment strategy for which we were able to incorporate both O_3-related benefits and $PM_{2.5}$-related co-benefits, in which the baseline is partial attainment of the current O_3 standard of 0.084 ppm and the control scenario is partial attainment of an alternative standard of 0.070 ppm.

7b.6.1 O_3-related Lives Saved and Life Years Saved

The methods used to calculate O_3-related lives saved and O_3-related life years saved under this scenario are the same as those described above in Section 7b.5. Estimated numbers of O_3-related premature deaths avoided are shown in Table 7b-12. The corresponding O_3-related life years saved, discounted using 3 percent and 7 percent discount rates, are shown in Tables 7b-13 and 7b-14, respectively.

Table 7b-12. Estimated Reduction in Incidence of O_3-Related Premature Mortality Associated with Illustrative O_3 NAAQS Attainment Strategy in 2020: Changing from Partial Attainment of the Current O_3 NAAQS to Partial Attainment of an Alternative O_3 NAAQS of 0.07 ppm

Age Interval	Reduction in O_3-Related Premature Mortality (95% CI)*	
	Baseline of Partial Attainment of Current (0.084 ppm) Standard to Control Scenario of Partial Attainment of 0.07 ppm	
	Bell et al. (2004)	Levy et al. (2005)
0 - 4	0 (0 - 1)	3 (2 - 3)
5 - 9	0 (0 - 0)	1 (1 - 2)
10 - 14	0 (0 - 0)	1 (1 - 1)
15 - 19	0 (0 - 0)	2 (1 - 3)
20 - 24	0 (0 - 0)	3 (2 - 4)
25 - 29	1 (0 - 1)	4 (3 - 6)
30 - 34	0 (0 - 1)	4 (3 - 6)
35 - 39	1 (0 - 2)	7 (4 - 9)
40 - 44	1 (0 - 2)	6 (4 - 8)
45 - 49	3 (1 - 5)	13 (9 - 17)
50 - 54	3 (1 - 5)	14 (9 - 18)
55 - 59	8 (2 - 14)	37 (25 - 50)
60 - 64	8 (2 - 14)	36 (24 - 48)
65 - 69	16 (5 - 27)	70 (47 - 94)
70 - 74	12 (4 - 21)	55 (37 - 73)
75 - 79	20 (6 - 33)	86 (58 - 110)
80 - 84	12 (4 - 21)	55 (37 - 73)
85+	40 (12 - 68)	170 (120 - 230)
Total:	130 (36 - 220)	570 (380 - 760)

*95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

Table 7b-13. Estimated O_3-Related Life Years Saved Associated with Illustrative O_3 NAAQS Attainment Strategy in 2020: Changing from Partial Attainment of the Current O_3 NAAQS to Partial Attainment of an Alternative O_3 NAAQS of 0.07 ppm, Using a 3 Percent Discount Rate

Estimated O_3-Related Life Years Saved (95% CI)*		
Baseline: Partial Attainment of Current (0.084 ppm) Standard; Control Scenario: Partial Attainment of Alternative Standard of 0.070 ppm		
Mortality Study:	Bell et al (2004)	Levy et al. (2005)
Assuming Life Expectancies of the General Population	1,300 (370 - 2,200)	6,100 (4,100 - 8,100)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity	980 (280 - 1,700)	4,700 (3,200 - 6,300)
Assuming Life Expectancies of the Sub-Population with Severe COPD	530 (150 - 910)	2,700 (1,800 - 3,500)

*95 percent confidence or credible intervals are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

Table 7b-14. Estimated O_3-Related Life Years Saved Associated with Illustrative O_3 NAAQS Attainment Strategy in 2020: Changing from Partial Attainment of the Current O_3 NAAQS to Partial Attainment of an Alternative O_3 NAAQS of 0.07 ppm, Using a 7 Percent Discount Rate

Estimated O_3-Related Life Years Saved (95% CI)*		
Baseline: Partial Attainment of Current (0.084 ppm) Standard; Control Scenario: Partial Attainment of Alternative Standard of 0.070 ppm		
Mortality Study:	Bell et al (2004)	Levy et al. (2005)
Assuming Life Expectancies of the General Population	990 (280 - 1,700)	4,600 (3,100 - 6,100)
Assuming Life Expectancies of the Sub-Population with COPD of Average Severity	790 (230 - 1,400)	3,700 (2,500 - 4,900)
Assuming Life Expectancies of the Sub-Population with Severe COPD	450 (130 - 780)	2,200 (1,500 - 2,900)

*95 percent confidence or credible intervals are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

7b.6.2 Reductions in $PM_{2.5}$-Related Premature Deaths

To generate $PM_{2.5}$-related health outcomes, we used the same framework as for the benefit-cost analysis described in Chapter 8 and briefly summarized above in the introductory portion of Section 8.4.

As in several recent air pollution health impact assessments (e.g., Kunzli et al., 2000; EPA, 2004), we focused on the prospective cohort long-term exposure studies in deriving the health impact function for the estimate of premature mortality. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli et al., 2001; NRC, 2002). We selected an effect estimate from the extended analysis of the ACS cohort (Pope et al., 2002) as well as from the Harvard Six City Study (Laden et al., 2006). Given the focus in this analysis on developing a broader expression of uncertainties in the benefits estimates, and the weight that was placed on both the ACS and Harvard Six-city studies by experts participating in the $PM_{2.5}$ mortality expert elicitation, we elected to provide estimates derived from both Pope et al. (2002) and Laden et al. (2006).

This latest re-analysis of the ACS cohort data (Pope et al, 2002) provides additional refinements to the analysis of PM-related mortality by (a) extending the follow-up period for the ACS study subjects to 16 years, which triples the size of the mortality data set; (b) substantially increasing exposure data, including consideration for cohort exposure to $PM_{2.5}$ following implementation of $PM_{2.5}$ standard in 1999; (c) controlling for a variety of personal risk factors including occupational exposure and diet; and (d) using advanced statistical methods to evaluate specific issues that can adversely affect risk estimates, including the possibility of spatial autocorrelation of survival times in communities located near each other. The effect estimate from Pope et al. (2002) quantifies the relationship between annual mean $PM_{2.5}$ levels and all-cause mortality in adults 30 and older. We selected the effect estimate estimated using the measure of PM representing average exposure over the follow-up period, calculated as the average of 1979–1984 and 1999–2000 $PM_{2.5}$ levels. The effect estimate from this study is 0.0058, which is equivalent to a relative risk of 1.06 for a 10 µg change in $PM_{2.5}$.

A recent follow up to the Harvard 6-city study (Laden et al., 2006) both confirmed the effect size from the first study and provided additional confirmation that reductions in $PM_{2.5}$ directly result in reductions in the risk of premature death. This additional evidence stems from the observed reductions in $PM_{2.5}$ in each city during the extended follow-up period. Laden et al. (2006) found that mortality rates consistently went down at a rate proportionate to the observed reductions in $PM_{2.5}$. The effect estimate obtained from Laden et al. (2006) is 0.0148, which is equivalent to a relative risk of 1.16 for a 10 $\mu g/m^3$ change in $PM_{2.5}$.

Age, cause, and county-specific mortality rates were obtained from CDC for the years 1996 through 1998. CDC maintains an online data repository of health statistics, CDC Wonder, accessible at http://wonder.cdc.gov/. The mortality rates provided are derived from U.S. death records and U.S. Census Bureau postcensal population estimates. Mortality rates were averaged across 3 years (1996 through 1998) to provide more stable estimates. When estimating rates for age groups that differed from the CDC Wonder groupings, we assumed that rates were uniform across all ages in the reported age group. For example, to estimate mortality rates for individuals ages 30 and up, we scaled the 25- to 34-year old death count and population by one-half and then generated a population-weighted mortality rate using data for the older age groups.

The reductions in incidence of $PM_{2.5}$-related premature mortality within each age group associated with the illustrative 0.07 ppm partial attainment strategy in 2020 are summarized in Table 7b-15.

Table 7b-15: Estimated Reduction in Incidence of $PM_{2.5}$-Related All-Cause Premature Mortality Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

	*Reduction in All-Cause Premature Mortality (95% CI)**	
Age Interval	Pope (2002)	Laden (2006)
30 – 34	4 (1 – 6)	8 (5 – 12)
35 – 44	11 (4 – 18)	25 (13 – 36)
45 – 54	23 (9 – 36)	51 (28 – 75)
55 – 64	56 (22 – 90)	130 (69 – 180)
65 – 74	93 (37 – 150)	210 (120 – 310)
75 – 84	110 (43 – 180)	250 (130 – 360)
85+	140 (56 – 230)	320 (180 – 470)
Total	440 (170 – 700)	990 (540 – 1,400)

*95% confidence intervals are based on the uncertainty surrounding the effect estimate (coefficient) in the mortality C-R function. All estimates rounded to two significant figures.

7b.6.3 Life Years Saved as a Result of Reductions in $PM_{2.5}$-Related Mortality Risk

To calculate life years saved associated with a given change in air pollution, we used a life table approach coupled with age-specific estimates of reductions in premature mortality. We began with the complete unabridged life table for the United States in 2000, obtained from CDC (CDC, 2002). For each 1-year age interval (e.g., zero to one, one to two) the life table provides estimates of the baseline probability of dying during the interval, person years lived in the interval, and remaining life expectancy. From this unabridged life table, we constructed an abridged life table to match the age intervals for which we have predictions of changes in incidence of premature mortality. We used the abridgement method described in CDC (2002). Table 7b-16 presents the abridged life table for 10-year age intervals for adults over 30 (to match the Pope et al. [2002] study population). Note that the abridgement actually includes one 5-year interval, covering adults 30 to 34, with the remaining age intervals covering 10 years each. This is to provide conformity with the age intervals available for mortality rates.

From the abridged life table (Table 7b-16), we obtained the remaining life expectancy for each age cohort, conditional on surviving to that age. This is then the number of life years lost for an individual in the general population dying during that age interval. This information can then be combined with the estimated number of premature deaths in each age interval calculated with BenMAP (see previous subsection). Total life years gained will then be the sum of life years gained in each age interval:

$$Total Life Years = \sum_{i=1}^{N} LE_i \times M_i ,$$

where LE_i is the remaining life expectancy for age interval *i*, M_i is the change in incidence of mortality in age interval *i*, and *N* is the number of age intervals.

As noted above, for the purposes of determining cost-effectiveness, it is also necessary to consider the time-dependent nature of the gains in life years. Standard economic theory suggests that benefits occurring in future years should be discounted relative to benefits occurring in the present. OMB and EPA guidance suggest discount rates of three and seven percent. Selection of a 3 percent discount rate is also consistent with recommendations from the U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine (Gold et al., 1996).

Table 7b-16. Abridged Life Table for the Total Population, United States, 2000

Age Interval		*Probability of Dying Between Ages x to x+1*	*Number Surviving to Age x*	*Number Dying Between Ages x to x+1*	*Person Years Lived Between Ages x to x+1*	*Total Number of Person Years Lived Above Age x*	*Expectation of Life at Age x*
Start Age	End Age	q_x	l_x	d_x	L_x	T_x	e_x
30	35	0.00577	97,696	564	487,130	4,723,539	48.3
35	45	0.01979	97,132	1,922	962,882	4,236,409	43.6
45	55	0.04303	95,210	4,097	934,026	3,273,527	34.4
55	65	0.09858	91,113	8,982	872,003	2,339,501	25.7
65	75	0.21779	82,131	17,887	740,927	1,467,498	17.9
75	85	0.45584	64,244	29,285	505,278	726,571	11.3
85	95	0.79256	34,959	27,707	196,269	221,293	6.3
95	100	0.75441	7,252	5,471	20,388	25,024	3.5
100+		1.00000	1,781	1,781	4,636	4,636	2.6

Unlike O_3-related premature deaths, $PM_{2.5}$-related premature deaths are associated with long-term exposures. We therefore did not assume that these deaths all occur in 2020. The $PM_{2.5}$-related premature deaths avoided and associated life years saved are thus further discounted to account for the lag between the reduction in ambient $PM_{2.5}$ and the corresponding reduction in mortality risk. We used the same 20-year segmented lag structure that is used in the benefit-cost analysis (see Chapter 8).

The most complete estimate of the impacts of $PM_{2.5}$ on life years is calculated using the Pope et al. (2002) C-R function relating all-cause mortality in adults 30 and over with ambient $PM_{2.5}$ concentrations averaged over the periods 1979–1983 and 1999–2000. Use of all-cause mortality is appropriate if there are no differences in the life expectancy of individuals dying from air pollution-related causes and those dying from other causes. The argument that long-term exposure to $PM_{2.5}$ may affect mainly individuals with serious preexisting illnesses is not supported by current empirical studies. For example, the Krewski et al. (2000) ACS reanalysis suggests that the mortality risk is no greater for those with preexisting illness at time of enrollment in the study. Life expectancy for the general population in fact includes individuals with serious chronic illness. Mortality rates for the general population then reflect prevalence of chronic disease, and as populations age the prevalence of chronic disease increases.

The only reason one might use a lower life expectancy is if the population at risk from air pollution was limited solely to those with preexisting disease. Also, note that the OMB Circular A-4 notes that "if QALYs are used to evaluate a lifesaving rule aimed at a population that happens to experience a high rate of disability (i.e., where the rule is not designed to affect the disability), the number of life years saved should not necessarily be diminished simply because the rule saves lives of people with life-shortening disabilities. Both analytic simplicity and fairness suggest that the estimate number of life years saved for the disabled population should be based on average life expectancy information for the relevant age cohorts." As such, use of a general population life expectancy is preferred over disability-specific life expectancies. Our primary life years calculations are thus consistent with the concept of not penalizing individuals with disabling chronic health conditions by assessing them reduced benefits of mortality risk reductions. $PM_{2.5}$-Related life years saved associated with the illustrative 0.07 ppm partial attainment strategy in 2020 are given in Table 7b-17.

Table 7b-17. Estimated $PM_{2.5}$-Related Life Years Saved Associated with Illustrative O_3 NAAQS Attainment Strategy in 2020: Changing from Partial Attainment of the Current O_3 NAAQS to Partial Attainment of an Alternative O_3 NAAQS of 0.07 ppm

Estimated $PM_{2.5}$-Related Life Years Saved (95% CI)*		
	Pope et al (2002)	Laden et al. (2006)
Discounted back to 2020, using a 3 percent discount rate:	4,400 (1,700 - 7,000)	9,900 (5,400 - 14,000)
Discounted back to 2020, using a 7 percent discount rate:	3,000 (1,200 - 4,800)	6,700 (3,700 - 9,800)

*95 percent confidence or credible intervals (CIs) are based on the uncertainty about the coefficient in the mortality C-R functions. All estimates rounded to two significant figures.

For this analysis, direct impacts on life expectancy are measured only through the estimated change in mortality risk based on the Pope et al. (2002) C-R function. The SAB-HES has advised against including additional gains in life expectancy due to reductions in incidence of chronic disease or nonfatal heart attacks (EPA-SAB-COUNCIL-ADV-04-002). Although reductions in these endpoints are likely to result in increased life expectancy, the HES has suggested that the cohort design and relatively long follow-up period in the Pope et al. study should capture any life-prolonging impacts associated with those endpoints. Impacts of CB and nonfatal heart attacks on quality of life will be captured separately in the QALY calculation as years lived with improved quality of life. The methods for calculating this benefit are discussed below.

7b.6.4 Calculating Changes in the Quality of Life Years ($PM_{2.5}$-Related Chronic Morbidity)

In addition to directly measuring the quantity of life gained, measured by life years, it may also be informative to measure gains in the quality of life. The indirect reductions in levels of $PM_{2.5}$ also lead to reductions in serious illnesses that affect quality of life. These include chronic bronchitis (CB) and cardiovascular disease, for which we are able to quantify changes in the incidence of nonfatal heart attacks. To capture these important benefits in the measure of effectiveness, they must first be converted into a life-year equivalent so that they can be combined with the direct gains in life expectancy.

For the cost effectiveness analysis for the PM NAAQS RIA, we developed estimates of the QALYs gained from reductions in the incidence of CB and nonfatal heart attacks associated with reductions in ambient $PM_{2.5}$. In general, QALY calculations require four elements:

1. the estimated change in incidence of the health condition,
2. the duration of the health condition,
3. the quality-of-life weight with the health condition, and
4. the quality-of-life weight without the health condition (i.e., the baseline health state).

The first element is derived using the health impact function approach. The second element is based on the medical literature for each health condition. The third and fourth elements are derived from the medical cost-effectiveness and cost-utility literature. In the following two subsections, we discuss the choices of elements for CB and nonfatal heart attacks.

The preferred source of quality-of-life weights are those based on community preferences, rather than patient or clinician ratings (Gold et al., 1996). Several methods are used to estimate quality-of-life weights. These include rating scale, standard gamble, time trade-off, and person trade-off approaches (Gold, Stevenson, and Fryback, 2002). Only the standard gamble approach is completely consistent with utility theory. However, the time trade-off method has also been widely applied in eliciting community preferences (Gold, Stevenson, and Fryback, 2002).

Quality-of-life weights can be directly elicited for individual specific health states or for a more general set of activity restrictions and health states that can then be used to construct QALY weights for specific conditions (Horsman et al., 2003; Kind, 1996). For this analysis, we used weights based on community-based preferences, using time trade-off or standard gamble when available. In some cases, we used patient or clinician ratings when no community preference-based weights were available. Sources for weights are discussed in more detail below.
Table 7b-18 summarizes the key inputs for calculating QALYs associated with chronic health endpoints.

Table 7b-18. Summary of Key Parameters Used in QALY Calculations for Chronic Disease Endpoints

Parameter	*Value(s)*	*Source(s)*
Discount rate	0.03 (0.07 sensitivity analysis)	Gold et al. (1996), U.S. EPA (2000), U.S. OMB (2003)
Quality of life preference score for chronic bronchitis	0.5 – 0.7	Triangular distribution centered at 0.7 with upper bound at 0.9 (Vos, 1999a) (slightly better than a mild/moderate case) and a lower bound at 0.5 (average weight for a severe case based on Vos [1999a] and Smith and Peske [1994])
Duration of acute phase of acute myocardial infarction (AMI)	5.5 days – 22 days	Uniform distribution with lower bound based on average length of stay for an AMI (AHRQ, 2000) and upper bound based on Vos (1999b).
Probability of CHF post AMI	0.2	Vos, 1999a (WHO Burden of Disease Study, based on Cowie et al., 1997)
Probability of angina post AMI	0.51	American Heart Association, 2003 (Calculated as the population with angina divided by the total population with heart disease)
Quality-of-life preference score for post-AMI with CHF (no angina)	0.80 – 0.89	Uniform distribution with lower bound at 0.80 (Stinnett et al., 1996) and upper bound at 0.89 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with CHF and angina	0.76 – 0.85	Uniform distribution with lower bound at 0.76 (Stinnett et al., 1996, adjusted for severity) and upper bound at 0.85 (Kuntz et al., 1996). Both studies used the time trade-off elicitation method.
Quality-of-life preference score for post-AMI with angina (no CHF)	0.7 – 0.89	Uniform distribution with lower bound at 0.7, based on the standard gamble elicitation method (Pliskin, Stason, and Weinstein, 1981) and upper bound at 0.89, based on the time trade-off method (Kuntz et al., 1996).
Quality-of-life preference score for post-AMI (no angina, no CHF)	0.93	Only one value available from the literature. Thus, no distribution is specified. Source of value is Kuntz et al. (1996).

7b.6.4.1 Calculating QALYs Associated with Reductions in the Incidence of Chronic Bronchitis

CB is characterized by mucus in the lungs and a persistent wet cough for at least 3 months a year for several years in a row. CB affects an estimated 5 percent of the U.S. population (American Lung Association, 1999). For gains in quality of life resulting from reduced incidences of PM-induced CB, discounted QALYs are calculated as

$$DISCOUNTED\ QALY\,GAINED \quad \sum_i \Delta CB_i \times D_i^* \times \; w_i - w_i^{CB}$$

where CB_i is the number of incidences of CB avoided in age interval i, w_i is the average QALY weight for the *i*th age interval, w_i^{CB} is the QALY weight associated with CB in the *i*th age interval, and D_i^* is the discounted duration of life with CB for individuals with onset of disease in the ith age interval, equal to $\int_0^{D_i} e^{-rt}\,dt$, where D_i is the duration of life with CB for individuals with onset of disease the ith age interval.

A limited number of studies have estimated the impact of air pollution on new incidences of CB. Schwartz (1993) and Abbey et al. (1995) provide evidence that long-term PM exposure gives rise to the development of CB in the United States. Only the Abbey et al. (1995) study was used, because it is the only study focusing on the relationship between $PM_{2.5}$ and new incidences of CB. The number of cases of CB in each age interval was derived by applying the impact function from Abbey et al. (1995) to the population in each age interval with the appropriate baseline incidence rate.[7] The effect estimate from the Abbey et al. (1995) study is 0.0137, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.15 for a 10 µg change in $PM_{2.5}$. Table 7b-19 presents the estimated reduction in new incidences of CB associated with the 0.070 ppm partial attainment strategy.

CB is assumed to persist for the remainder of an affected individual's lifespan. Duration of CB will thus equal life expectancy conditioned on having CB. CDC has estimated that COPD (of which CB is one element) results in an average loss of life years equal to 4.26 per COPD death, relative to a reference life expectancy of 75 years (CDC, 2003). Thus, we subtracted 4.26 from the remaining life expectancy for each age group, up to age 75. For age groups over 75, we applied the ratio of 4.26 to the life expectancy for the 65 to 74 year group (0.237) to the life expectancy for the 75 to 84 and 85 and up age groups to estimate potential life years lost and then subtracted that value from the base life expectancy.

[7] Prevalence rates for CB were obtained from the 1999 National Health Interview Survey (American Lung Association, 2002). Prevalence rates were available for three age groups: 18–44, 45–64, and 65 and older. Prevalence rates per person for these groups were 0.0367 for 18–44, 0.0505 for 45–64, and 0.0587 for 65 and older. The incidence rate for new cases of CB (0.00378 per person) was taken directly from Abbey et al. (1995).

Table 7b-19. Estimated Reduction in Incidence of Chronic Bronchitis Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

Age Interval	*Reduction in Incidence (95% Confidence Interval)**
25 – 34	75 (14 – 140)
35 – 44	85 (16 – 150)
45 – 54	80 (15 – 150)
55 – 64	85 (16 – 160)
65 – 74	60 (11 – 110)
75 – 84	30 (6 – 54)
85+	13 (2 – 24)
Total	430 (78 – 770)

*95% confidence intervals are based on the uncertainty surrounding the effect estimate (coefficient) in the CB C-R function. All estimates rounded to two significant figures.

Quality of life with chronic lung diseases has been examined in several studies. In an analysis of the impacts of environmental exposures to contaminants, de Hollander et al. (1999) assigned a weight of 0.69 to years lived with CB. This weight was based on physicians' evaluations of health states similar to CB. Salomon and Murray (2003) estimated a pooled weight of 0.77 based on visual analogue scale, time trade-off, standard gamble, and person trade-off techniques applied to a convenience sample of health professionals. The Harvard Center for Risk Analysis catalog of preference scores reports a weight of 0.40 for severe COPD, with a range from 0.2 to 0.8, based on the judgments of the study's authors (Bell et al., 2001). The Victoria Burden of Disease (BoD) study used a weight of 0.47 for severe COPD and 0.83 for mild to moderate COPD, based on an analysis by Stouthard et al. (1997) of chronic diseases in Dutch populations (Vos, 1999a). Based on the recommendations of Gold et al. (1996), quality-of-life weights based on community preferences are preferred for CEA of interventions affecting broad populations. Use of weights based on health professionals is not recommended. It is not clear from the Victoria BoD study whether the weights used for COPD are based on community preferences or judgments of health professionals. The Harvard catalog score is clearly identified as based on author judgment. Given the lack of a clear preferred weight, we selected a triangular distribution centered at 0.7 with an upper bound at 0.9 (slightly better than a mild/moderate case defined by the Victoria BoD study) and a lower bound at 0.5 based on the Victoria BoD study. We will need additional empirical data on quality of life with chronic respiratory diseases based on community preferences to improve our estimates.

Selection of a reference weight for the general population without CB is somewhat uncertain. It is clear that the general population is not in perfect health; however, there is some uncertainty as to whether individuals' ratings of health states are in reference to a perfect health state or to a generally achievable "normal" health state given age and general health status. The U.S. Public Health Service Panel on Cost Effectiveness in Health and Medicine recommends that "since lives saved or extended by an intervention will not be in perfect health, a saved life year will count as less than 1 full QALY" (Gold et al., 1996). Following Carrothers, Evans, and Graham (2002), we assumed that the reference weight for the general population without CB is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0. Note that the reference weight for the general population is used solely to determine the incremental quality-of-life improvement applied to the duration of life that would have been lived with the chronic disease. For example, if CB has a quality-of-life weight of 0.7 relative to a reference quality-of-life weight of 0.9, then the incremental quality-of-life improvement in 0.2. If the reference quality-of-life weight is 0.95, then the incremental quality-of-life improvement is 0.25. As noted above, the population is assumed to have a reference weight of 1.0 for all life years gained due to mortality risk reductions.

We present discounted QALYs over the duration of the lifespan with CB using a 3 percent discount rate. Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of CB for each age interval.[8] Based on the assumptions defined above, the mean 3 percent discounted QALY gained per incidence of CB for each age interval along with the 95 percent confidence interval resulting from the Monte Carlo simulation is presented in Table 7b-20. Table 7b-20 presents both the undiscounted and discounted QALYs gained per incidence, using a 3 percent discount rate.

[8] Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables. For more details, see Gentile (1998).

Table 7b-20. QALYs Gained per Avoided Incidence of CB

Age Interval		*QALYs Gained per Incidence*	
Start Age	End Age	Undiscounted	Discounted (3%)
25	34	12.15 (4.40-19.95)	6.52 (2.36-10.71)
35	44	9.91 (3.54-16.10)	5.94 (2.12-9.66)
45	54	7.49 (2.71-12.34)	5.03 (1.82-8.29)
55	64	5.36 (1.95-8.80)	4.03 (1.47-6.61)
65	74	3.40 (1.22-5.64)	2.84 (1.02-4.71)
75	84	2.15 (0.77-3.49)	1.92 (0.69-3.13)
85+		0.79 (0.27-1.29)	0.77 (0.26-1.25)

7b.6.4.2 Calculating QALYs Associated with Reductions in the Incidence of Nonfatal Myocardial Infarctions

Nonfatal heart attacks, or acute myocardial infarctions, require more complicated calculations to derive estimates of QALY impacts. The actual heart attack, which results when an area of the heart muscle dies or is permanently damaged because of oxygen deprivation, and subsequent emergency care are of relatively short duration. Many heart attacks result in sudden death. However, for survivors, the long-term impacts of advanced coronary heart disease (CHD) are potentially of long duration and can result in significant losses in quality of life and life expectancy.

In this phase of the analysis, we did not independently estimate the gains in life expectancy associated with reductions in nonfatal heart attacks. Based on recommendations from the SAB-HES, we assumed that all gains in life expectancy are captured in the estimates of reduced mortality risk provided by the Pope et al. (2002) analysis. We estimated only the change in quality of life over the period of life affected by the occurrence of a heart attack. This may understate the QALY impacts of nonfatal heart attacks but ensures that the overall QALY impact estimates across endpoints do not double-count potential life-year gains.

Our approach adapts a CHD model developed for the Victoria Burden of Disease study (Vos, 1999b). This model accounts for the lost quality of life during the heart attack and the possible health states following the heart attack. Figure 7b-1 shows the heart attack QALY model in diagrammatic form.

The total gain in QALYs is calculated as:

DISCOUNTED AMI QALY GAINED

$$\sum_{i} \Delta AMI_i \times D_i^{*AMI} \times \; w_i - w_i^{AMI} \; + \sum_{i} \sum_{j \; 1}^{4} \; \Delta AMI_i \times p_j D_{ij}^{*PostAMI} \times \; w_i - w_{ij}^{postAMI}$$

where AMI_i is the number of nonfatal acute myocardial infarctions avoided in age interval *i*, w_i^{AMI} is the QALY weight associated with the acute phase of the AMI, p_j is the probability of being in the *j*th post-AMI status, $w_{ij}^{postAMI}$ is the QALY weight associated with post-AMI health status *j*, w_i is the average QALY weight for age interval i, $D_i^{*AMI} \quad \int_{t \; 1}^{D_i^{AMI}} e^{-rt} dt$, the discounted value of D_i^{AMI}, the duration of the acute phase of the AMI, and $D_i^{*postAMI} \quad \int_{t \; 1}^{D_i^{postAMI}} e^{-rt} dt$, is the discounted value of $D_{ij}^{PostAMI}$, the duration of post-AMI health status *j*.

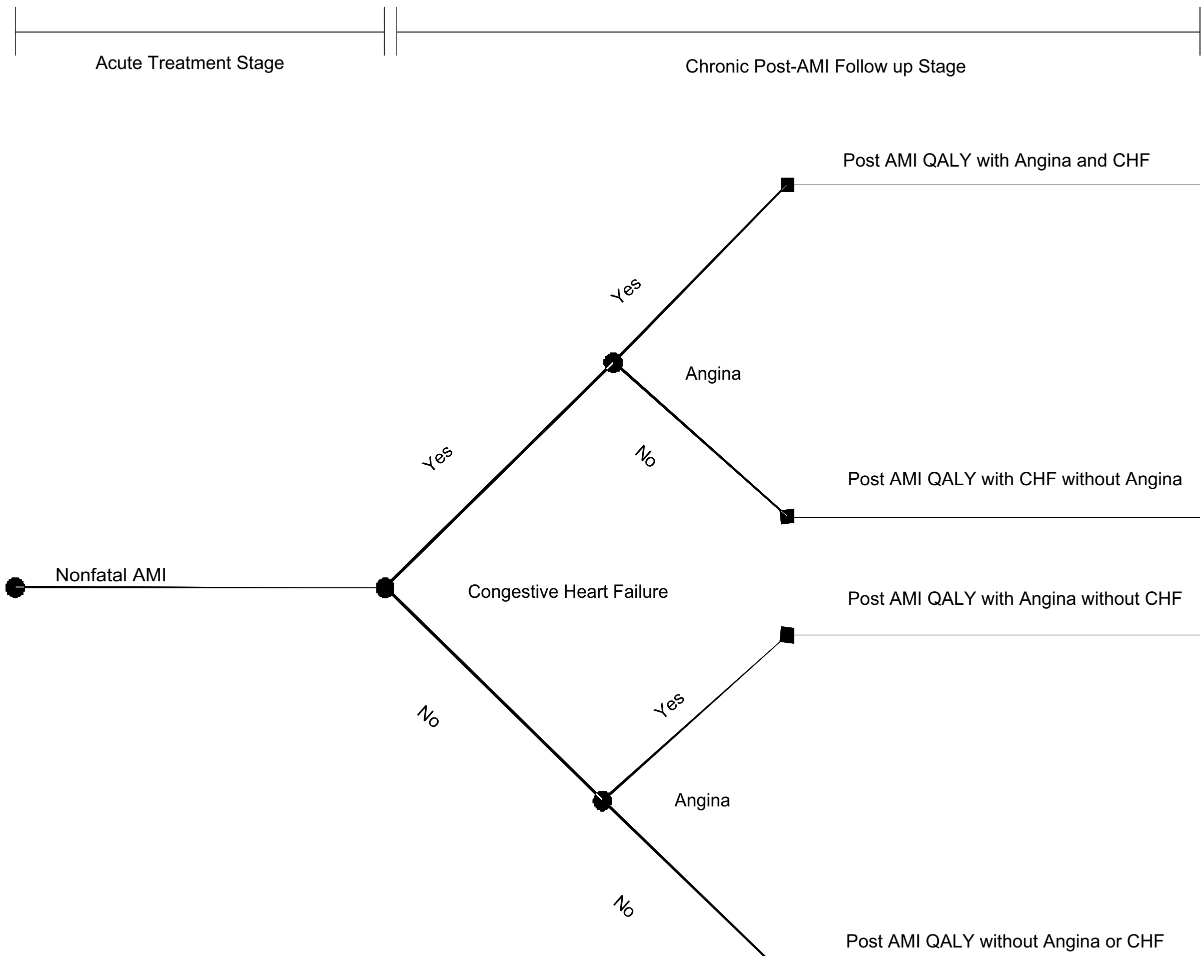

Figure 7b-1. Decision Tree Used in Modeling Gains in QALYs from Reduced Incidence of Nonfatal Acute Myocardial Infarctions

Nonfatal heart attacks have been linked with short-term exposures to $PM_{2.5}$ in the United States (Peters et al., 2001) and other countries (Poloniecki et al., 1997). We used a recent study by Peters et al. (2001) as the basis for the impact function estimating the relationship between $PM_{2.5}$ and nonfatal heart attacks. Peters et al. is the only available U.S. study to provide a specific estimate for heart attacks. Other studies, such as Samet et al. (2000) and Moolgavkar (2000), show a consistent relationship between all cardiovascular hospital admissions, including for nonfatal heart attacks, and PM. Given the lasting impact of a heart attack on longer-term health costs and earnings, we chose to provide a separate estimate for nonfatal heart attacks based on the single available U.S. effect estimate. The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the United States. These studies provide a weight of evidence for this type of effect. Several epidemiologic studies (Liao et al., 1999; Gold et al., 2000; Magari et al., 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other CHDs (Carthenon et al., 2002; Dekker et al., 2000; Liao et al., 1997, Tsuji et al., 1996). As such, significant impacts of PM on heart rate variability are consistent with an increased risk of heart attacks.

The number of avoided nonfatal AMI in each age interval was derived by applying the impact function from Peters et al. (2001) to the population in each age interval with the appropriate baseline incidence rate.[9] The effect estimate from the Peters et al. (2001) study is 0.0241, which, based on the logistic specification of the model, is equivalent to a relative risk of 1.27 for a 10 μg change in $PM_{2.5}$. Table 7b-21 presents the estimated reduction in nonfatal AMI associated with the illustrative Ozone NAAQS attainment strategies.

Table 7b-21. Estimated Reduction in Nonfatal Acute Myocardial Infarctions Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

Age Interval	*Reduction in Incidence (95% Confidence Interval)**
18 – 24	1 (0 – 1)
25 – 34	5 (2 – 7)
35 – 44	32 (17 – 46)
45 – 54	97 (52 – 140)
55 – 64	240 (130 – 350)
65 – 74	290 (150 – 420)
75 – 84	210 (120 – 310)
85+	130 (71 – 190)
Total	1,000 (540 – 1,500)

*95% confidence intervals are based on the uncertainty surrounding the effect estimate (coefficient) in the AMI C-R function.

[9] Daily nonfatal myocardial infarction incidence rates per person were obtained from the 1999 National Hospital Discharge Survey (assuming all diagnosed nonfatal AMI visit the hospital). Age-specific rates for four regions are used in the analysis. Regional averages for populations 18 and older are 0.0000159 for the Northeast, 0.0000135 for the Midwest, 0.0000111 for the South, and 0.0000100 for the West.

Acute myocardial infarction results in significant loss of quality of life for a relatively short duration. The WHO Global Burden of Disease study, as reported in Vos (1999b), assumes that the acute phase of an acute myocardial infarction lasts for 0.06 years, or around 22 days. An alternative assumption is the acute phase is characterized by the average length of hospital stay for an AMI in the United States, which is 5.5 days, based on data from the Agency for Healthcare Research and Quality's Healthcare Cost and Utilization Project (HCUP).[10] We assumed a distribution of acute phase duration characterized by a uniform distribution between 5.5 and 22 days, noting that due to earlier discharges and in-home therapy available in the United States, duration of reduced quality of life may continue after discharge from the hospital. In the period during and directly following an AMI (the acute phase), we assigned a quality of life weight equal to 0.605, consistent with the weight for the period in treatment during and immediately after an attack (Vos, 1999b).

During the post-AMI period, a number of different health states can determine the loss in quality of life. We chose to classify post-AMI health status into four states defined by the presence or absence of angina and congestive heart failure (CHF). This makes a very explicit assumption that without the occurrence of an AMI, individuals would not experience either angina or CHF. If in fact individuals already have CHF or angina, then the quality of life gained will be overstated. We do not have information about the percentage of the population have been diagnosed with angina or CHF with no occurrence of an AMI. Nor do we have information on what proportion of the heart attacks occurring due to PM exposure are first heart attacks versus repeat attacks. Probabilities for the four post-AMI health states sum to one.

Given the occurrence of a nonfatal AMI, the probability of congestive heart failure is set at 0.2, following the heart disease model developed by Vos (1999b). The probability is based on a study by Cowie et al. (1997), which estimated that 20 percent of those surviving AMI develop heart failure, based on an analysis of the results of the Framingham Heart Study.

The probability of angina is based on the prevalence rate of angina in the U.S. population. Using data from the American Heart Association, we calculated the prevalence rate for angina by dividing the estimated number of people with angina (6.6 million) by the estimated number of people with CHD of all types (12.9 million). We then assumed that the prevalence of angina in the population surviving an AMI is similar to the prevalence of angina in the total population with CHD. The estimated prevalence rate is 51 percent, so the probability of angina is 0.51.

Combining these factors leads to the probabilities for each of the four health states as follows:

I. Post AMI with CHF and angina = 0.102

II. Post AMI with CHF without angina = 0.098

III. Post AMI with angina without CHF = 0.408

IV. Post AMI without angina or CHF = 0.392

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[10] Average length of stay estimated from the HCUP data includes all discharges, including those due to death. As such, the 5.5-day average length of stay is likely an underestimate of the average length of stay for AMI admissions where the patient is discharged alive.

Duration of post-AMI health states varies, based in part on assumptions regarding life expectancy with post-AMI complicating health conditions. Based on the model used for established market economies (EME) in the WHO Global Burden of Disease study, as reported in Vos (1999b), we assumed that individuals with CHF have a relatively short remaining life expectancy and thus a relatively short period with reduced quality of life (recall that gains in life expectancy are assumed to be captured by the cohort estimates of reduced mortality risk). Table 7b-22 provides the duration (both discounted and undiscounted) of CHF assumed for post-AMI cases by age interval.

Table 7b-22. Assumed Duration of Congestive Heart Failure

Age Interval		*Duration of Heart Failure (years)*	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	7.11	6.51
25	34	6.98	6.40
35	44	6.49	6.00
45	54	5.31	4.99
55	64	1.96	1.93
65	74	1.71	1.69
75	84	1.52	1.50
85+		1.52	1.50

Duration of health states without CHF is assumed to be equal to the life expectancy of individuals conditional on surviving an AMI. Ganz et al. (2000) note that "Because patients with a history of myocardial infarction have a higher chance of dying of CHD that is unrelated to recurrent myocardial infarction (for example, arrhythmia), this cohort has a higher risk for death from causes other than myocardial infarction or stroke than does an unselected population." They go on to specify a mortality risk ratio of 1.52 for mortality from other causes for the cohort of individuals with a previous (nonfatal) AMI. The risk ratio is relative to all-cause mortality for an age-matched unselected population (i.e., general population). We adopted the same ratios and applied them to each age-specific all-cause mortality rate to derive life expectancies (both discounted and undiscounted) for each age group after an AMI, presented in Table 7b-23. These life expectancies were then used to represent the duration of non-CHF post-AMI health states (III and IV).

Table 7b-23. Assumed Duration of Non-CHF Post-AMI Health States

Age Interval		Post-AMI Years of Life Expectancy (non-CHF)	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	55.5	27.68
25	34	46.1	25.54
35	44	36.8	22.76
45	54	27.9	19.28
55	64	19.8	15.21
65	74	12.8	10.82
75	84	7.4	6.75
85+		3.6	3.47

For the four post-AMI health states, we used QALY weights based on preferences for the combined conditions characterizing each health state. A number of estimates of QALY weights are available for post-AMI health conditions.

The first two health states are characterized by the presence of CHF, with or without angina. The Harvard Center for Risk Analysis catalog of preference scores provides several specific weights for CHF with and without mild or severe angina and one set specific to post-AMI CHF. Following the Victoria Burden of Disease model, we assumed that most cases of angina will be treated and thus kept at a mild to moderate state. We thus focused our selection on QALY weights for mild to moderate angina. The Harvard database includes two sets of community preference-based scores for CHF (Stinnett et al., 1996; Kuntz et al., 1996). The scores for CHF with angina range from 0.736 to 0.85. The lower of the two scores is based on angina in general with no delineation by severity. Based on the range of the scores for mild to severe cases of angina in the second study, one can infer that an average case of angina has a score around 0.96 of the score for a mild case. Applying this adjustment raises the lower end of the range of preference scores for a mild case of angina to 0.76. We selected a uniform distribution over the range 0.76 to 0.85 for CHF with mild angina, with a midpoint of 0.81. The same two studies in the Harvard catalog also provide weights for CHF without angina. These scores range from 0.801 to 0.89. We selected a uniform distribution over this range, with a midpoint of 0.85.

The third health state is characterized by angina, without the presence of CHF. The Harvard catalog includes five sets of community preference-based scores for angina, one that specifies scores for both mild and severe angina (Kuntz et al., 1996), one that specifies mild angina only (Pliskin, Stason, and Weinstein, 1981), one that specifies severe angina only (Cohen, Breall, and Ho, 1994), and two that specify angina with no severity classification (Salkeld, Phongsavan, and Oldenburg, 1997; Stinnett et al., 1996). With the exception of the Pliskin, Stason, and Weinstein score, all of the angina scores are based on the time trade-off method of elicitation. The Pliskin, Stason, and Weinstein score is based on the standard gamble elicitation method. The scores for the nonspecific severity angina fall within the range of the two scores for mild angina specifically. Thus, we used the range of mild angina scores as the endpoints of a uniform distribution. The range of mild angina scores is from 0.7 to 0.89, with a midpoint of 0.80.

For the fourth health state, characterized by the absence of CHF and/or angina, there is only one relevant community preference score available from the Harvard catalog. This score is 0.93, derived from a time trade-off elicitation (Kuntz et al., 1996). Insufficient information is available to provide a distribution for this weight; therefore, it is treated as a fixed value.

Similar to CB, we assumed that the reference weight for the general population without AMI is 0.95. To allow for uncertainty in this parameter, we assigned a triangular distribution around this weight, bounded by 0.9 and 1.0.

Based on the assumptions defined above, we used Monte Carlo simulation methods as implemented in the Crystal Ball™ software program to develop the distribution of QALYs gained per incidence of nonfatal AMI for each age interval. For the Monte Carlo simulation, all distributions were assumed to be independent. The mean QALYs gained per incidence of nonfatal AMI for each age interval is presented in Table 7b-24, along with the 95 percent confidence interval resulting from the Monte Carlo simulation. Table 7b-24 presents both the undiscounted and discounted QALYs gained per incidence.

Table 7b-24. QALYs Gained per Avoided Nonfatal Myocardial Infarction

Age Interval		QALYs Gained per Incidence[a]	
Start Age	*End Age*	*Undiscounted*	*Discounted (3%)*
18	24	4.18 (1.24-7.09)	2.17 (0.70-3.62)
25	34	3.48 (1.09-5.87)	2.00 (0.68-3.33)
35	44	2.81 (0.88-4.74)	1.79 (0.60-2.99)
45	54	2.14 (0.67-3.61)	1.52 (0.51-2.53)
55	64	1.49 (0.42-2.52)	1.16 (0.34-1.95)
65	74	0.97 (0.30-1.64)	0.83 (0.26-1.39)
75	84	0.59 (0.20-0.97)	0.54 (0.19-0.89)
85+		0.32 (0.13-0.50)	0.31 (0.13-0.49)

[a] Mean of Monte Carlo generated distribution; 95% confidence interval presented in parentheses.

7b.6.5 Aggregating Life Expectancy and Quality-of-Life Gains

Given the estimates of changes in life expectancy and quality of life, the next step is to aggregate life expectancy and quality-of-life gains to form an effectiveness measure that can be compared to costs to develop cost-effectiveness ratios. This section discusses the proper characterization of the combined effectiveness measure for the denominator of the cost-effectiveness ratio.

To develop an integrated measure of changes in health, we simply sum together the gains in life years from reduced mortality risk in each age interval with the gains in QALYs from reductions in incidence of chronic morbidity endpoints (CB and acute myocardial infarctions). The resulting measure of effectiveness then forms the denominator in the cost-effectiveness ratio. This combined measure of effectiveness is not a QALY measure in a strict sense, because we have not adjusted life-expectancy gains for preexisting health status (quality of life). It is however, an effectiveness measure that adds a scaled morbidity equivalent to the standard life years calculation. Thus, we term the aggregate measure morbidity inclusive life years, or MILYs. Alternatively, the combined measure could be considered as QALYs with an assumption that the community preference weight for all life-expectancy gains is 1.0. If one considers that this weight might be considered to be a "fair" treatment of those with preexisting disabilities, the effectiveness measure might be termed "fair QALY" gained. However, this implies that all aspects of fairness have been addressed, and there are clearly other issues with the fairness of QALYs (or other effectiveness measures) that are not addressed in this simple adjustment. The MILY measure violates some of the properties used in deriving QALY weights, such as linear substitution between quality of life and quantity of life. However, in aggregating life expectancy and quality-of-life gains, it merely represents an alternative social weighting that is consistent with the spirit of the recent OMB guidance on CEA. The guidance notes that "fairness is important in the choice and execution of effectiveness measures" (OMB, 2003). The resulting aggregate measure of effectiveness will not be consistent with a strict utility interpretation of QALYs; however, it may still be a useful index of effectiveness.

Applying the life expectancies and distributions of QALYs per incidence for CB and AMI to estimated distributions of incidences yields distributions of life expectancy and QALYs gained under the illustrative attainment strategy with a baseline of partial attainment of the current (0.084 ppm) O_3 NAAQS and a control scenario of partial attainment of an alternative 0.070 ppm O_3 NAAQS. These distributions reflect both the quantified uncertainty in estimates of avoided incidence and the quantified uncertainty in QALYs gained per incidence avoided.

Tables 7b-25 and 7b-26 present the discounted life years, QALYs, and MILYs gained, based on each combination of O_3-mortality study, $PM_{2.5}$-mortality study, and life expectancy assumption for O_3-related life years saved used for the analysis of this attainment strategy, using a 3 percent and 7 percent discount rate, respectively.

Table 7b-25. Estimated Gains in Discounted MILYs, Using a 3 Percent Discount Rate, Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	1,300 (400 - 2,200)	4,400 (1,700 - 7,000)	1,970 (270 - 4,700)	870 (220 - 1,800)	8,500 (4,700 - 12,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	1,000 (300 - 1,700)				8,200 (4,500 - 12,000)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	500 (200 - 900)				7,700 (4,100 - 12,000)
Levy et al. (2005)	Pope et al. (2002)	General Population	6,100 (4,100 - 8,100)				13,000 (9,100 - 18,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	4,700 (3,200 - 6,300)				12,000 (7,900 - 16,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	2,700 (1,800 - 3,500)				9,900 (6,200 - 14,000)
Bell et al. (2004)	Laden et al. (2006)	General Population	1,300 (400 - 2,200)	9,900 (5,400 - 14,000)			14,000 (8,500 - 20,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	1,000 (300 - 1,700)				14,000 (8,200 - 19,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	500 (200 - 900)				13,000 (7,800 - 19,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	6,100 (4,100 - 8,100)				19,000 (13,000 - 25,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	4,700 (3,200 - 6,300)				17,000 (12,000 - 23,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	2,700 (1,800 - 3,500)				15,000 (9,900 - 21,000)

*Life years, QALYs, and MILYs are discounted back to 2020. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

Table 7b-26. Estimated Gains in Discounted MILYs, Using a 7 Percent Discount Rate, Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	O3-Related Life Years Gained from Mortality Risk Reductions (95% CI)	PM2.5-Related Life Years Gained from Mortality Risk Reductions (95% CI)	QALYs Gained from Reductions in PM2.5-Related Chronic Bronchitis (95% CI)	QALYs Gained from Reductions in PM2.5-Related Non-Fatal Myocardial Infarction (95% CI)	Total MILYs Gained (95% CI)
Bell et al. (2004)	Pope et al. (2002)	General Population	990 (280 - 1,700)	3,000 (1,200 - 4,800)	1,300 (180 - 3,000)	680 (180 - 1,400)	5,900 (3,300 - 8,700)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	790 (230 - 1,400)				5,700 (3,100 - 8,500)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	450 (130 - 780)				5,400 (2,800 - 8,100)
Levy et al. (2005)	Pope et al. (2002)	General Population	4,600 (3,100 - 6,100)				9,500 (6,600 - 13,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	3,700 (2,500 - 4,900)				8,600 (5,800 - 12,000)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	2,200 (1,500 - 2,900)				7,100 (4,400 - 10,000)
Bell et al. (2004)	Laden et al. (2006)	General Population	990 (280 - 1,700)	6,700 (3,700 - 9,800)			9,700 (5,900 - 13,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	790 (230 - 1,400)				9,500 (5,700 - 13,000)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	450 (130 - 780)				9,200 (5,400 - 13,000)
Levy et al. (2005)	Laden et al. (2006)	General Population	4,600 (3,100 - 6,100)				13,000 (9,400 - 17,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	3,700 (2,500 - 4,900)				12,000 (8,600 - 16,000)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	2,200 (1,500 - 2,900)				11,000 (7,200 - 15,000)

*Life years, QALYs, and MILYs are discounted back to 2020. 95% confidence or credible intervals (CIs) around the point estimates are based on the uncertainty surrounding the effect estimates (coefficients) in the C-R functions and, for QALYs and MILYs, the uncertainty surrounding the quality of life weights. All estimates rounded to two significant figures.

7b.6.6 Estimating the Avoided Costs of Chronic Illness

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. As noted above (see Section 7b.4.1), our estimate of costs in the numerator is net of the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). Among the morbidity costs subtracted from the direct costs of controls in the numerator are the avoided costs of illness (COI) associated with $PM_{2.5}$-related CB and nonfatal AMI.

Avoided costs for CB and nonfatal AMI are based on estimates of lost earnings and medical costs.[11] Using age-specific annual lost earnings and medical costs estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a lifetime present discounted value (in 2006$) due to CB of $185,774 for someone between the ages of 27 and 44; $121,177 for someone between the ages of 45 and 64; and $14,293 for someone over 65. The corresponding age-specific estimates of lifetime present discounted value (in 2006$) using a 7 percent discount rate are $105,974, $89,506, and $11,641, respectively. These estimates assumed that 1) lost earnings continue only until age 65, 2) medical expenditures are incurred until death, and 3) life expectancy is unchanged by CB.

Because the costs associated with a myocardial infarction extend beyond the initial event itself, we consider costs incurred over several years. Using age-specific annual lost earnings estimated by Cropper and Krupnick (1990) and a 3 percent discount rate, we estimated a present discounted value in lost earnings (in 2006$) over 5 years due to a myocardial infarction of $10,758 for someone between the ages of 25 and 44, $15,856 for someone between the ages of 45 and 54, and $91,647 for someone between the ages of 55 and 65. The corresponding age-specific estimates of lost earnings (in 2006$) using a 7 percent discount rate are $9,631, $14,195, and $82,051, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for populations under 25 or over 65. Thus, we do not include lost earnings in the cost estimates for these age groups.

Two estimates of the direct medical costs of myocardial infarction are used. The first estimate is from Wittels, Hay, and Gotto (1990), which estimated expected total medical costs of MI over 5 years to be $51,211 (in 1986$) for people who were admitted to the hospital and survived hospitalization (there does not appear to be any discounting used). Using the CPI-U for medical care, the Wittels estimate is $141,124 in year 2006$. This estimated cost is based on a medical cost model, which incorporated therapeutic options, projected outcomes, and prices (using "knowledgeable cardiologists" as consultants). The model used medical data and medical

[11] Gold et al. (1996) recommend not including lost earnings in the cost-of-illness estimates, suggesting that in some cases, they may be already be counted in the effectiveness measures. However, this requires that individuals fully incorporate the value of lost earnings and reduced labor force participation opportunities into their responses to time-tradeoff or standard-gamble questions. For the purposes of this analysis and for consistency with the way costs-of-illness are calculated for the benefit-cost analysis, we have assumed that individuals do not incorporate lost earnings in responses to these questions. This assumption can be relaxed in future analyses with improved understanding of how lost earnings are treated in preference elicitations.

decision algorithms to estimate the probabilities of certain events and/or medical procedures being used. The second estimate is from Russell et al. (1998), which estimated first-year direct medical costs of treating nonfatal myocardial infarction of $15,540 (in 1995$), and $1,051 annually thereafter. Converting to year 2006$, that would be $28,787 for a 5-year period (without discounting).

The two estimates from these studies are substantially different, and we have not adequately resolved the sources of differences in the estimates. Because the wage-related opportunity cost estimates from Cropper and Krupnick (1990) cover a 5-year period, we used estimates for medical costs that similarly cover a 5-year period. We used a simple average of the two 5-year estimates, or $84,956, and add it to the 5-year opportunity cost estimate. The resulting estimates are given in Table 7b-27.

Table 7b-27. Estimated Costs Over a 5-Year Period (in 2006$) of a Nonfatal Myocardial Infarction

Age Group	Opportunity Cost	Medical Cost[a]	Total Cost
0 – 24	$0	$84,956	$84,956
25-44	$10,757b	$84,956	$95,714
45 – 54	$15,856[b]	$84,956	$100,812
55 – 65	$91,647[b]	$84,956	$176,603
>65	$0	$84,956	$84,956

[a] An average of the 5-year costs estimated by Wittels, Hay, and Gotto (1990) and Russell et al. (1998).

[b] From Cropper and Krupnick (1990), using a 3 percent discount rate.

The total avoided COI by age group associated with the reductions in CB and nonfatal acute myocardial infarctions (using a 3 percent discount rate) is provided in Table 7b-28. The total avoided COI associated with this illustrative attainment strategy (using a 3 percent discount rate) is about $172 million. Note that these estimates do not include any direct avoided medical costs associated with premature mortality. Nor do they include any medical costs that occur more than 5 years from the onset of a nonfatal AMI. Therefore, they are likely underestimates of the true avoided COI associated with this illustrative attainment strategy.

Table 7b-28. Avoided Costs of Illness Associated with Reductions in Chronic Bronchitis and Nonfatal Acute Myocardial Infarctions Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020

	Avoided Cost of Illness (in millions of 2006$)	
Age Range	*Chronic Bronchitis*	*Nonfatal Acute Myocardial Infarction*
18-24	—	$0.07
25-34	$17	$0.4
35-44	$19	$3
45-54	$12	$9.8
55-64	$13	$42
65-74	$1.1	$24
75-84	$0.5	$18
85+	$0.2	$11
Total	$63	$110

7b.6.7 Cost-Effectiveness Ratios

Construction of cost-effectiveness ratios requires estimates of effectiveness (in this case measured by lives saved, life years gained, or MILYs gained) in the denominator and estimates of costs in the numerator. As noted above (see Section 7b.4.1), the estimate of costs in the numerator should include both the direct costs of the controls necessary to achieve the reduction in ambient O_3 (and, indirectly, $PM_{2.5}$) and the avoided costs (cost savings) associated with the reductions in morbidity (Gold et al., 1996). In general, because reductions in air pollution do not require direct actions by the affected populations, there are no specific costs to affected individuals (aside from the overall increases in prices that might be expected to occur as control costs are passed on by affected industries). Likewise, because individuals do not engage in any specific actions to realize the health benefit of the pollution reduction, there are no decreases in utility (as might occur from a medical intervention) that need to be adjusted for in the denominator. Thus, the elements of the numerator are direct costs of controls minus the avoided COI associated with CB and nonfatal AMI. In addition, to account for the value of reductions in O_3- and $PM_{2.5}$-related acute health impacts and non-health benefits, we netted out the monetized value of these benefits from the numerator to yield a "net cost" estimate. For the MILY aggregate effectiveness measure, the denominator is simply the sum of (O_3- and $PM_{2.5}$-related) life years gained from increased life expectancy and QALYs gained from the ($PM_{2.5}$-related) reductions in CB and nonfatal AMI. The separate O_3- and $PM_{2.5}$-related inputs to the denominators of the cost-effectiveness ratios are summarized above in Tables 7b-25 through 7b-26. The cost-effectiveness ratios and 95 percent confidence (credible) intervals resulting from all of the sources of uncertainty considered, using Monte Carlo procedures as implemented in the Crystal Ball™ software program and incorporating both the O_3- and $PM_{2.5}$-related benefits are shown in the tables below. Tables 7b-29 and 7b-30 show cost per life saved, using a 3 percent and 7 percent discount rate, respectively. Tables 7b-31 and 7b-32 show cost per life year saved at the two discount rates; and Tables 7b-33 and 7b-34 show cost per MILY gained.

Table 7b-29. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related Life Saved Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Saved* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	$4.5 ($2.7 - $8.7)
Bell et al. (2004)	Laden et al. (2006)	$2.3 ($1.5 - $3.8)
Levy et al. (2005)	Pope et al. (2002)	$2.3 ($1.7 - $3.4)
Levy et al. (2005)	Laden et al. (2006)	$1.5 ($1.1 - $2.2)

*The 3 percent discounted cost of the regulation is estimated to be $2.6 billion. $PM_{2.5}$-related avoided deaths are discounted back to 2020. O_3-related deaths are assumed to occur in 2020.

**95 percent confidence or credible intervals incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 7b-30. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related Life Saved Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Saved* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	$5.4 ($3.2 - $9.9)
Bell et al. (2004)	Laden et al. (2006)	$2.7 ($1.8 - $4.5)
Levy et al. (2005)	Pope et al. (2002)	$2.6 ($1.9 - $3.8)
Levy et al. (2005)	Laden et al. (2006)	$1.8 ($1.3 - $2.6)

*The 7 percent discounted cost of the regulation is estimated to be $2.8 billion. $PM_{2.5}$-related avoided deaths are discounted back to 2020. O_3-related deaths are assumed to occur in 2020.

**95 percent confidence or credible intervals incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 7b-31. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related Life Year Saved Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Year Saved* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	General Population	$0.42 ($0.25 - $0.81)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$0.45 ($0.26 - $0.89)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.50 ($0.28 - $1)
Levy et al. (2005)	Pope et al. (2002)	General Population	$0.22 ($0.16 - $0.32)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$0.25 ($0.18 - $0.38)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.33 ($0.22 - $0.54)
Bell et al. (2004)	Laden et al. (2006)	General Population	$0.21 ($0.13 - $0.35)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$0.21 ($0.14 - $0.36)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.22 ($0.14 - $0.38)
Levy et al. (2005)	Laden et al. (2006)	General Population	$0.14 ($0.1 - $0.2)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$0.16 ($0.11 - $0.23)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.18 ($0.12 - $0.29)

*The 3 percent discounted cost of the regulation is estimated to be $2.6 billion. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020. O_3-related deaths are assumed to occur in 2020.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 7b-32. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related Life Year Saved Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Million $) per Life Year Saved* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	General Population	$0.67 ($0.39 - $1.2)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$0.71 ($0.41 - $1.4)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.79 ($0.44 - $1.6)
Levy et al. (2005)	Pope et al. (2002)	General Population	$0.33 ($0.24 - $0.47)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$0.37 ($0.26 - $0.55)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.49 ($0.33 - $0.78)
Bell et al. (2004)	Laden et al. (2006)	General Population	$0.33 ($0.21 - $0.55)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$0.34 ($0.22 - $0.56)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.35 ($0.23 - $0.6)
Levy et al. (2005)	Laden et al. (2006)	General Population	$0.22 ($0.16 - $0.31)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$0.24 ($0.17 - $0.34)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.28 ($0.19 - $0.42)

*The 7 percent discounted cost of the regulation is estimated to be $2.8 billion. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020. O_3-related deaths are assumed to occur in 2020.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 7b-33. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related MILY Gained Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 3 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Million $) per MILY Gained* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	General Population	$0.27 ($0.17 - $0.46)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$0.28 ($0.18 - $0.49)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.30 ($0.19 - $0.53)
Levy et al. (2005)	Pope et al. (2002)	General Population	$0.17 ($0.12 - $0.24)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$0.19 ($0.14 - $0.28)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.23 ($0.16 - $0.35)
Bell et al. (2004)	Laden et al. (2006)	General Population	$0.16 ($0.11 - $0.26)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$0.17 ($0.11 - $0.27)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.17 ($0.12 - $0.28)
Levy et al. (2005)	Laden et al. (2006)	General Population	$0.12 ($0.09 - $0.17)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$0.13 ($0.09 - $0.18)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.15 ($0.1 - $0.22)

*The 3 percent discounted cost of the regulation is estimated to be $2.6 billion. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020. All QALYs are discounted back to 2020. O_3-related deaths are assumed to occur in 2020.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

Table 7b-34. Estimated Net Cost (2006$) per O_3- and $PM_{2.5}$-Related MILY Gained Under an Illustrative Strategy of Changing from Partial Attainment of the Current (0.084 ppm) O_3 NAAQS to Partial Attainment of an Alternative 0.070 ppm O_3 NAAQS in 2020, Using a 7 Percent Discount Rate

O_3 Mortality Study	$PM_{2.5}$ Mortality Study	Life Expectancy Assumption for O_3-Related Mortality	Cost Effectiveness Ratio: Net Cost (in Million $) per MILY Gained* (95% CI)**
Bell et al. (2004)	Pope et al. (2002)	General Population	$0.43 ($0.27 - $0.73)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Average COPD	$0.45 ($0.28 - $0.77)
Bell et al. (2004)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.48 ($0.29 - $0.86)
Levy et al. (2005)	Pope et al. (2002)	General Population	$0.26 ($0.19 - $0.37)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Average COPD	$0.29 ($0.2 - $0.41)
Levy et al. (2005)	Pope et al. (2002)	Subpopulation with Severe COPD	$0.35 ($0.24 - $0.54)
Bell et al. (2004)	Laden et al. (2006)	General Population	$0.26 ($0.17 - $0.41)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Average COPD	$0.26 ($0.18 - $0.42)
Bell et al. (2004)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.27 ($0.18 - $0.44)
Levy et al. (2005)	Laden et al. (2006)	General Population	$0.18 ($0.14 - $0.26)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Average COPD	$0.20 ($0.14 - $0.28)
Levy et al. (2005)	Laden et al. (2006)	Subpopulation with Severe COPD	$0.23 ($0.16 - $0.33)

*The 7 percent discounted cost of the regulation is estimated to be $2.8 billion. All life years are discounted back to the year of death. $PM_{2.5}$-related avoided deaths are discounted back to 2020. All QALYs are discounted back to 2020. O_3-related death are assumed to occur in 2020.

**95 percent confidence or credible intervals (CIs) incorporate uncertainty surrounding the O_3 and $PM_{2.5}$ coefficients in the mortality and morbidity C-R functions as well as the uncertainty surrounding unit values of morbidity endpoints. All estimates rounded to two significant figures.

7b.7 Conclusions

We estimated the effectiveness of several illustrative O_3 NAAQS attainment strategies based on reductions in premature deaths and, in the case of the one strategy for which we were able to estimate both direct O_3-related benefits and indirect $PM_{2.5}$-related co-benefits, incidence of chronic disease. We measured effectiveness using several different metrics, including lives saved, life years saved, and QALYs gained (for improvements in quality of life due to reductions in incidence of chronic disease). We suggested a new metric for aggregating life years saved and improvements in quality of life, morbidity inclusive life years (MILY) which assumes that society assigns a weight of one to years of life extended regardless of preexisting disabilities or chronic health conditions. As noted above, however, the cost effectiveness metrics presented for all but one of the illustrative O_3 NAAQS attainment strategies omit the $PM_{2.5}$-related co-benefits and are therefore likely to understate the cost effectiveness of those strategies

CEA of environmental regulations that have substantial public health impacts may be informative in identifying programs that have achieved cost-effective reductions in health impacts and can suggest areas where additional controls may be justified. However, the overall efficiency of a regulatory action can only be judged through a complete benefit-cost analysis that takes into account all benefits and costs, including both health and non-health effects. The benefit-cost analysis for the O_3 NAAQS attainment strategies, provided in Chapter 9, shows that the attainment strategies we modeled have potentially large net benefits, indicating that implementation of the revised O_3 NAAQS will likely result in improvements in overall public welfare.

7b.8 References

Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancuren, and P.K. Mills. 1995. "Estimated Long-Term Ambient Concentrations of PM(10) and Development of Respiratory Symptoms in a Nonsmoking Population." *Archives of Environmental Health* 50(2): 139-152.

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

American Lung Association. 2002. *Trends in Chronic Bronchitis and Emphysema: Morbidity and Mortality*. American Lung Association, Best Practices and Program Services, Epidemiology and Statistics Unit.

American Heart Association. 2003. Heart Disease and Stroke Statistics—2003 Update. Dallas, Texas: American Heart Association.

Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. 2004. Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3): Report of a WHO task group. Copenhagen, Denmark: World Health Organization.

Bala, M.V., and G.A. Zarkin. 2000. "Are QALYs an Appropriate Measure for Valuing Morbidity in Acute Diseases?" *Health Economics* 9:177-180.

Bell, C.M., R.H. Chapman, P.W. Stone, E.A. Sandberg, and P.J. Neumann. 2001. "An Off-the-Shelf Help List: A Comprehensive Catalog of Preference Scores from Published Cost-Utility Analyses." *Medical Decision Making* 21:288-94.

Bleichrodt, H., P.P. Wakker, and M. Johannesson. 1996. "Characterizing QALYs by Risk Neutrality." *Journal of Risk and Uncertainty* 15:107-114.

Brock, D.W. 2002. "Chapter 14.3: Fairness and Health." In *Summary Measures of Population Health: Concepts, Ethics, Measurement and Applications*, C.J.L. Murray, J.A. Salomon, C.D. Mathers, and A.D. Lopez (eds.). Geneva: World Health Organization.

Carrothers, T. J., J.S. Evans, and J.D. Graham. 2002. "The Lifesaving Benefits of Enhanced Air Quality." Harvard Center for Risk Analysis Working Paper.

Carnethon, M.R., D. Liao, G.W. Evans, W.E. Cascio, L.E. Chambless, W.D. Rosamond, and G. Heiss. 2002. "Does the Cardiac Autonomic Response to Postural Change Predict Incident Coronary Heart Disease and Mortality? The Atherosclerosis Risk in Communities Study." *American Journal of Epidemiology* 155(1):48-56.

Centers for Disease Control and Prevention (CDC) Health, United States. 2003. Table 30. Years of Potential Life Lost before Age 75 for Selected Causes of Death, According to Sex, Race, and Hispanic Origin: United States, Selected Years 1980–2000.

Centers for Disease Control and Prevention (CDC). 2002. *National Vital Statistics Reports* 51(3).

Cohen, D.J., J.A. Breall, and K.K. Ho. 1994. "Evaluating the Potential Cost-Effectiveness of Stenting as a Treatment for Symptomatic Single-Vessel Coronary Disease: Use of a Decision-Analytic Model." *Circulation* 89(4):1859-1874.

Cohen, J.T., J.K. Hammitt, and J.I. Levy. 2003. "Fuels for Urban Transit Buses: A Cost-effectiveness Analysis." *Environmental Science and Technology* 37:1477-1484.

Cowie, M.R., A. Mosterd, D.A. Wood, et al. 1997. "The Epidemiology of Heart Failure." *European Heart Journal* 18:208-25.

Coyle, D., D. Stieb, R.T. Burnett, P. DeCivita, D. Krewski, Y. Chen, and M.J. Thun. 2003. "Impact of Particulate Air Pollution on Quality Adjusted Life Expectancy in Canada." *Journal of Toxicology and Environmental Health, Part A* 66:1847-1863.

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

de Hollander, A.E.M., J.M. Melse, E. Lebret, and P.G.N. Kramers. 1999. "An Aggregate Public Health Indicator to Represent the Impact of Multiple Environmental Exposures." *Epidemiology* 10:606-617.

Dekker, J.M., R.S. Crow, A.R. Folsom, P.J. Hannan, D. Liao, C.A. Swenne, and E.G. Schouten. 2000. "Low Heart Rate Variability in a 2-Minute Rhythm Strip Predicts Risk of Coronary Heart Disease and Mortality From Several Causes: The ARIC Study." *Circulation 2000* 102:1239-1244.

Freeman, A.M., J.K. Hammitt, and P. De Civita. 2002. "On Quality Adjusted Life Years (QALYs) and Environmental/Consumer Safety Valuation." *AERE Newsletter* 22(1):7-12.

Ganz, D.A., K.M. Kuntz, G.A. Jacobson, and J. Avorn. 2000. "Cost-Effectiveness of 3-Hydroxy-3-Methylglutaryl Coenzyme A Reductase Inhibitor Therapy in Older Patients with Myocardial Infarction." *Annals of Internal Medicine* 132:780-787.

Garber, A.M., and C.E. Phelps. 1997. "Economic Foundations of Cost-Effectiveness Analysis." *Journal of Health Economics* 16:1-31.

Gentile, J.E. 1998. *Random Number Generation and Monte Carlo Methods*. New York, NY: Springer Verlag.

Gold, M.R., J.E. Siegel, L.B. Russell, and M.C. Weinstein. 1996. *Cost-effectiveness in Health and Medicine*. New York: Oxford University Press.

Gold, D.R., A. Litonjua, J. Schwartz, E. Lovett, A. Larson, B. Nearing, G. Allen, M. Verrier, R. Cherry, and R. Verrier. 2000. "Ambient Pollution and Heart Rate Variability." *Circulation* 101(11):1267-1273.

Gold, M.R., D. Stevenson, and D.G. Fryback. 2002. "HALYS and QALYS and DALYS, Oh My: Similarities and Differences in Summary Measures of Population Health." *Annual Review of Public Health* 23:115–34.

Hammitt, J.K. 2002. "QALYs versus WTP." *Risk Analysis* 22(5):985-1001.

Harvard Center for Risk Analysis, Catalog of Preference Scores. Available at: http://www.hcra.harvard.edu/pdf/preferencescores.pdf.

Horsman, J., W. Furlong, D. Feeny, and G. Torrance. 2003. "The Health Utilities Index (HUI): Concepts, Measurement Properties, and Applications." *Health and Quality of Life Outcomes* 1:54.

Johnson, F.R., and K. Lievense. 2000. Stated-Preference Indirect Utility and Quality-Adjusted Life Years. Report prepared for Health Canada, July.

Kerridge, R.K., P.P. Glasziou, and K.M. Hillman. 1995. "The Use of "Quality-Adjusted Life Years" (QALYs) to Evaluate Treatment in Intensive Care." *Anaesthia and Intensive Care* 23:322-31.

Kind, P. 1996. The EuroQoL Instrument: An Index of Health-Related Quality of Life. Quality of Life and Pharmacoeconomics in Clinical Trials, Second Edition, B. Spilker (ed.), pp. 191-201. Philadelphia, PA: Lippincott-Raven Publishers.

Krewski, D., R.T. Burnett, M.S. Goldbert, K. Hoover, J. Siemiatycki, M. Jerrett, M. Abrahamowicz, and W.H. White. 2000. *Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality*. Special Report to the Health Effects Institute, Cambridge, MA.

Kuntz, K.M, J. Tsevant, L. Goldman, and M.C. Weinstein. 1996. "Cost-Effectiveness of Routine Coronary Angiography after Acute Myocardial Infarction." *Circulation* 94(5):957-65.

Kunzli, N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horak Jr., V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J-C Vergnaud, and H. Sommer. 2000. "Public-Health Impact of Outdoor and Traffic-Related Air Pollution: A European Assessment." *The Lancet* 356:795-801.

Kunzli, N., S. Medina, R. Kaiser, P. Quenel, F. Horak Jr, and M. Studnicka. 2001. "Assessment of Deaths Attributable to Air Pollution: Should We Use Risk Estimates Based on Time Series or on Cohort Studies?" *American Journal of Epidemiology* 153(11):1050-55.

Liao, D., J. Cai, W.D. Rosamond, R.W. Barnes, R.G. Hutchinson, E.A. Whitsel, P. Rautaharju, and G. Heiss. 1997. "Cardiac Autonomic Function and Incident Coronary Heart Disease: A Population-Based Case-Cohort Study. The ARIC Study. Atherosclerosis Risk in Communities Study." *American Journal of Epidemiology* 145(8):696-706.

Liao, D., J. Creason, C. Shy, R. Williams, R. Watts, and R. Zweidinger. 1999. "Daily Variation of Particulate Air Pollution and Poor Cardiac Autonomic Control in the Elderly." *Environmental Health Perspectives* 107:521-5.

Magari, S.R., R. Hauser, J. Schwartz, P.L. Williams, T.J. Smith, and D.C. Christiani. 2001. "Association of Heart Rate Variability with Occupational and Environmental Exposure to Particulate Air Pollution." *Circulation* 104(9):986-91.

Mannino, D.M., D. E. Dohertya, A. S. Buist. 2006. Global Initiative on Obstructive Lung Disease (GOLD) Classification of Lung Disease and Mortality: Findings from the Atherosclerosis Risk in Communities (ARIC) Study. *Respiratory Medicine* 100: 115-122.

Miller, B.G., and J.F. Hurley. 2003. "Life Table Methods for Quantitative Impact Assessments in Chronic Mortality." *Journal of Epidemiology and Community Health* 57:200-206.

Moolgavkar, S.H. 2000. "Air Pollution and Hospital Admissions for Diseases of the Circulatory System in Three U.S. Metropolitan Areas." *Journal of the Air Waste Management Asso*ciation 50:1199-206.

Murray, C.J.L., J.A. Salomon, C.D. Mathers, and A.D. Lopez. 2002. "Summary Measures of Population Health: Concepts, Ethics, Measurement and Applications." Geneva: World Health Organization.

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

Neumann, P. 2003. "A Web-based Registry of Cost-utility Analyses." *Risk in Perspective* 11(3).

Peters, A., D.W. Dockery, J.E. Muller, and M.A. Mittleman. 2001. "Increased Particulate Air Pollution and the Triggering of Myocardial Infarction." *Circulation* 103:2810-2815.

Pliskin, J.S., D.S. Shepard, and M.C. Weinstein. 1980. "Utility Functions for Life Years and Health Status." *Operations Research* 28:206-224.

Pliskin, J.S., W.B. Stason, and M.C. Weinstein. 1981. "Coronary Artery Bypass Graft Surgery: Clinical Decision Making and Cost-Effective Analysis." *Medical Decision Making* 1(1):10-28.

Poloniecki, J.D., R.W. Atkinson, A.P. de Leon, and H.R. Anderson. 1997. "Daily Time Series for Cardiovascular Hospital Admissions and Previous Day's Air Pollution in London, UK." *Occupational and Environmental Medicine* 54(8):535-40.

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

Rabl, A. 2003. "Interpretation of Air Pollution Mortality: Number of Deaths or Years of Life Lost?" *Journal of the Air and Waste Management Association* 53:41-50.

Russell, M.W., D.M. Huse, S. Drowns, E.C. Hamel, and S.C. Hartz. 1998. "Direct Medical Costs of Coronary Artery Disease in the United States." *American Journal of Cardiology* 81(9):1110-5.

Salkeld, G., P. Phongsavan, and B. Oldenburg. 1997. "The Cost-Effectiveness of a Cardiovascular Risk Reduction Program in General Practice." *Health Policy* 41:105-19.

Salomon, J.A., and C.J.L. Murray. 2003. "A Multi-Method Approach to Measuring Health-State Valuations." *Health Economics*, online.

Samet, J.M., S.L. Zeger, F. Dominici, F. Curriero, I. Coursac, D.W. Dockery, J. Schwartz, and A. Zanobetti. June 2000. The National Morbidity, Mortality and Air Pollution Study: Part II: Morbidity, Mortality and Air Pollution in the United States. Research Report No. 94, Part II. Cambridge, MA: Health Effects Institute.

Schwartz, J. 1993. "Particulate Air Pollution and Chronic Respiratory Disease." *Environmental Research* 62:7-13.

Singer, P., J. McKie, H. Kuhse, J. Richardson, and J. Harris. 1995. "Double Jeopardy and the Use of QALYs in Health Care Allocation." *Journal of Medical Ethics* 21:144-157.

Smith, K.J., and R.R. Pesce. 1994. "Pulmonary Artery Catheterization in Exacerbations of COPD Requiring Mechanical Ventilation: A Cost-Effectiveness Analysis." *Respiratory Care* 39:961-7.

Stinnett, A.A., M.A. Mittleman, M.C. Weinstein, K.M. Kuntz, D.J. Cohen, L.W. Williams, P.A. Goldman, D.O. Staiger, M.G.M. Hunink, J. Tsevat, A.N.A. Tosteson, and L. Goldman. 1996. "The Cost-effectiveness of Dietary and Pharmacologic Therapy for Cholesterol Reduction in Adults." In *Cost-effectiveness in Health and Medicine*, Gold, M.E., J. E. Siegel, L.B. Russell, and M.C. Weinstein (eds.). New York: Oxford University Press.

Stouthard, M.E.A., J.L. Essink-Bot, G.J. Bonsel, J.J. Barendregt, P.G.N. Kramers, H.P.A. Van de Water, and L.J. Gunning-Schepers. 1997. "Disability Weights for Diseases in the Netherlands." Rotterdam: Department of Public Health, Erasmus University Rotterdam.

Suwa, T. J.C. Hogg, K.B. Quinlan, A. Ohgami, R. Vincent, and S.F. van Eeden. 2002. "Particulate Air Pollution Induces Progression of Atherosclerosis." *Journal of the American College of Cardiology* 39:935-942.

Tsuji, H., M.G. Larson, F.J. Venditti, Jr., E.S. Manders, J.C. Evans, C.L. Feldman, and D. Levy. 1996. "Impact of Reduced Heart Rate Variability on Risk for Cardiac Events. The Framingham Heart Study." *Circulation* 94(11):2850-2855.

U.S. Environmental Protection Agency (EPA). 2000. *Guidelines for Preparing Economic Analyses*. EPA 240-R-00-003.

U.S. Environmental Protection Agency (EPA). 2004. Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines.

U.S. Environmental Protection Agency, 2006. Final Regulatory Impact Analysis: $PM_{2.5}$ NAAQS. Prepared by Office of Air and Radiation. Available: http://www.epa.gov/ttn/ecas/ria.html [accessed 10 March 2008].

U.S. Environmental Protection Agency (EPA) Science Advisory Board (SAB). EPA-SAB-COUNCIL-ADV-04-002. March 2004. Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act, 1990-2020: Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis.

U.S. Environmental Protection Agency (EPA) Science Advisory Board (SAB). 2005. EPA's Review of the National Ambient Air Quality Standards for Particulate Matter (Second Draft PM Staff Paper, January 2005). EPA-SAB-CASAC-05-007. June.

U.S. Food and Drug Administration (FDA). 2004. Bar Code Label Requirements for Human Drug Products and Biological Products; Final Rule. Federal Register: February 26, 2004 Volume 69 (38): 9119-9171.

U.S. Office of Management and Budget (OMB). 2003. Circular A-4: Regulatory Analysis, September 17, 2003. Available at: http://www.whitehouse.gov/omb/ circulars/a004/a-4.pdf.

Vos, T. 1999a. Final worksheet VM1 COPD.xls, prepared for Victoria Burden of Disease Study. Available at: http://www.dhs.vic.gov.au/phd/bod/daly.htm.

Vos, T. 1999b. Final worksheet VL2 IHD.xls, prepared for Victoria Burden of Disease Study. Available at: http://www.dhs.vic.gov.au/phd/bod/daly.htm.

Wittels, E.H., J.W. Hay, and A.M. Gotto, Jr. 1990. "Medical Costs of Coronary Artery Disease in the United States." *American Journal of Cardiology* 65(7):432-40.

Appendix 6c: Additional Sensitivity Analyses Related To the Benefits Analysis

The analysis presented in Chapter 6 is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies and the assumptions that are most appropriate to adopt in the face of important uncertainties. The majority of the analytical assumptions used to develop the primary estimates of benefits have been reviewed and approved by EPA's SAB. Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions.

This appendix supplements our primary analysis of benefits with three additional sensitivity calculations. These supplemental estimates examine sensitivity to both valuation issues (e.g., the appropriate income elasticity) and for physical effects issues (e.g., the structure of the cessation lag and the sensitivity of the premature mortality estimate to the presence of a presumed threshold). These supplemental estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. The individual adjustments in the tables should not simply be added together because 1) there may be overlap among the alternative assumptions and 2) the joint probability among certain sets of alternative assumptions may be low.

6c.1 Premature Mortality Cessation Lag Structure

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient $PM_{2.5}$ will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question. The SAB-HES has recognized this lack of direct evidence. However, in early advice, they also note that "although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population" (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9). In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags. The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using "a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions" (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that "an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate" (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its followup advice provided in December 2004, this SAB suggested that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004). The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). The 0-year lag is representative of EPA's assumption in previous RIAs. The 8- and 15-year lags are based on the study periods from the Pope et al. (1995) and Dockery et al. (1993) studies, respectively.[1] However, neither the Pope et al. nor Dockery et al. studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope et al. and Dockery et al. analyses do not supporting or refute the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an

[1]Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

assumed structure. The 8- and 15-year lags implicitly assume that all premature mortalities occur at the end of the study periods (i.e., at 8 and 15 years).

In addition to the simple 8- and 15-year lags, we have added three additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 30 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment. The third sensitivity analysis assumes a negative exponential relationship between reduction in exposure and reduction in mortality risk. This structure is based on an analysis by Röösli et al. (2004), which estimates the percentage of total mortality impact in each period t as

$$\%\ \text{Mortality Reduction(t)}\quad \frac{\left[\,RR-1\ e^{-0.5t}+1\right]-1}{\sum_{t\ \ 1}^{\infty}\left[\,RR-1\ e^{-0.5t}+1\right]-1} \qquad \text{(C.1)}$$

The Röösli et al. (2004) analysis derives the lag structure by calculating the rate constant (–0.5) for the exponential lag structure that is consistent with both the relative risk from the cohort studies and the change in mortality observed in intervention type studies (e.g., Pope et al. [1992] and Clancy et al. [2002]). This is the only lag structure examined that is based on empirical data on the relationship between changes in exposure and changes in mortality.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table J-1. These estimates are based on the value of statistical lives saved approach (i.e., $6.6 million per incidence in 2006$) and are presented for both a 3 and 7 percent discount rate over the lag period.

The results of this sensitivity analyses demonstrate that because of discounting of delayed benefits, the lag structure may also have a large impact on monetized benefits, reducing benefits by 30 percent if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits. For example, the overall impact of moving from the previous 5-year distributed lag to the segmented lag recommended by the SAB-HES in 2004 in the primary estimate is relatively modest, reducing benefits by approximately 5 percent when a 3 percent discount rate is used and 17 percent when a 7 percent discount rate is used. If no lag is assumed, benefits are increased by approximately 10 percent relative to the segmented lag with a 3 percent discount rate and 22 percent with a 7 percent discount rate.

Table 6c-1: Sensitivity of Benefits of Premature Mortality Reductions to Alternative Cessation Lag Structures, Using Pope et al (2002) Effect Estimate

Alternative Lag Structures for PM-Related Premature Mortality		Value (billions of 2006$)[a]	Percent Difference from Base Estimate
None	Incidences all occur in the first year		
	3% discount rate	$3.4	10.4%
	7% discount rate	$3.4	22.5%
8-year	Incidences all occur in the 8th year		
	3% discount rate	$2.8	-10.3%
	7% discount rate	$2.1	-23.7%
15-year	Incidences all occur in the 15th year		
	3% discount rate	$2.2	-27.0%
	7% discount rate	$1.3	-52.5%
Alternative Segmented	20 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20		
	3% discount rate	$3.0	-3.2%
	7% discount rate	$2.6	-6.6%
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5		
	3% discount rate	$3.2	4.9%
	7% discount rate	$3.0	9.4%
Exponential	Incidences occur at an exponentially declining rate following year of change in exposure		
	3% discount rate	$3.2	5.6%
	7% discount rate	$3.1	11.3%

[a] All valuations rounded to two significant figures. This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

6c.2 Threshold Sensitivity Analysis

Chapter 6 presents the results of the $PM_{2.5}$ premature mortality benefits analysis based on an assumed cutpoint in the long-term mortality concentration-response function at 10 µg/m^3, and an assumed cutpoint in the short-term morbidity concentration-response functions at 10 µg/m^3. There is ongoing debate as to whether there exists a threshold below which there would be no benefit to further reductions in $PM_{2.5}$. Some researchers have hypothesized the presence of a threshold relationship. The nature of the hypothesized relationship is the possibility that there exists a PM concentration level below which further reductions no longer yield premature mortality reduction benefits. EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies" (U.S. EPA, 2004b, p. 9-44).

EPA's Science Advisory Board (SAB) that provides advice on benefits analysis methods[2] has been to model premature mortality associated with PM exposure as a non-threshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations.

For these reasons we provide the results of a sensitivity analysis in which we estimate the change in reduction in incidence of $PM_{2.5}$-related premature mortality resulting from changes in the presumed threshold. We also provide a corresponding estimate of the valuation of these changes in incidence.

Table 6c-2: Mortality Threshold Sensitivity Analysis for 0.070 ppm Ozone Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug) 95th Percentile Confidence Intervals Provided in Parentheses [a]

		East	Western U.S. Excluding CA	California	Total
Less Certain That Benefits Are at Least as Large	No Threshold	580 (120--1,000)	56 (15--98)	12 (3.9--19)	640 (140--1,100)
	Threshold at 7.5 µg	570 (130--1,000)	49 (16--81)	11 (3.6--18)	630 (150--1,100)
	Threshold at 10 µg	420 (110--730)	6.3 (2.1--10)	5.4 (2--9)	430 (110--750)
	Threshold at 12 µg	46 (14--79)	0.00 (0.00--0.00)	3.7 (1.2--6.2)	50 (15--85)
More Certain That Benefits are at Least as Large	Threshold at 14 µg	1.0 (0.35--1.7)	0.00 (0.00--0.00)	2.9 (1.0--4.9)	4.0 (1.3--6.6)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns. Estimates do not include South Coast and San Joaquin Air Basins.

[2] The advice from the 2004 SAB-HES (U.S. EPA-SAB, 2004b) is characterized by the following: "For the studies of long-term exposure, the HES notes that Krewski et al. (2000) have conducted the most careful work on this issue. They report that the associations between $PM_{2.5}$ and both all-cause and cardiopulmonary mortality were near linear within the relevant ranges, with no apparent threshold. Graphical analyses of these studies (Dockery et al., 1993, Figure 3, and Krewski et al., 2000, page 162) also suggest a continuum of effects down to lower levels. Therefore, it is reasonable for EPA to assume a no threshold model down to, at least, the low end of the concentrations reported in the studies."

Table 6c-3: Sensitivity of Monetized Benefits of Reductions in Mortality Risk to Assumed Thresholds for 0.070 ppm Partial Attainment Scenario (Using Pope et al., 2002 Effect Estimate with Slope Adjustment for Thresholds Above 7.5 ug, 95th Percentile Confidence Intervals Provided in Parentheses, in billions of 2006$)[a]

			Eastern U.S.	**Western U.S. Excluding CA**	**California**	**Total Nationwide Attainment**
Less Certain that Benefits Are at Least as Large	No Threshold	3%	4.0 ($0.49--$10)	0.40 ($0.05--$0.94)	0.08 ($0.01--$0.19)	4.5 ($0.55--$11)
		7%	3.6 ($0.44--$8.8)	0.36 ($0.05--$0.84)	0.02 ($0.01--$0.17)	4.1 ($0.49--$10)
	Threshold at 7.5 µg	3%	4.0 ($0.49--$10)	0.34 ($0.05--$0.78)	0.08 ($0.01--$0.17)	4.4 ($0.55--$11)
		7%	3.6 ($0.44--$8.6)	0.31 ($0.04--$0.70)	0.07 ($0.01--$0.16)	4.0 ($0.49--$9.5)
	Threshold at 10 µg	3%	3.0 ($0.38--$7.0)	0.04 ($0.01--$0.10)	0.04 ($0.01--$0.09)	3.0 ($0.39--$7.2)
		7%	2.7 ($0.35--$6.3)	0.04 ($0.01--$0.09)	0.03 ($0.00--$0.08)	2.7 ($0.36--$6.5)
	Threshold at 12 µg	3%	0.33 ($0.04--$0.76)	0.00 ($0.00--$0.0)	0.03 ($0.00--$0.06)	0.35 ($0.05--$0.82)
		7%	0.29 ($0.04--$0.68)	0.00 ($0.00--$0.00)	0.02 ($0.00--$0.05)	0.32 ($0.04--$0.73)
More Certain that Benefits Are at Least as Large	Threshold at 14 µg	3%	0.01 ($0.00--$0.02)	0.00 ($0.00--$0.0)	0.02 ($0.00--$0.05)	0.03 ($0.00--$0.06)
		7%	0.01 ($0.00--$0.01)	0.00 ($0.00--$0.00)	0.02 ($0.00--$0.04)	0.03 ($0.00--$0.06)

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns. Estimates do not include South Coast and San Joaquin Air Basins.

6c.3 Income Elasticity of Willingness to Pay

As discussed in Chapter 6, our estimates of monetized benefits account for growth in real GDP per capita by adjusting the WTP for individual endpoints based on the central estimate of the adjustment factor for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility). We examined how sensitive the estimate of total benefits is to alternative estimates of the income elasticities. Table 6c.3 lists the ranges of elasticity values used to calculate the income adjustment factors, while Table 6c.4 lists the ranges of corresponding adjustment factors. The results of this sensitivity analysis, giving the monetized benefit subtotals for the four benefit categories, are presented in Table 6c.5.

Table 6c-4. Ranges of Elasticity Values Used to Account for Projected Real Income Growth[a]

Benefit Category	Lower Sensitivity Bound	Upper Sensitivity Bound
Minor Health Effect	0.04	0.30
Severe and Chronic Health Effects	0.25	0.60
Premature Mortality	0.08	1.00
Visibility[b]	—	—

[a] Derivation of these ranges can be found in Kleckner and Neumann (1999) and Chestnut (1997). COI estimates are assigned an adjustment factor of 1.0.

[b] No range was applied for visibility because no ranges were available in the current published literature.

Table 6c-5. Ranges of Adjustment Factors Used to Account for Projected Real Income Growth[a]

Benefit Category	Lower Sensitivity Bound	Upper Sensitivity Bound
Minor Health Effect	1.018	1.147
Severe and Chronic Health Effects	1.121	1.317
Premature Mortality	1.037	1.591
Visibility[b]	—	—

[a] Based on elasticity values reported in Table C-4, U.S. Census population projections, and projections of real GDP per capita.

[b] No range was applied for visibility because no ranges were available in the current published literature.

Table 6c-6. Sensitivity of Monetized Benefits to Alternative Income Elasticities[a]

Benefit Category	Ozone Analysis		PM Analysis	
	Lower Sensitivity Bound	**Upper Sensitivity Bound**	**Lower Sensitivity Bound**	**Upper Sensitivity Bound**
Minor Health Effect	$48	$48	$8.3	$8.5
Severe and Chronic Health Effects	--	--	$170	$200
Premature Mortality[b]	$340	$520	$2,600	$4,000
Total Benefits[b]	$380	$560	$2,800	$4,200

[a] All estimates rounded to two significant digits. All Benefits Incremental to 080 ppm Partial Attainment Strategy (Millions of 2006$). This table reflects full attainment in all locations of the U.S. except two areas of California. These two areas, which have high levels of ozone, are not planning to meet the current standard until after 2020. The estimates in the table do not reflect benefits for the San Joaquin and South Coast Air Basins.

[b] Using mortality effect estimate from Bell (2004) and mortality effect estimate from Pope et al (2002) to estimate $PM_{2.5}$ mortality at a 3% discount rate.

[c] No range was applied for visibility because no ranges were available in the current published literature.

Consistent with the impact of mortality on total benefits, the adjustment factor for mortality has the largest impact on total benefits. The value of mortality in 2020 ranges from 90 percent to 130 percent of the primary estimate based on the lower and upper sensitivity bounds on the income adjustment factor. The effect on the value of minor and chronic health effects is much less pronounced, ranging from 98 percent to 105 percent of the primary estimate for minor effects and from 93 percent to 106 percent for chronic effects.

6c.4 References

Chestnut, L.G. 1997. "Draft Memorandum: Methodology for Estimating Values for Changes in Visibility at National Parks." April 15.

Chestnut, L.G., and R.D. Rowe. 1990a. *Preservation Values for Visibility Protection at the National Parks: Draft Final Report.* Prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC and Air Quality Management Division, National Park Service, Denver, CO.

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

Clancy, L., P. Goodman, H. Sinclair, and D.W. Dockery. 2002. "Effect of Air-pollution Control on Death Rates in Dublin, Ireland: An Intervention Study." *Lancet* Oct 19;360(9341):1210-4.

Desvousges, W.H., F.R. Johnson, and H.S. Banzhaf. 1998. *Environmental Policy Analysis With Limited Information: Principles and Applications of the Transfer Method (New Horizons in Environmental Economics.)* Edward Elgar Pub: London.

EPA-SAB-COUNCIL-ADV-00-001. October 1999. *The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects*. Part 2.

EPA-SAB-COUNCIL-ADV-99-012. July 1999. *The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects*. Part 1.

EPA-SAB-COUNCIL-ADV-01-004. September 2001. *Review of the Draft Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act 1990-2020: An Advisory by a Special Panel of the Advisory Council on Clean Air Compliance Analysis.*

EPA-SAB-COUNCIL-ADV-04-002. March 2004. *Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act, 1990-2020: Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis.*

Kleckner, N., and J. Neumann. June 3, 1999. "Recommended Approach to Adjusting WTP Estimates to Reflect Changes in Real Income." Memorandum to Jim Democker, US EPA/OPAR.

Roosli M, Kunzli N, Braun-Fahrlander C, Egger M. 2005. "Years of life lost attributable to air pollution in Switzerland: dynamic exposure-response model." *International Journal of Epidemiology* 34(5):1029-35.

U.S. Environmental Protection Agency (EPA). 2004. Air Quality Criteria for Particulate Matter, Volume II. Office of Research and Development. EPA/600/P-99/002bF, October 2004.

Appendix Chapter 6d: Exploring the Effects of Changes in Tropospheric Ozone on UVB

Atmospheric ozone filters harmful solar ultraviolet radiation (UV-B), thereby reducing the amount of UV-B reaching the Earth's surface. The majority of ozone—about 90%—is located in the stratosphere, and the stratospheric ozone layer provides most of this protective filtration. Tropospheric ozone, located at ground level, accounts for the remaining 10% of atmospheric ozone. Although only a portion of ground level ozone can be attributed to anthropogenic sources, it is reasonable to assume that reducing ground level ozone would reduce the UV-B filtration provided, and thus would lead to increases in health effects normally associated with reductions in stratospheric ozone. UV radiation-induced health effects are primarily related to the skin (e.g., melanoma and nonmelanoma skin cancer), eyes (e.g., cataracts), and immune system.

The attached preliminary report entitled "Analysis of the Impact of Emissions Changes on Tropospheric Ozone" represents the EPA's first attempt to develop a methodology for capturing the changes in skin cancers and their economic value that might be associated with changes in tropospheric ozone. This initial effort was designed as a scoping analysis to determine the potential magnitude of impacts, and is not intended to serve as a standard methodology for assessing UVB impacts in future RIAs. This scoping analysis focuses on a scenario reflecting the likely distribution of ground level ozone in the Eastern United States domain under an illustrative set of controls intended to reduce ozone concentrations towards attainment of an ozone standard of 70 parts per billion (ppb), as compared to the current ozone National Ambient Air Quality Standard (NAAQS) for 2020.[1] The report only examines the effects of this reduced UV filtration on incidence of and mortality associated with skin cancers – specifically, basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and cutaneous malignant melanoma (CMM).

The general methodology developed for this draft scoping analysis was applied in four steps. First, changes in ground level UV radiation (for geographical extent) were estimated using the Community Multiscale Air Quality model results as an input to the Tropospheric Ultraviolet – Visible radiation model (TUV). The CMAQ model runs provided data for each of 14 altitude layers for each location on a 12x12 km grid at hourly intervals for 24 hours of each day from June 1, 2020 to August 31, 2020. Using these data, the TUV model produced estimates of the daily integrated dose of UV exposure. Second, population-weighted exposure estimates were derived using county based population projections developed using a cohort-component methodology. Third, the resulting estimates were used in the Atmospheric Health Effects Framework model to quantify expected changes in incidence in and mortality from basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and cutaneous malignant melanoma (CMM) associated with the given change in ground level ozone. Fourth, the resulting health effects were monetized using a combination of estimates of the value of statistical life and willingness to pay to avoid a case of skin cancer.

This research makes use of results from the CMAQ, TUV and AHEF models. These models have all been applied extensively in other contexts but this is their first application to estimate

[1] This scenario was developed for the Ozone NAAQS Proposal and does not match runs produced for the Ozone NAAQS Final.

skin cancer effects associated with changes in tropospheric ozone.[2] While all of these models have been extensively peer reviewed and validated in different contexts, the reviews were focused on different model applications and did not extend necessarily to the current problem.

We subjected this scoping analysis to peer review by five experts external to the Agency, including Dr. Edward DeFabo, George Washington University; Dr. Hugh Ellis, Johns Hopkins University; Dr. Scott Farrow, University of Maryland – Baltimore County; Dr. Randy Kawa, National Atmospheric Sciences Administration; and Dr. Helen Suh, Harvard School of Public Health.[3] Unfortunately, due to time constraints, we were unable to incorporate the recommendations from the reviewers in time for this rule. However, the Agency plans to respond to peer reviewer remarks in the near future as we continue our efforts on exploring this topic.

Although the draft report addresses a number of sources of uncertainty, we recognize that others may remain including, but not limited to, the applicability of epidemiologic studies of long-term UV-B exposures over broad geographic regions to scenarios involving impacts of smaller, more variable, localized changes in ground level ozone; the variation in activity patterns and other factors that determine population exposures and sensitivities to UV-B radiation; as well as the effects of aerosols. These uncertainties have been recognized by the Agency and discussed in Chapter 10 of the most recent Ozone Criteria Document (U.S. EPA, 2006). The Agency will consider whether to conduct additional exploratory analyses related to UVB screening as we continue our efforts to quantify health effects associated with reduced tropospheric ozone in a rigorous and defensible manner.

Because the CMAQ modeling runs used for this scoping analysis do not match those used for the Ozone NAAQS Final Regulatory Impact Assessment (RIA), direct comparisons of the monetized skin cancer effects associated with reduced UV-B filtration presented in this report cannot be made with health benefit results presented in the RIA for the final rule. Still, comparing the results of this scoping analysis with the estimates of benefits presented in the proposal RIA, provides a general sense of the order of magnitude of the resulting effects. The estimates of monetized disbenefits resulting from increased UVB levels due to reduced tropospheric ozone as captured by this scoping analysis amount to approximately 0.3 to 0.6 percent of the monetized health benefits associated with the modeled set of ozone precursor control strategies reported in the proposal RIA.

[2] TUV and AHEF were developed to estimate health effects associated with changes in stratospheric ozone.
[3] The individual reports from each of the peer reviewers are contained in the docket for this rule.

Analysis of the Impact of Emissions Changes on Tropospheric Ozone

DRAFT Report
February 18, 2008

Prepared by:

ICF International

Table of Contents

Introduction

Atmospheric ozone filters harmful solar ultraviolet radiation (UV-B), thereby reducing the amount of the UV-B reaching the Earth's surface. The majority of ozone—about 90%—is located in the stratosphere, and the stratospheric ozone layer provides most of this protective filtration. Tropospheric ozone, located at ground level, accounts for the remaining 10% of atmospheric ozone. Although only a portion of ground level ozone can be attributed to anthropogenic sources, it is reasonable to assume that reducing ground level ozone would reduce the UV-B filtration provided, and thus would lead to increases in health effects normally associated with reductions in stratospheric ozone. UV radiation-induced health effects are primarily related to the skin (e.g., melanoma and nonmelanoma skin cancer), eyes (e.g., cataracts), and immune system.

The purpose of this report is to assess these human health effects of reduced UV filtration associated with the reduction of ground level ozone under an ozone standard of 70 parts per billion (ppb) compared to the current ozone National Ambient Air Quality Standard (NAAQS) for 2020.

The remainder of this paper is organized as follows:

- Section 2 describes the methodology used to carry out this assessment, including modeling using the Tropospheric Ultraviolet-Visible radiation model (TUV) and the U.S. EPA's Atmospheric and Health Effects Framework (AHEF);
- Section 3 presents the results of the analysis, including changes in ground level UV and health effects; and
- Section 4 addresses the uncertainties associated with modeling undertaken for this analysis.

Methodology

1.1. CMAQ Modeling

The inputs for this analysis were generated through Community Multiscale Air Quality (CMAQ) ozone modeling runs. The CMAQ model produced spatial fields of gridded ozone concentrations on an hourly basis for the Eastern United States domain with 12 km horizontal resolution and 14 vertical layers topping out at 16,200 meters.

1.2. TUV Modeling

1.2.1. Tropospheric Ozone Scenarios

The CMAQ model provided ozone concentrations in parts per billion (ppb) for each of the 14 altitude layers given in Table 1. These values are specified for each location (latitude, longitude) on a 12 × 12 km grid (66920 locations) at hourly intervals for 24 hours (UT) of each day from 1

Jun to 31 Aug 2020. Two scenarios are considered with identifiers:

2020bk_v4.5_084_12km.o3_hr_shift_LST, and

2020bk_v4.5_070b_12km.o3_hr_shift_LST.

For brevity, these scenarios will be called 084 and 070, respectively.

In order to model a hypothetical control strategy incremental to attainment of the current standard (84 ppb), EPA approached the analysis in stages. First, EPA identified controls to be included in the baseline. These included current state and federal programs plus controls to attain the current ozone standard and PM2.5 PM standards (see http://www.epa.gov/ttnecas1/ria.html for a complete list of controls). Then, EPA applied additional known controls within geographic areas designed to bring areas predicted to exceed 70 ppb in 2020 into attainment (U.S. EPA, 2008).

Table 1 gives the vertical structure of the model. The 14 layers are bounded by 15 levels defined on unequally spaced modified normalized pressure coordinates (sigma = 1 at the surface, 0 at the top of the model). The actual atmospheric pressures, and corresponding geometric altitudes, are determined by the meteorological input to CMAQ and vary in time and space. Approximate values are given in the table. For the purposes of the radiative transfer calculations, the approximate heights given in Table 1 were used, and sensitivity calculations were made to bracket the effect of this approximation. The last column of Table 1 gives the number of air molecules, per square centimeter, in a vertical column within each layer, and their calculation is described in the following section.

Table 1: Vertical Structure for 14 Layer CMAQ (heights are the top of layer).

Layer Number	Sigma	Approximate Height (m)	Approximate Pressure (mb)	Air column between levels (molecules cm^{-2})
0	1.000	0	1000	—
1	0.995	38	995	9.67×10^{22}
2	0.990	77	991	9.89×10^{22}
3	0.980	154	982	1.94×10^{23}
4	0.960	310	964	3.89×10^{23}
5	0.940	469	946	3.90×10^{23}
6	0.910	712	919	5.85×10^{23}
7	0.860	1,130	874	9.73×10^{23}
8	0.800	1,657	820	1.17×10^{24}
9	0.740	2,212	766	1.17×10^{24}
10	0.650	3,108	685	1.75×10^{24}
11	0.550	4,212	595	1.95×10^{24}

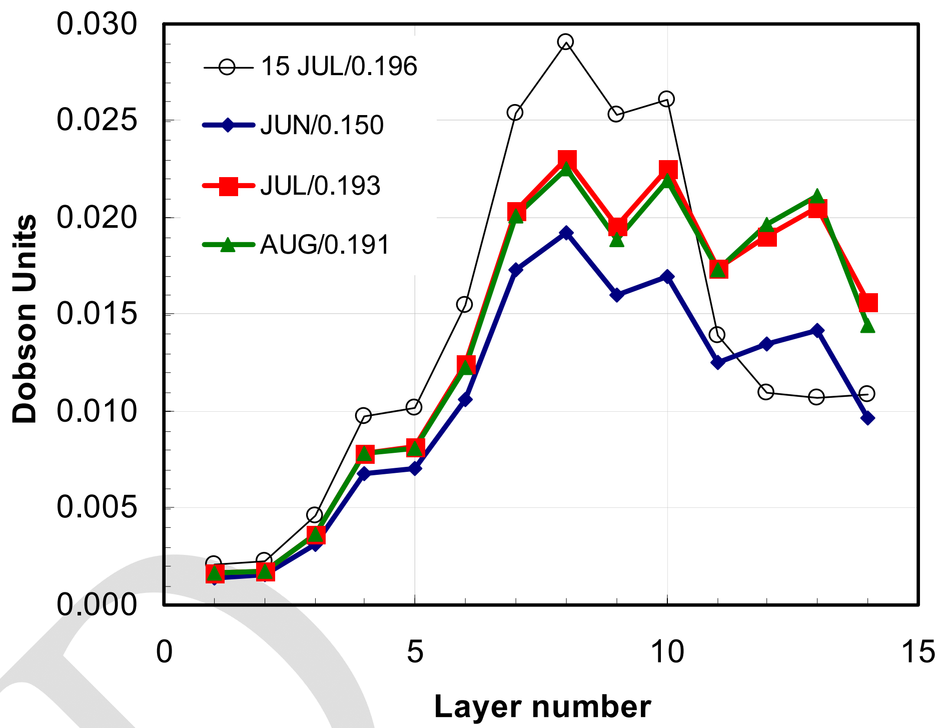
Layer Number	Sigma	Approximate Height (m)	Approximate Pressure (mb)	Air column between levels (molecules cm^{-2})
12	0.400	6,153	460	2.91×10^{24}
13	0.200	9,625	280	3.85×10^{24}
14	0.000	15,674	100	3.58×10^{24}

The detailed CMAQ ozone values were used in the calculations of the UV radiation. However, to illustrate the magnitude of the changes in ozone, Figure 1 shows the concentration changes from the 084 to the 070 CMAQ scenarios, averaged over the entire geographic domain and over hours of all days of each month. Also shown are the values for 15 July (the mid-time of the simulation), since this date will be used in some sensitivity studies in Section 4.3. The largest changes are seen to occur between ca. 500 and 1000 m above the surface (layers 5–7, see Table 1) and are non-negligible even in the highest layers.

Figure 1: Domain-averaged ozone concentration changes (ppb) in each CMAQ layer. Vertically averaged changes (ppb) are given in the legend.

The contribution of each layer to the ozone column change is given in Figure 2. This was obtained by multiplying the concentration changes (ppb) by 10^{-9} times the air column in each corresponding layer (from Table 1), and converting to Dobson Units (DU) by dividing by 2.687×10^{16} molecules cm^{-3} DU^{-1}. The total ozone column change is the sum of the contributions in each layer, and is shown in the figure legend. The small contribution from the lowest levels is due mainly to their small vertical thickness, while the decreasing contribution of the uppermost layers is due to the exponential decrease in air density with altitude. Notably, the highest contributions are from layers 7–10 (ca. 1–3 km altitudes), with non-negligible contributions from the upper troposphere as already noted above.

Figure 2: Domain-averaged ozone column changes (Dobson Units) in each CMAQ layer. The sum of the ozone changes (Dobson Units) is given in the legend, and is the total ozone column change.



The ozone changes shown in Figures 1 and 2 cannot be translated directly into changes of surface UV radiation, because they are averaged over different locations and times. For example, they include night-time values when the UV radiation is non-existent. This can be seen in Table 2, where the domain-averaged ozone changes for 15 July were divided according to whether they occur for solar zenith angels (sza) smaller than 45 degrees (high sun) and lower than 45 degrees (low sun). The table shows that the changes in surface and column values are largest for high sun, consistent with photochemical formation near sources, and coincident with times of highest surface biologically active irradiances. Mid-tropospheric values have a weaker dependence on sza, consistent with long-range transport and a relatively long ozone lifetime.

Table 2: Ozone change statistics for 15 July 2020, CMAQ scenarios 084-070

		Number of points	Average ozone change (ppb) at surface	Average ozone change (ppb) at level 12 (~ 500 mb)	Average ozone column change, Dobson Units
All sza		1,605,600	0.58	0.10	0.20
sza < 45^o	high sun	426,139	0.69	0.11	0.22
45^o < sza < 90^o	low sun	538,529	0.60	0.09	0.19
sza > 90^o	night	640,932	0.50	0.11	0.19

An independent albeit rough estimate of the ozone column (DU) change can be obtained from the concentrations given in Table 2. Considering only the values for sza < 45^o (c.f., the simple rule that UV exposure should be avoided when a person's shadow is shorter than a person's height), even a simple linear average of the ozone changes at the surface and 500 mb yields ~ 0.4 ppb, and can be taken as applicable to the lower half of the atmosphere (below 500 mb). The total atmospheric column of air is about 2.0×10^{25} molecules cm^{-2}, so taking half of this and 0.4 ppb ozone yields 4×10^{15} molecules cm^{-2} of ozone ($1.0 \times 10^{25} \times 0.4 \times 10^{-9}$), or ≈ 0.15 Dobson Units. This is reasonably close to the column value in the table, 0.22 DU, which was calculated within TUV from the full vertical variation of ozone and air concentrations, and included changes above 500 mb as well as an exponential profile of air density which of course gives more weight to the lower altitudes.

1.2.2. TUV Model Calculations

The surface ultraviolet radiation was calculated with the Tropospheric Ultraviolet-Visible (TUV) model developed by Madronich and co-workers at the National Center for Atmospheric Research (NCAR). The TUV model is widely used for the calculation of atmospheric and surface UV radiation including international assessments of the environmental effects of stratospheric ozone depletion (e.g., Madronich et al., 1998), and has been evaluated in numerous model-measurement intercomparison studies (e.g., Koepke et al., 1998; Bais et al., 2003). An early version of TUV, of similar accuracy but lesser flexibility, is used within the CMAQ atmospheric chemistry module to compute photolysis frequencies. The model has been described in the literature (e.g., Madronich and Flocke, 1999) and the latest version (version 4.5, used here) is freely available to the scientific community through NCAR Community Data Portal (http://cdp.ucar.edu).

Several modifications to the TUV model were made for the present purposes, specifically to (i) interface the model with the CMAQ ozone concentrations, and (ii) to speed up the computational time in view of the large number of locations reported by the CMAQ model.

The altitude grid was modified to match the values given in Table 1, then continuing to 16 km and increasing by 2 km to 40 km, and by 5 km to 80 km. These represent altitude levels, while layers (to which the ozone concentrations are applied) are the volume between these levels. The TUV model used the U.S. Standard Atmosphere (USSA, 1976) vertical profiles of temperature

(K), air density and ozone (both molecules cm^{-3}), specified from sea level to 80 km in 1 km increments, and then interpolated to the altitude grid described above. Because the CMAQ model has layers that are both smaller and larger than the standard USSA 1 km grid, some attention was given to proper vertical interpolation of air density. Specifically, the logarithm of the USSA air number density (molecules cm^{-3}) was interpolated linearly to obtain the logarithm of the air density at the CMAQ levels. Then, the vertical air column (molecules cm^{-2}) of each layer was obtained by logarithmic integration:

$$\text{Air column in layer } k = dz\,[\, y(k+1) - y(k)\,] / \ln[\, y(k+1) / y(k)\,]$$

where $dz = z(k+1) - z(k)$ = vertical thickness of the layer. The air column of each layer was then multiplied by the CMAQ ozone concentrations (ppb × 10^{-9}) to yield the ozone column in each layer (molecules cm^{-2}), so overwriting the USSA ozone values for these altitudes. For altitudes above the highest level of Table 1, the interpolated USSA ozone values were used.

For each wavelength interval (see below), the radiative transfer solution was expressed analytically using the delta-Eddington approximation (Joseph et al., 1976) formulated in generalized 2-stream equations (Toon et al., 1989) corrected for atmospheric curvature using a pseudo-spherical approximation (Petropavlovskih, 1995). The resulting set of coupled 2N equations (N = number of layers) was solved by tridiagonal matrix inversion to obtain the spectral irradiance, $I(\lambda)$ in W m^{-2} nm^{-1} for a given wavelength, time, and location. This calculation was repeated for the center of each wavelength interval, for each location, for each hour (on the half-hour) of each day of June, July, and August for each of the two given CMAQ scenarios. The spectral irradiance was multiplied by a biological sensitivity function (action spectrum) $B(\lambda)$, then integrated numerically all wavelengths with non-zero contributions, to obtain the surface biological exposure (biologically effective irradiance) I_{bio} (W m^{-2}). Two different action spectra were considered: (1) the CIE standard erythemal (skin-reddening) spectrum (McKinlay and Diffey, 1987) which forms the basis of the WMO/WHO-recognized UV Index computed operationally in the United States by NOAA and highlighted by the EPA, and (2) the spectrum for the induction of non-melanoma skin cancer in mice, corrected for human skin transmission (deGruijl and van der Leun, 1994). The latter spectrum has been used extensively in the assessments of ozone depletion, and is named SCUP-h (Skin Cancer Utrecht-Philadelphia, reflecting the location of the research groups that originated it), and its sensitivity to ozone changes is quite similar to that of the erythemal spectrum (as shown by Madronich et al., 1998). For brevity, biologically effective irradiances computed from these two spectra are hereafter called I_{ERY} and I_{SCUP}. Values of I_{SCUP} are used in ICF's AHEF model as measures of human exposure to UV radiation.

The TUV wavelength (nm) grid extended from 294 to 330 by 2 nm, to 350 by 5 nm, and to 400 by 10 nm. The higher resolution at the shorter wavelengths is required to represent accurately the absorption by ozone which is strongly dependent on wavelength, while the coarser resolution provides computational efficiency. A resolution of 2 nm in the ozone-dependent region has been show to be sufficiently accurate for photolysis calculations, including $O_3 + h\nu \rightarrow O_2 + O(^1D)$ which has a spectral dependence similar or steeper (and therefore more sensitive to spectral resolution) than the action spectra used here (Madronich and Weller, 1990).

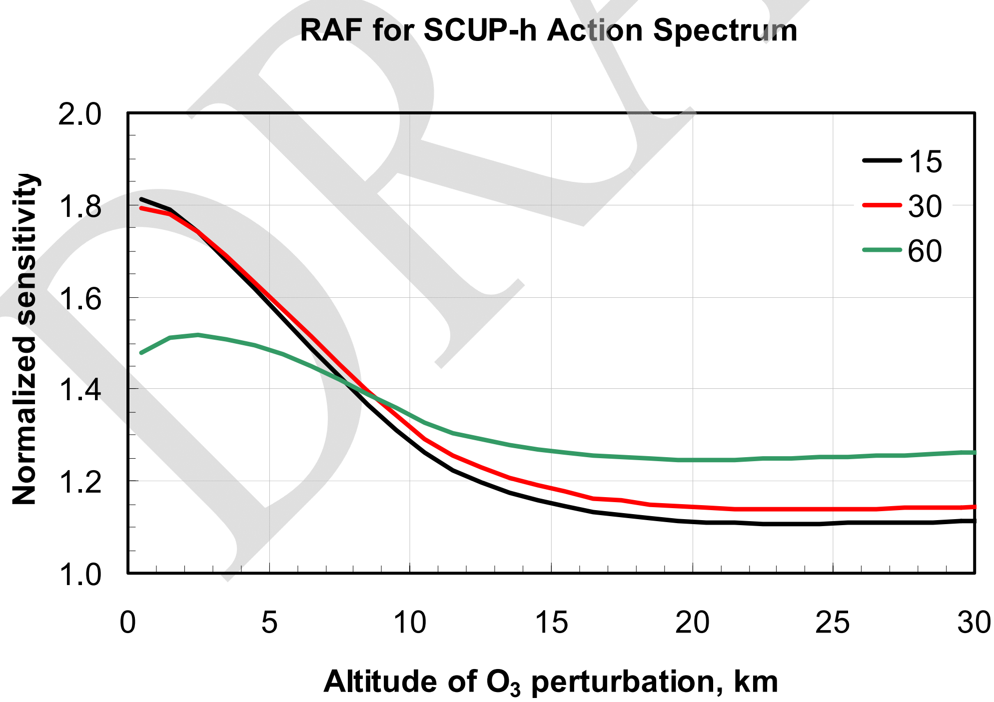
For each location on the 12 × 12 km grid, the values of I_{ERY} and I_{SCUP} were integrated over 24 hours to provide daily integrated doses, and over each month (June, July, and August) to provide monthly integrated values. Otherwise identical calculations were performed for the 070 and 084 scenarios, and the difference between scenarios was computed for each location.

Tropospheric ozone causes a larger change, on a per molecule basis, than stratospheric ozone (Bruhl and Crutzen, 1989), at least for high sun. This is because of coupling between molecular (Rayleigh) scattering and ozone absorption: Scattering increases the tropospheric photon path lengths and therefore increases the probability of absorption by tropospheric absorbers including ozone. Figure 3 shows the normalized sensitivity of SCUP-h weighted UV as a function of the altitude where the ozone perturbation occurs. The normalized sensitivity (also called the Radiation Amplification Factor, RAF) is the % increase in radiation for each % decrease in ozone column. For this plot, a 1 DU of ozone was inserted in a 1 km layer at various altitudes (the altitudes of ozone perturbation in the figure), and the resultant surface UV-SCUP values compared to the reference calculation (without the 1 DU). The RAF is then:

$$\text{RAF} = -\ln(UV_2/UV_1)/\ln(DU_2/DU_1)$$

where the subscripts 2 and 1 refer to the perturbed and reference calculations (Micheletti et al., 2003).

Figure 3: Normalized sensitivity (% for %) of UV-SCUP changes to the altitude at which ozone perturbations are made.



For example, a 0.22 DU increment (from Table 1, 15 July, high sun) represents about 0.06% change in the ozone column (349 DU for the USSA, but actually somewhat different and variable when using the CMAQ values up to 16 km). From Figure 3, a RAF of 1.6–1.7 is reasonable for ozone perturbations in the low-mid troposphere and relatively high sun when UV matters. Multiplying (0.06 % × 1.65), the surface UV-SCUP radiation is expected to change by about 0.1 %. This is the approximated magnitude of the UV-SCUP changes expected between the two CMAQ scenarios.

Of course, the full TUV calculations were done with high spectral resolution (not simple scaling with RAFs), time integration over actual sza values, full vertical distributions of tropospheric ozone given by the CMAQ, and fully coupled scattering-absorption multi-layer radiative transfer. Therefore they are expected to be more accurate, and more firmly anchored in the state-of-the-science.

1.2.3. TUV Results

Detailed maps of UV-SCUP distributions and percent changes are given in Appendix A. Here, the results are summarized in Figure 4 as domain-averaged UV-SCUP percent changes for each day. They range from 0.05 % to 0.16 %, with most values near 0.1 % or slightly higher (note that % changes of the monthly UV increments are not strictly equal to the monthly averages of daily % changes, though they happen to be quite similar). Figure 5 shows the frequency distribution of the monthly increments expressed as percent. The most common value is near zero, and few values above 0.3%. A few negative values were noted. Finally, it should be clear that the data in these figures are not yet weighted by the affected populations, and therefore should be viewed as changes in the physical state of the atmosphere, not as measures of population exposure.

Figure 4: Domain-averaged percent changes in SCUP-weighted daily doses changes between 070 and 084 scenarios

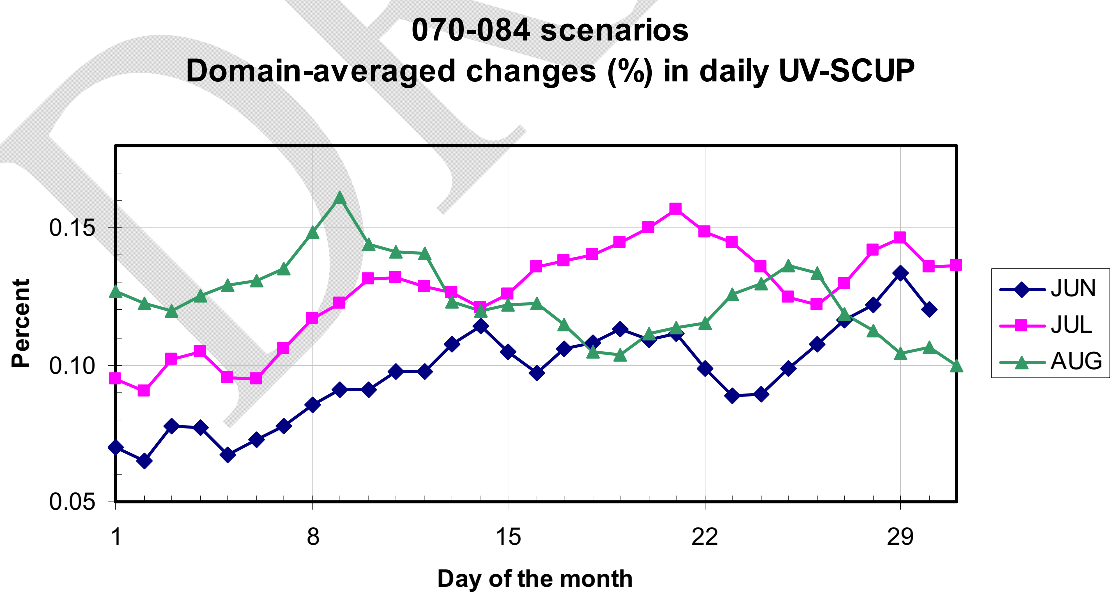
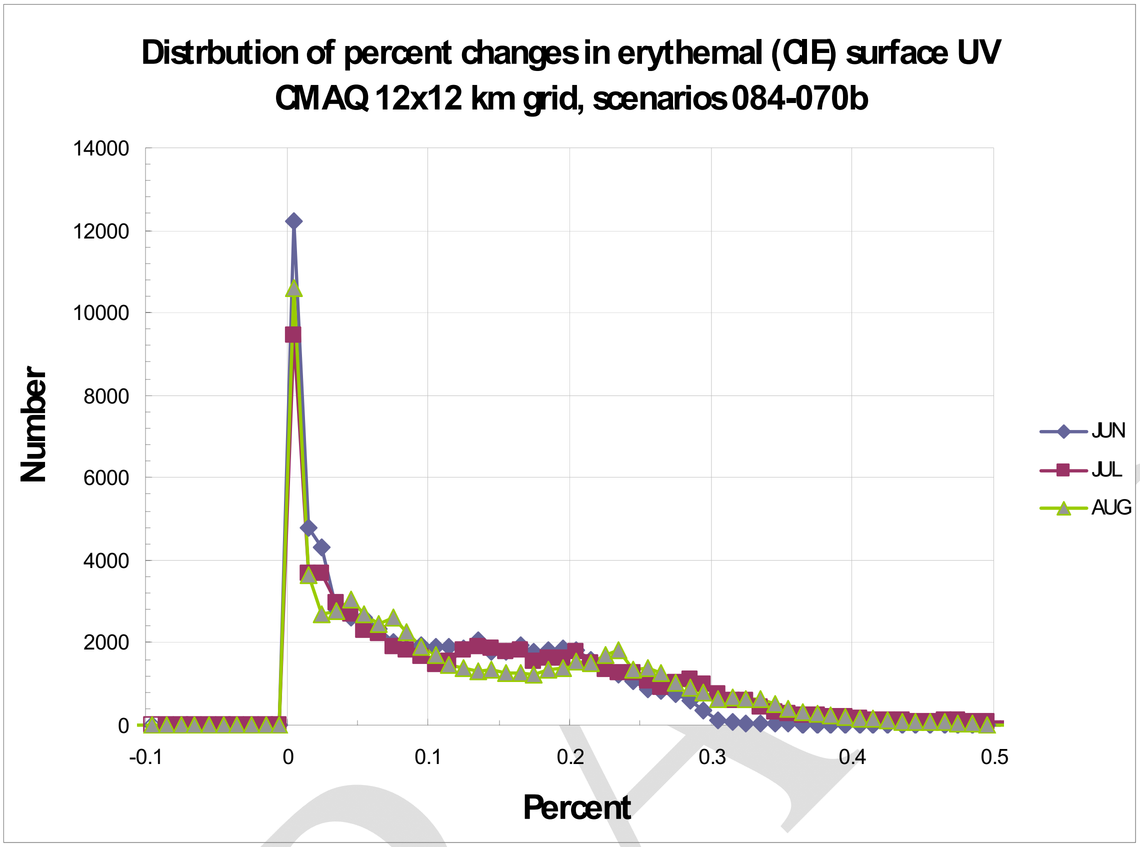


Figure 5: Frequency distribution of percent changes in erythemal surface UV radiation



1.3. Population Adjustments

This analysis required county-based population projections for two purposes: to calculate the population-weighted changes in ground level UV for each latitude band modeled in the AHEF model for the year 2020 and to provide future population projections for the years 2005–2050. Although the U.S. Census Bureau provides population projections, they could not be used for this purpose because the publicly available datasets lack the level of detail needed by the AHEF model: population by county, race, gender, and five-year age cohorts. Existing population projections traditionally used by the AHEF model also could not be used because they cover the entire United States, while the area analyzed by CMAQ model covers all or part of 42 states. To meet the data needs of this analysis, county-based population projections were developed using a simple cohort-component methodology.

1.3.1. Cohort-Component Methodology Overview

The cohort-component methodology is a common technique for projecting population changes over time. In this case, three independent components of population change were used: fertility, mortality, and net international migration (i.e., migrations between U.S. counties and foreign countries). Domestic migration (i.e., migrations between U.S. counties) was not included in this projection exercise for reasons discussed below. To project population changes over time, the population was divided into cohorts that were age-, gender-, and race-specific. Changes due to these three components of change were estimated over time as each cohort was tracked separately, hence the term "cohort-component."

The population of a county in any year *t* as estimated by the model is determined using the following equation:

$$P_t = P_{t-1} + B_t - D_t + NIM_t$$

Equation 1

where:

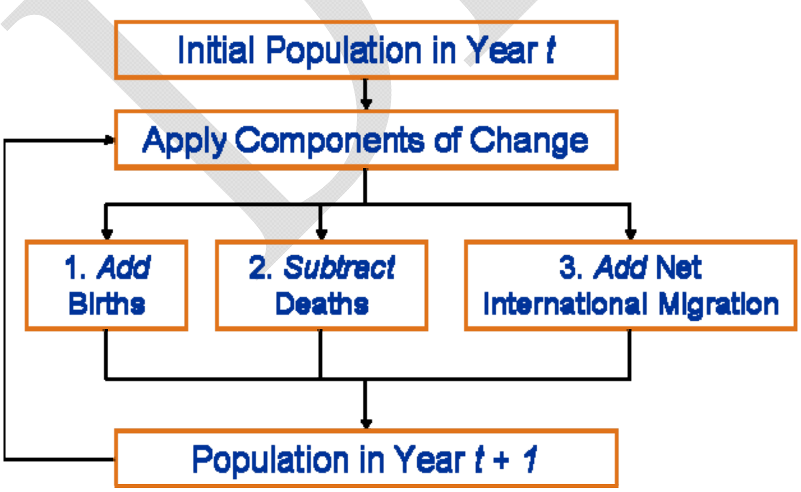
- P_t = Population in year *t*
- P_{t-1} = Population in the previous year
- B_t = Births in year *t*
- D_t = Deaths in year *t*
- NIM_t = Net International Migration in year *t*

Beginning with an initial set of populations, annual components of change were applied in the following process, which were repeated annually until the desired end year was reached:

1. Add births by cohort
2. Deduct deaths by cohort
3. Add net international migration
4. Age population one year and repeat for the next year

This methodology is illustrated in Figure 6 below. The cycle begins with an initial Year 2000 population and is repeated until reaching Year 2100.

Figure 6: Demographic model flow



In the following sections, the methods and data used for the initial population and each component are discussed in greater detail.

1.3.2. Component Data and Methods

Initial Population

In order to use the rates for components of change provided by the U.S. Census Bureau (discussed below), it was necessary to begin with an initial Year 2005 population dataset that was disaggregated using the same cohorts. These cohorts in the rates data are divided into two genders (male and female), 100 age groups (0–99 in one year increments), and four racial groups (White, Black, American Indian or Alaskan Native, and Asian or Pacific Islander). This represents 800 distinct population cohorts (2 genders × 100 ages × 4 bridged race groups). County populations using bridged race and one-year age cohorts were most readily accessible using the Vintage 2006 July 1, 2005 dataset provided by the National Center for Health Statistics (NCHS; 2007).

Fertility and Mortality

For fertility, the number of children born equals the number of women in a given cohort times the average number of children born annually to every 1000 women in that cohort divided by 1000. Because virtually all births occur to women between the ages of 10 and 49, only those cohorts were considered in this model. These births are summed by race and used to create a new age zero cohort. To allocate births between males and females, a historic ratio of 1046 males born for every 1000 females born was calculated and it was assumed that this ratio holds steady. Data from the CDC's "Trend Analysis the Sex Ratio at Birth in the United States" were used to complete this calculation (Matthews and Hamilton 2005).
Similarly, mortality was estimated by multiplying the number of people in a given cohort by the cohort-specific mortality rates. The resulting number of deaths was then subtracted from the cohort. Unlike fertility, all cohorts are subject to mortality. Therefore, mortality rates were applied to each cohort. Although an increasing number of Americans are living to the age of 100 or more, the model assumes 100% mortality after age 99 for the sake of computational efficiency. Even with continued rates of survivorship past this age, the 100-plus age group will remain a miniscule portion of the population (0.02% of national population on July 1, 2005).

For fertility and mortality rates, the U.S. Census Bureau's "Component Assumptions of the Resident Population by Age, Sex, Race, and Hispanic Origin" were used (U.S. Census Bureau 2000). These are the same data used in Census projections. These components of change are associated with the 1990 National Projections and were used in both the 1990 State Projections and the 2000 National Projections. While it would be preferable to use more recent data, at this time components of change based on the 2000 Census have not yet been released.

For both fertility and mortality, the so-called Middle Series of component information was used. Fertility rates were provided in a single file; mortality rates for each component were provided in three different tables, for the years 1999–2010, 2015–2055, and 2060–2100. Projected fertility rates were provided for each year to 2100, but beginning with 2010, mortality rates were provided in five year increments only. We assumed that 2010 mortality rates held steady from 2010–2014, 2015 mortality rates held steady from 2015–2019, and so on.

Net International Migration

The projections for net international migration utilized a simple method based on the Census Bureau's international migration projections for the entire country. These files contain the projected net international migration for each gender, age, and race cohort for the years 2000–2100. Like the fertility and morality rates, these data are part of the Census Bureau's "Component Assumptions of the Resident Population by Age, Sex, Race, and Hispanic Origin" (U.S. Census Bureau 2000). Since the tables "Foreign-born Net Migration to the United States" contain only national level data, it was necessary to allocate the national migrants to the counties. Using 2000 Census data (Summary File 3, Table P22), we determined each county's share of the total population of recent immigrants (i.e., those who entered within the last five years). These county shares were then used to allocate each cohort of immigrants among the nation's counties. The estimated number of immigrants in each cohort was then added to the existing county population of each cohort. This method assumes a constant distribution of recent immigrants based on Year 2000 immigration patterns. While it is likely that new settlement patterns for immigrants will develop in the future, this is the same method the Census Bureau uses for assigning immigrants to states in its state projections (U.S. Census Bureau 2005). The Census Bureau provides a low, medium, and high series for net international immigration. In the base case, the middle series was used.

Domestic Migration

Although domestic migration is also a major component of local population change, it could not be accurately modeled here. The Census Bureau's methodology for state estimates does contain data about state-to-state migration rates based on the observed trend from 1975–2000, but that method does not consider county-to-county migration patterns. The commonly used Woods and Poole projections do consider domestic migration, but are only available to 2030. Developing a method for estimating future migrations was beyond the requirements of this analysis, and likely to introduce more error. The potential impacts of excluding domestic migration from this analysis are discussed in the Section 4.4 which addresses uncertainty in the population adjustments.

1.3.3. Use of these Projections

The population projections developed using the above methodology were used for two purposes in this analysis. First, they were used to calculate the population-weighted change in UV exposure based on the CMAQ and TUV modeling discussed above. These models provided the percent change in ground-level UV exposure for each 12 × 12 km cell in a grid that roughly covers the eastern two-thirds of the United States. To link the change in UV exposure to the population in each county, the average percent change in UV exposure was calculated for each county. In calculating the average for any given county, each cell was given a weighting equal to the percentage of its area of that is located in that county. These county averages were then used to calculate the population-weighted average change in UV exposure for each sex, age group, and latitude band. The modeled population for 2020 was aggregated into male and female, 18 age cohorts (0–4 years, 5–9 years, 10–14 years, and…85-plus years), and three latitude bands (20–30°, 30–40°, and 40–50°), or 108 population groups (2 sexes × 18 age groups × 3 latitude bands = 108 population groups). For each population group, the population-weighted average exposure was calculated by summing the product of the population in each county multiplied by the change in UV exposure in each county divided by the total population of that population group across all counties.

These projections were also used in the AHEF model runs. Model outputs for each five-year increment from 2005 to 2050 were aggregated for the 108 population groups. Because the CMAQ model did not cover the entire United States, those counties that were not included in the CMAQ modeling area were not included in the aggregated populations.

1.4. AHEF Modeling

The projections of population-weighted percentage change in UV exposure and future populations, as described in Section 2.3.3 above, were inputted into the AHEF model to estimate associated changes in health effects—specifically basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and cutaneous malignant melanoma (CMM) incidences and mortalities.

1.4.1. Overview of Methodology to Estimate Changes in Health Effects

To yield health effects estimates, the AHEF first projected future baseline skin cancer incidence and mortality; this calculation was based on the future population estimates derived in Section 2.3 and baseline incidence and mortality rates for each health effect (based on a scenario of compliance with the Montreal Adjustments to the Montreal Protocol). Then the AHEF multiplied the population-weighted percentage changes in UV exposure in a future year by the appropriate dose-response relationship (described in Section 4.2.2 below) to yield the percentage change in future skin cancer incidence/mortality attributable to the proposed change in the NAAQS ozone standard (from 84 ppb to 70 ppb). These percentages were then multiplied by the baseline incidence and/or mortality for that health effect to compute the absolute number of additional future cases or deaths attributable to the tropospheric ozone standard change.[4] These calculations are shown in Equation 2 below using BCC as an example health effect.

These calculations were performed for each health effect and for each future population group[5] to produce predictions of the incremental health effects in each future year through 2100 associated with a one-pulse change in the NAAQS ozone standard from 84 ppb to 70 ppb in

[4] This method of multiplying the changes in UV exposure by the biological amplification factor (BAF) and the underlying baseline incidence or mortality is the same as that used by other researchers to estimate changes in health effects based on changes in ozone concentrations (e.g., Madronich and de Gruijl 1994, Pitcher and Longstreth 1991).

[5] The future population group is a subset of the total U.S. population, calculated specifically for this analysis, as described in Section **Error! Reference source not found.** above.

2020. It is important to note that because the percentage increase in UV exposure associated with the tightening of the NAAQS standard from 84 ppb to 70 ppb is being used as the environmental input in the AHEF, only the incremental number of health effects associated with the standard change were modeled. The absolute number of health effects associated with the current NAAQS standard was not expressly calculated.

1.4.2. Selected Action Spectrum and Derived Dose-Response Relationships

The calculation of incremental health effects in Equation 2 above involves the use of a derived dose-response relationship, or biological amplification factor (BAF). Determining the health effects caused by UV exposure first requires information on the relative weights to be placed on each discrete UV wavelength to reflect the degree to which each wavelength causes biologic damage. Such a weighting function is called an action spectrum—an experimentally derived function that describes the relative effectiveness of each UV wavelength in the induction of skin cancers. The AHEF relies on action spectra for each health effect because action spectra provide information regarding which wavelengths of the total UV spectrum are most effective at causing the particular health effect. Based on the available action spectra, the Skin Cancer Utrecht-Philadelphia-human (SCUP-h) action spectrum (derived based on the induction of SCC in hairless mice and corrected for human skin transmission) was selected for modeling SCC, BCC, and CMM in the AHEF.[6]

Based on the action spectrum selected for each health effect, the relationship between those health effects and the intensity of UV exposure can then be explored. These dose-response relationships are derived by correlating measurements or estimates of UV exposure received for a specific action spectrum and given health effect at various locations, and the level of incidence or mortality for that health effect at those same locations. In the AHEF, statistical regression analyses were used to estimate the dose-response relationship, known in technical terms as the BAF, for each health effect. The BAF measures the degree to which changes in UV exposure weighted by the appropriate action spectrum (as measured in Watts/m^2) cause incremental changes in health effects (incidence or mortality), and is estimated after accounting for the influence of birth year and age, as necessary.

BAFs are defined as the percent change in a health effect resulting from a one-percent change in the intensity of UV radiation (weighted by the chosen action spectrum). For example, for BCC incidence in white males, a one-percent change in the intensity of UV radiation results in a 1.5 percent change in BCC incidence. For each health effect, the AHEF applies the BAF to predict future incidence and mortality as shown in Equation 2 above.

Table 3 presents a summary of calculated BAFs and selected action spectra for each health effect.

[6] Since a mammalian action spectrum for CMM still remains to be determined, the SCUP-h is also used to model CMM.

Table 3: Summary of Calculated BAFs, Selected Action Spectra, and Key Inputs

Health Effect	Data Sources	Selected Action Spectrum	BAF: Used in AHEF (Annual Exposures)	
			Males	Females
CMM Incidence/ Mortality	*Incidence*: Ratios from SEER data set *Mortality*: EPA/NCI data set *BAF*: Developed using econometric analysis	SCUP-h (1993)	0.5846	0.5047
BCC Incidence	*Incidence:* Based on methods used in U.S. EPA (1987) and Fears and Scotto (1983) *BAF:* de Gruijl and Forbes (1995)	SCUP-h (1993)	1.5	1.3
SCC Incidence	*Incidence:* Based on methods used in U.S. EPA (1987) and Fears and Scotto (1983) *BAF:* de Gruijl and Forbes (1995)	SCUP-h (1993)	2.6	2.6
Nonmelanoma Mortality	*Mortality:* EPA/NCI data set *BAF*: Developed using econometric analysis	SCUP-h (1993)	0.7094	0.4574

1.5. Valuation of Human Health Effects

The monetary value of incremental cases of basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and cutaneous malignant melanoma (CMM) was calculated as the number of additional cases multiplied by the medical and productivity loss cost per case. Cost per case is for cancer care only and excludes the costs of unrelated care, such as increased costs for treating other medical conditions later in life that might have occurred after the projected skin cancer mortality. For a change in the NAAQS ozone standard in one year (2020) only, the AHEF output gave the associated increase in skin cancer incidence and mortality, by health effect type, in each year through 2150. Total incremental costs were calculated over 2020–2150 and discounted to 2020 using discount rates of 3 percent and 7 percent, consistent with the guidance provided in the Office of Management and Budget's (OMB) (2003) Circular A-4.

The medical costs and productivity loss per case are shown in Table 4. These monetary values (in 2005$) were employed in a peer-reviewed publication (Kyle et al. forthcoming).

Table 4: Total Cost per Case of Non-fatal Skin Cancer and Mortality (2005 $)

	Medical Cost	Productivity Loss Cost	Total Cost per Case/Mortality
Non-fatal Skin Cancer Case			
Basal Cell Carcinoma	$1,066*	$1,161†	$2,228
Squamous Cell Carcinoma	$1,066*	$4,477†	$5,543
Cutaneous Malignant Melanoma	--	--	$37,220‡
Skin Cancer Mortality			$6.6 million§

* Chen et al. (2001), adjusted to 2005 $ using the medical care component of the Consumer Price Index (CPI-U).

† Calculated by ICF, based on U.S. EPA (1988) and U.S. BLS (2007).
‡ U.S. EPA (1988), adjusted to 2005 $ using the CPI-U for medical care.
§ Adjusted from $5.5 million at 1990 income levels (2000 $) to $6,600,000 at 2020 income levels. $5.5 million is the mean of a normal distribution with a 95% confidence interval between $1 million (Mrozek and Taylor 2002) and $10 million (Viscusi and Aldy 2003).

Medical costs per case of BCC and SCC were based on Chen et al. (2001); this study used data from the Medicare Current Beneficiary Survey (1999–2000) to estimate medical treatment costs associated with BCC and SCC in different practice settings. To determine an average medical treatment cost per case, weighted averages were calculated based on the percentage of episodes managed in each setting.

Productivity loss costs were based on a U.S. EPA analysis supporting the Regulatory Impact Analysis: Protection of Stratospheric Ozone (U.S. EPA 1988). The cost per case was calculated by multiplying EPA's estimates of the loss of work due to illness and care giving performed by others for the patient for BCC and SCC by the national mean annual wage for 2005 (U.S. BLS 2007). For CMM, EPA's estimate of the total medical cost and productivity loss per case was used and adjusted to 2005 $ using the CPI-U for medical care (U.S. EPA 1988).

The value of a statistical life (VSL) is estimated to be $5.5 million at 1990 income levels and $6.6 million at 2020 income levels. The estimate of $5.5 million is the mean of a normal distribution with a 95 % confidence interval between $1 and $10 million. The confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis; and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.

Results

This section provides an overview of the results of this analysis, including changes in ground level SCUP-h UV, changes in health effects (i.e., incremental skin cancer incidence and mortalities), and the resulting monetized disbenefits.

1.6. Changes in Ground Level SCUP-h UV

Using the methodology described in Section 2 above, the percent change in ground-level SCUP-h UV was calculated for each day and averaged across each month. The figures below represent average changes in SCUP-h UV associated with achieving an ozone standard of 70 ppb (down from 84 ppb) in the summer months of June, July, and August.

Figure 7: Ground Level UV Percent Change between 70 and 84 ppb, June

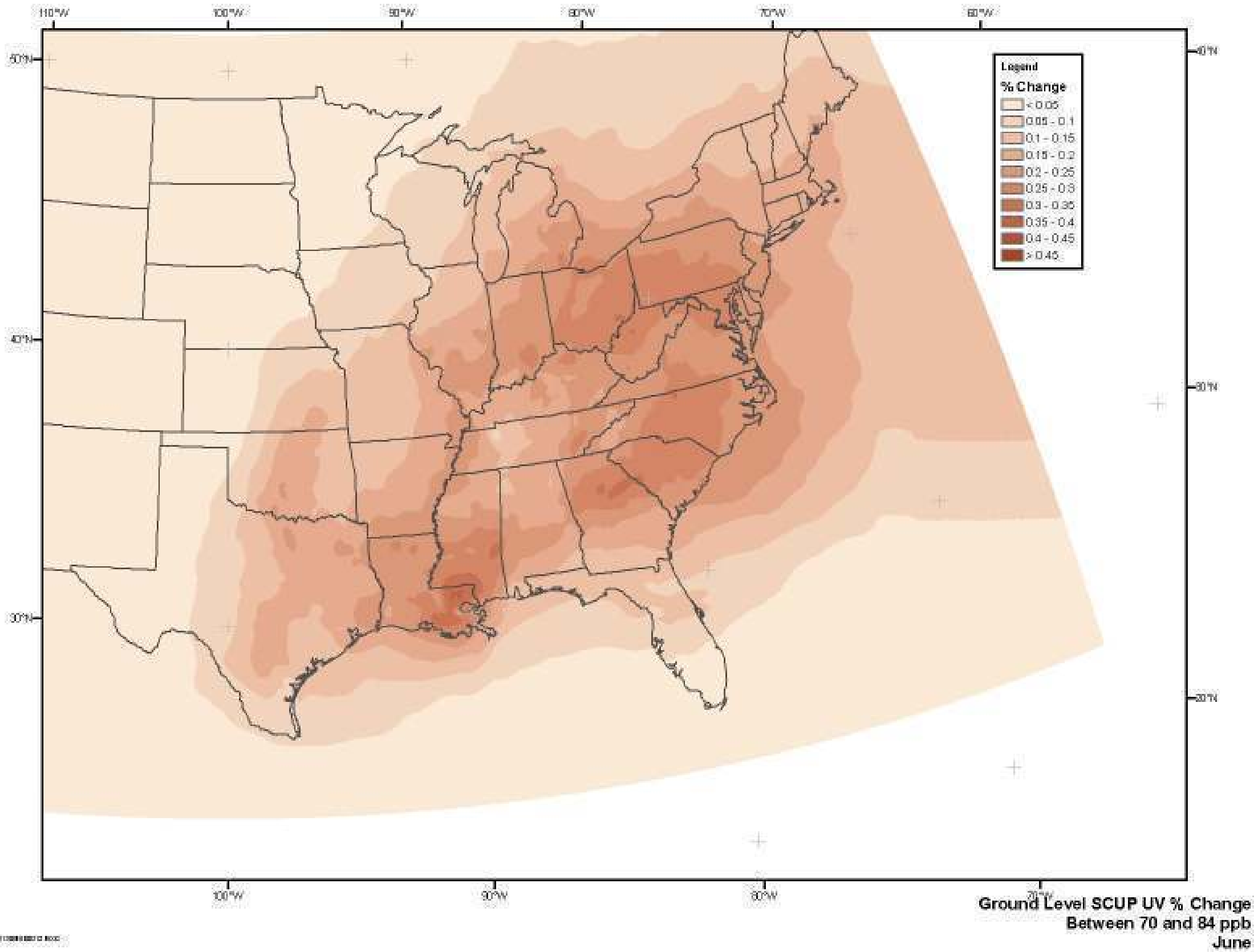


Figure 8: Ground Level SCUP-h UV Percent Change between 70 and 84 ppb, July

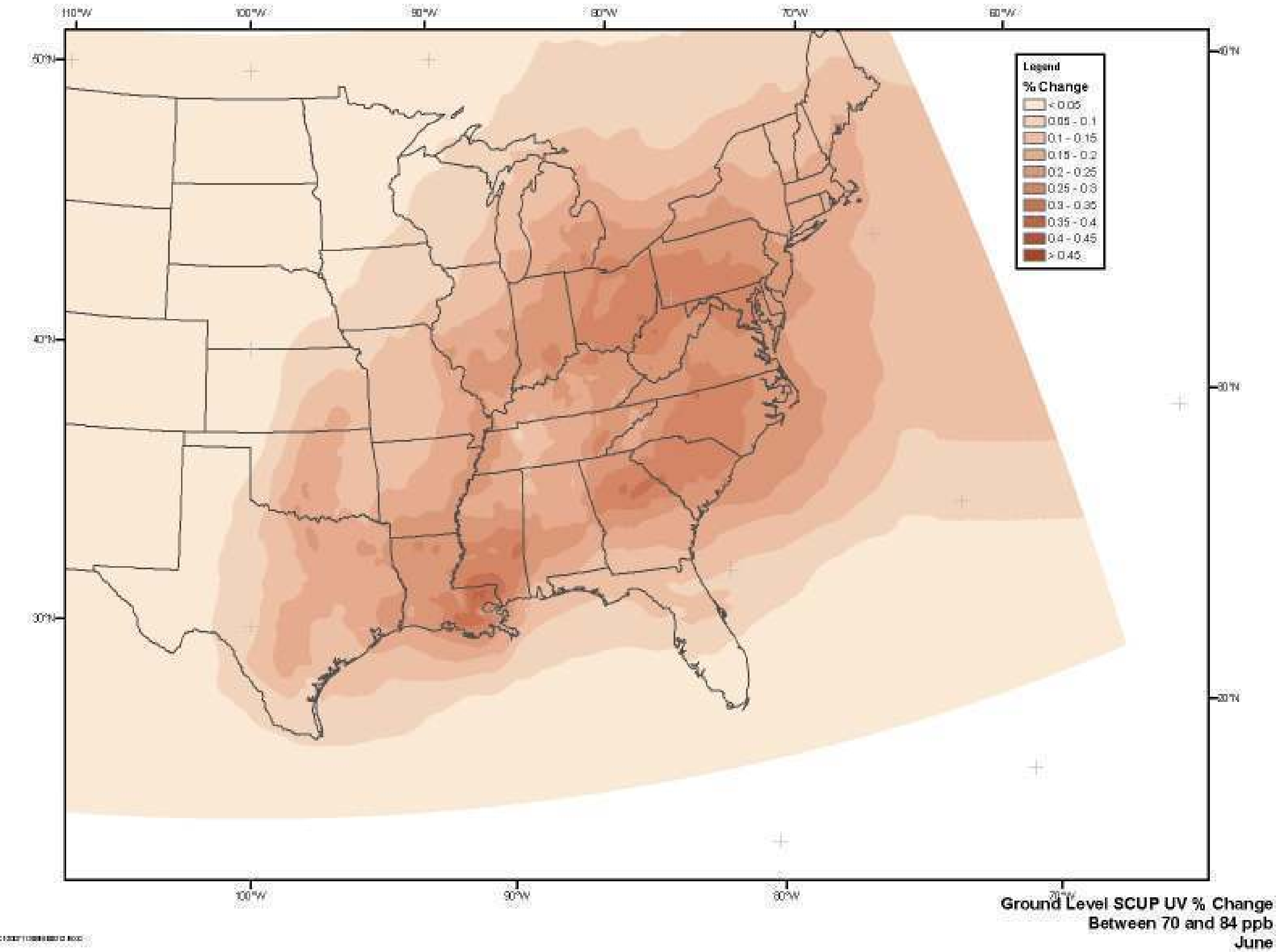
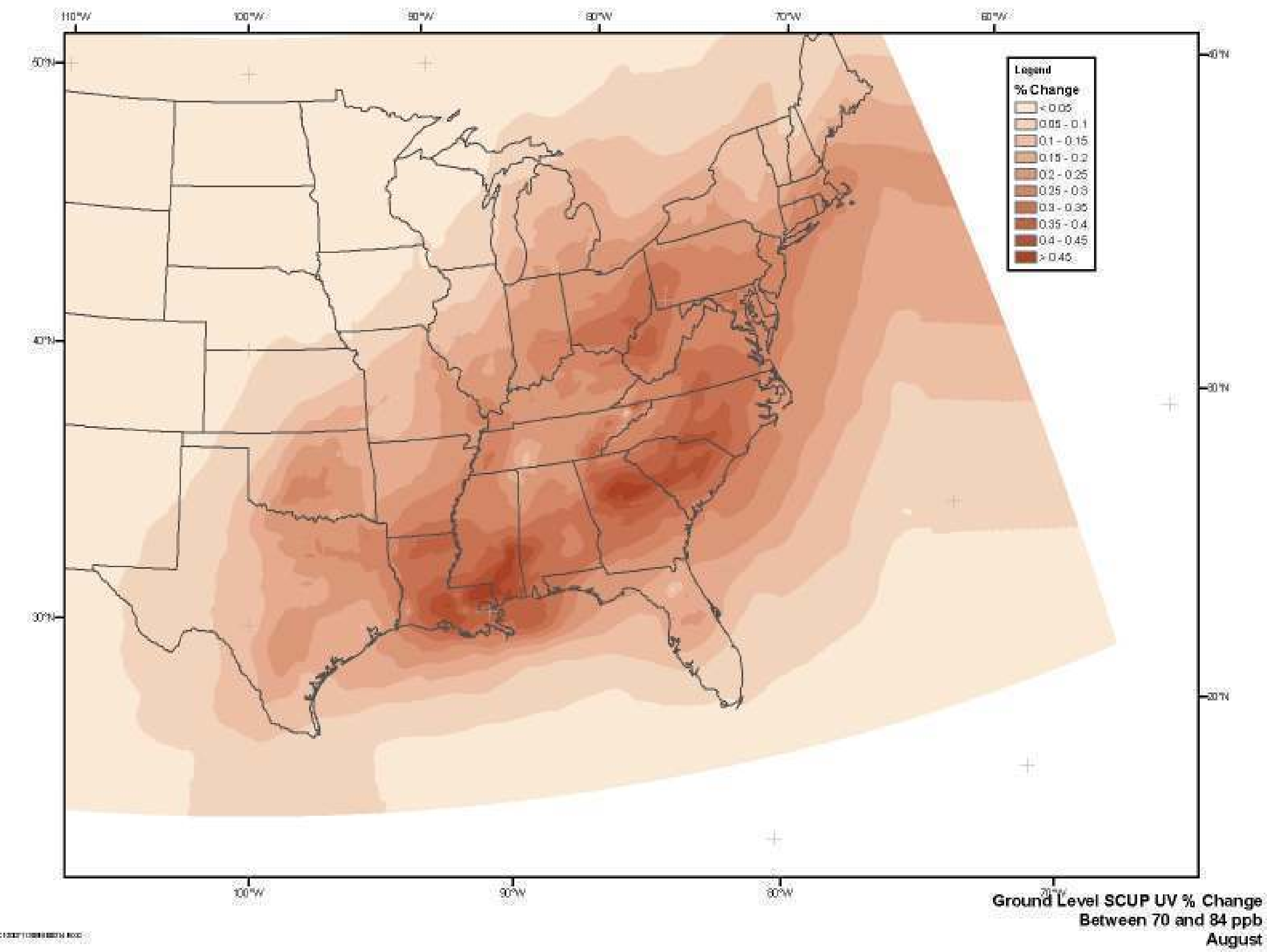


Figure 9: Ground Level SCUP-h UV Percent Change between 70 and 84 ppb, August



1.7. Changes in Human Health Effects

This section presents results in terms of the changes in skin cancer incidence and mortality associated with a one-year change in the ozone standard in 2020. Table 5 below gives the cumulative change in incidence and premature mortality associated with a one-time pulse (i.e., a change in the ozone standard from 84 ppb to 70 ppb in one year, 2020). As shown, 3,538 additional cases of skin cancer and about 16 additional mortalities are expected. For the age cohorts relevant to this analysis (those populations potentially alive in 2020 and thereafter; i.e., those born from 1930 to 2100) and for the population subset analyzed, baseline skin cancer modeled in the AHEF through 2150 totals more than 188 million cases and about 2.6 million mortalities. Thus, the additional cases and mortalities associated with changing the ozone standard represent less than 0.002% and less than 0.001% of baseline, respectively.

This section also provides the monetary value of those future health effects, discounted back to 2020, in Table 6 and Table 7.

Table 5: Additional Skin Cancer Incidence and Mortality Associated with a Change in the Ozone Standard in 2020

Skin Cancer Type	Incidence	Mortality
	Central Estimate* *(Uncertainty Range†)*	
Nonmelanoma Skin Cancer	3,454 *(2,348–4,560)*	5.7 *(3.9–7.5)*
Cutaneous Malignant Melanoma	84 *(57–110)*	10.5 *(7.1–13.8)*
Total	3,538 *(2,405–4,671)*	16.2 *(11.0–21.3)*

* From the AHEF model.
† The uncertainty range is derived by applying the quantified uncertainty (approximately 32%), as calculated in Section 1.15, to the central estimate.

Table 6: Monetized Summary Table (3% discount rate, discounted to 2020 with prices in 2005 $)

Skin Cancer Type	Incidence	Mortality
	Central Estimate* *(Uncertainty Range†)*	
Nonmelanoma Skin Cancer	$4,717,452 *($3,207,130–$6,227,773)*	$13,334,430 *($9,065,329–$17,603,530)*
Cutaneous Malignant Melanoma	$1,399,631 *($951,531–$1,847,732)*	$28,630,454 *($19,464,236–$37,796,672)*
Total	$6,117,083 *($4,158,661–$8,075,505)*	$41,964,884 *($28,529,566–$55,400,202)*

* Based on incidence and mortality projected by the AHEF model.
† The uncertainty range is derived by applying the quantified uncertainty (approximately 32%), as calculated in Section 1.15, to the central estimate.

Table 7: Monetized Summary Table (7% discount rate, discounted to 2020 with prices in 2005 $)

Skin Cancer Type	Incidence	Mortality
	Central Estimate* *(Uncertainty Range†)*	
Nonmelanoma Skin Cancer	$2,234,469 *($1,519,090–$2,949,848)*	$5,819,781 *($3,956,542–$7,683,021)*
Cutaneous Malignant Melanoma	$720,816 *($490,042–$951,590)*	$14,068,218 *($9,564,191–$18,572,246)*
Total	$2,955,285 *($2,009,132–$3,901,438)*	$19,888,000 *($13,520,733–$26,255,267)*

* Based on incidence and mortality projected by the AHEF model..
† The uncertainty range is derived by applying the quantified uncertainty (approximately 32%), as calculated in Section 1.15, to the central estimate.

Uncertainty

1.8. Uncertainty in estimated impacts

Uncertainty in the estimation of human health impacts arising from a tightening of the NAAQS standards from 84 ppb to 70 ppb arise from various sources. These uncertainties are addressed in the following sections:

- **CMAQ Modeling**—uncertainty in the prediction of precise tropospheric ozone column changes under the NAAQS scenarios
- **TUV Modeling**—uncertainty in the calculation of consequent changes in surface UV-SCUP
- **Population Adjustments**—uncertainty in the determination of county based population projections
- **AHEF Modeling**—uncertainty in the estimate of associated changes in health effects including latency
- **Valuation Of Human Health Effects**—uncertainty in the monetary value of incremental skin cancer incidence/mortality
- **Unquantified Sources of Uncertainty**—other qualitative sources of uncertainty
- **Summary of Quantified and Unquantified Sources of Uncertainty**

The sources and magnitudes of the uncertainties associated with each step of the analysis were identified and are discussed in the relevant sections below.

1.9. Uncertainty in CMAQ Modeling

Output from CMAQ modeling runs from U.S. EPA (CMAQ version 4.5) were provided for the two NAAQS scenarios with identifiers:

- 2020bk_v4.5_084_12km.o3_hr_shift_LST, and
- 2020bk_v4.5_070b_12km.o3_hr_shift_LST

The CMAQ model did not cover the entire United States, the area analyzed covers all or part of 42 states in the eastern two-thirds of the country

Eder and Yu (2006) have conducted performance evaluations comparing annual simulations (2001) of CMAQ (version 4.4) covering the contiguous United States against monitoring data for four nationwide networks. This effort represents one of the most spatially and temporally comprehensive performance evaluations of the model. Simulations of the peak 1- and 8-h ozone concentrations during the summer (April–September) were "relatively good" (correlation (r)=0.68, 0.69; normalized mean bias = 4.0 %, 8.1 % and normalized mean error = 18.3 % and 19.6 % respectively). No performance evaluation could be assessed for the provided scenarios; however, analysis for the CMAQ review process (see http://www.cmascenter.org/index.cfm) typically returns normalized mean errors for ozone ≈ 20%.

As described in Section 2.2, the CMAQ ozone concentrations are accommodated into the TUV model to determine overall column ozone values.

1.10. Uncertainty in TUV Modeling

1.10.1. Uncertainty Analysis of TUV Calculations

The uncertainties in the TUV calculations can be divided into two types:

1) Uncertainties inherent in the TUV numerical model, primarily from the approximate 2-stream (delta-Eddington) solution of the radiative transfer equation, and the discretization of altitudes and wavelength and related interpolations. These uncertainties have been shown in many earlier studies to be negligible, on the order of 5% or less, when compared to higher stream models and higher vertical and spectral resolution.

2) Uncertainties in the input parameters that describe atmospheric composition (vertical profiles of air, ozone, other absorbing gases, aerosols, and clouds) and the earth's surface reflectivity.

If the input parameters are well known (e.g., cloud-free and pollution-free conditions with measured total ozone column as inputs), the TUV results are accurate to a few percent, which is also the accuracy of the best instruments for measuring atmospheric UV radiation. For the present purposes, the inherent TUV uncertainty (item 1) is taken, conservatively, as 5%.

The atmospheric input parameters (item 2 above) are generally not well known in any specific situation, and are highly variable spatially and temporally, with long-term trends also a possibility. For the purposes of these calculations, we adopt the principle that UV changes stemming from CMAQ scenario changes in tropospheric ozone can be calculated under the premise that **all other atmospheric conditions remain exactly the same between the two scenarios**, including clouds, aerosols, and surface reflectivity. This is consistent with the approach used in calculations relating stratospheric ozone changes to surface UV increases.

Table 8 shows the predicted changes in UV-SCUP calculated by the TUV model, between the two CMAQ scenarios (084 to 070), for 15 July. The changes are expressed as percent changes in daily UV-SCUP doses at each location, then domain-averaged to give the values in the third column of the table. The reference model (test number 0) would be used in the AHEF estimates of skin cancer changes. The other entries in the table (tests number 1–6), show the UV-SCUP % change between scenarios, if other atmospheric conditions are changed individually and equally for both scenarios, as described in the second column. The last column gives the % effect of changing the atmospheric conditions. For example, the reference calculation (test 0) gives a UV-SCUP increase of 0.118% in going from scenario 084 to 070. If aerosols are removed from the model (test 1), the UV-SCUP increase between scenarios is only 0.112, which is a 5.1 % reduction relative to the reference case. A brief explanation of the effects from each factor is given below.

Table 8: UV-SCUP changes between CMAQ scenarios 084 and 070 on 15 July, for different values of other factors (aerosol, surface albedo, clouds, and stratospheric ozone).

Test number	Description	Domain-averaged change in UV-SCUP, %	Effect of other factors, %
0	Reference (Elterman* aerosols, 10% surface albedo, no clouds, sea level, USSA stratospheric O_3)	0.118	≡ 0
1	No aerosols	0.112	-5.1
2	0% surface albedo	0.112	-5.1
3	High thin cloud, at 9-10 km, optical depth =2	0.132	11.9
4	Low moderately heavy cloud, at 1-2 km, optical depth = 16	0.169	43
5	850 mb surface pressure	0.098	-17
6	20 DU reduction in stratospheric O_3 (above 16 km)	0.123	4.2

(*) Elterman continental aerosol vertical profile, with total optical depth (at 550 nm) = 0.235, Angstrom alpha = 1.0, single scattering albedo = 0.99, asymmetry factor = 0.61.

1. Aerosols increase the photons' pathlengths, and therefore increase the probability of absorption by tropospheric ozone. By removing aerosols from the reference run, the UV increase from changing ozone scenarios is somewhat smaller.

2. Surface albedo reflects light back to the atmosphere, and a fraction of this can be scattered back toward the surface, effectively increasing the photons' path-lengths for absorption by tropospheric ozone. If the surface is not reflecting (albedo = 0%), these photon reflections do not occur and the interaction with tropospheric ozone is smaller.

3. High clouds (e.g., cirrus) make the incident (down-welling) light more diffuse and therefore more slanted as it passes the troposphere. They also reflect a fraction of the up-welling radiation (up-scattered by tropospheric molecules), back to the lower troposphere (much like surface albedo, but in the opposite direction). Both effects increase tropospheric photon pathlengths and therefore the probability of absorption from any additional tropospheric ozone.

4. Low thick clouds (e.g., stratocumulus, marine stratus) have a larger effect because they are at altitudes closer to where the ozone changes are largest. In-cloud increases of ozone are particularly significant because of the long in-cloud photon pathlengths, as has been observed and modeled (e.g., Mayer et al., 1997). Broken clouds (e.g., fair-weather cumulus) are expected to be intermediate between fully overcast and fully clear (Nack and Green, 1974).

5. Decreases in atmospheric pressure reduce, in direct proportion according to the ideal gas law, the conversion factor between ozone molar mixing ratios (ppb, specified by CMAQ) and the ozone number density (molecules cm^{-3}, which is integrated to obtain the ozone column in Dobson Units) used for atmospheric transmission. Also, lower pressures decrease the Rayleigh optical depth and therefore the photon path coupling between scattering and absorption. These factors combine to yield a smaller SCUP-UV change. The pressure reduction chosen here, 850 mb, is roughly representative of cities at high elevation. Thus, this case can also be considered a surrogate test for the effect of surface elevation (varying the surface elevation directly is possible within the TUV code, but would have created some ambiguity between the nominal CMAQ altitudes and the TUV geometric grid).

6. Reductions in stratospheric ozone imply that any tropospheric ozone changes are a larger fraction of the total column ozone. Therefore the sensitivity to CMAQ scenario changes is greater if the stratospheric ozone is smaller. This is consistent with the power law first proposed by Madronich (1993):

$$UV_{\text{bio}} \propto (DU)^{-RAF}$$

for which the theoretical basis is described by Micheletti et al. (2003).

The sensitivity studies (cases 1-6) show that how the baseline environmental conditions, under which the difference between the two tropospheric ozone scenarios was assessed, could contribute to the uncertainties of the TUV-calculated changes in surface SCUP-UV radiation. The worst case is that of low clouds: If the entire domain were actually covered by low clouds for the entire period of interest (June–August), the TUV calculations made under cloud-free assumption would underestimate the UV increases stemming from the changes in tropospheric ozone, by about 43%. This extreme case is patently unrealistic. Conservatively, if it is assumed that low clouds are present no more than 1/4 of the time, their error is reduced to about 11%. Thus, the uncertainty budget can be summarized as follows:

Inherent TUV uncertainties	5	%
Aerosols	5.1	%
Surface albedo	5.1	%
High clouds	11.9	%
Low clouds (1/4 of the time)	11	%
Surface pressure	17	%
Stratospheric ozone	4.2	%
TOTAL (quadrature)	25	%

For example, for the 15 July case, the reference UV-SCUP change of 0.118 % is estimated to be, with high certainty, in the range 0.088–0.148 %.

Finally, it should be noted that these estimates are generally overly conservative. For example, high clouds are likely to be present only a fraction of the time, and the 850 mb pressure may apply to only a few locations. Therefore the 25% uncertainty estimated here should be viewed as a very conservative upper limit.

The TUV model also has the option of calculating radiation incidence on a sphere or on a horizontal plane. Incidence on a sphere is presently considered a better metric for UV exposure and was therefore used in this analysis. A small uncertainty is introduced over incidence on a horizontal plane, the previous standard. The percent change in UV is reduced by about 8 % by taking the spherical output in preference to the planar output (i.e., for the 15 July domain-average, from 0.126 % to 0.118 %). This is a small effect and it should be noted that the average SCUP-UV changes are still near 0.1 % using either output.

1.10.2. Comparison with UV Changes Due to Other Factors

In Section 2.2.3, the UV-SCUP change resulting from tropospheric ozone change between the two CMAQ scenarios was calculated and shown to be of order ~ 0.1 %, if all other environmental factors are kept constant between the two scenarios. Below, we consider, for comparison only, the UV changes that would result if these other factors are allowed to vary between two scenarios. To illustrate this, Table 9 shows the UV changes, calculated for the CMAQ 084 tropospheric ozone scenario, when other environmental conditions, rather than tropospheric ozone, are changed relative to the reference conditions. The magnitude of changes in the conditions is the same as used for Table 8. **It should be emphasized that the % UV changes shown in Table 9 are NOT those associated with changes in tropospheric ozone, but rather with direct changes in the other environmental conditions.**

Table 9: Effect on surface SCUP-UV radiation of varying environmental conditions other than tropospheric O_3.

Test number	Description	Domain-averaged % change in UV-SCUP
0	Reference (Elterman aerosols, 10% surface albedo, no clouds, sea level, USSA stratospheric O_3), tropospheric O_3 scenario 084	≡ 0
1a	No aerosols	7.3
2a	0% surface albedo	-3.8
3a	High thin cloud, at 9-10 km, optical depth =2	-12.1
4a	Low moderately heavy cloud, at 1-2 km, optical depth = 16	-50.
5a	850 mb surface pressure	10.4
6a	20 DU reduction in stratospheric O_3 (above 16 km)	7.6

Should the baseline environmental conditions actually change **between** the two CMAQ tropospheric ozone scenarios (084 and 070), the SCUP-UV changes could be far larger. Of course, there is no solid scientific basis for expecting such environmental changes in response to relatively small changes in tropospheric ozone. Some interactions are known, (e.g. oxidant photochemistry leading to the formation of sulfate and secondary organic aerosols, which can affect radiation directly as well as change cloud nucleation and lifetimes) but these effects are still poorly quantified, and although subjects of active current research, are not expected to be as large as the variations used in this sensitivity analysis.

1.11. Uncertainty in Population Adjustments

The Cohort-Component Methodology (see Section 2.3.1) for population adjustment used in the analysis gave a 2020 total population of 336.1 million in very close agreement with the U.S. Census Bureau projection for 2020 of 335.8 million—a difference of less than 0.1 %. However, as discussed above, the model did not consider domestic migration between counties due to the lack of suitable alternative estimates. It is assumed that migration between neighboring counties within the same metropolitan area is not likely to have an impact on the results because the change in ozone concentration is similar in adjacent areas. When aggregated across broad latitude bands with hundreds of counties, small differences from one county to the next due to migration are likely to cancel each other out.

Interregional migration—such as the observed historic migrations from the Northeast and upper Midwest to the Sun Belt states—is a potential source of uncertainty in this analysis. Since the model estimated that all local populations change only through births, deaths, and the arrival of international immigrants, it is possible that populations of regions that are losing migrants to other parts of the country are overrepresented in this analysis, while the populations of fast-growing regions attracting these migrants are underrepresented. Because the population-weighted change in UV exposure is higher in the southern latitude band than in the northern latitude band, this analysis may be underestimating the change in exposure if the historic north-to-south migration pattern holds. However, this effect is not uniform—Florida, for example, exhibits much lower changes in UV than other areas of the South, but has traditionally received a large portion of migrants from the North.

Ultimately, it was decided that the uncertainty associated with predicting migration patterns outweighed the uncertainty introduced by excluding domestic migration from this model. Because migration between regions is a matter of percentage points rather than degrees of magnitude, it is assumed that the overall uncertainty associated with the population projections is relatively small.

The CMAQ model area also has population implications. The area analyzed covers all or part of 42 states in the eastern two-thirds of the country. As a result, those counties that were not included in the CMAQ modeling area were not included in the aggregated populations (26.2 % of the total population). It would be reasonable to assume, given this truncation of population (e.g., 13.5 % of the population reside in California) and the historically high proportion of cases of skin cancer and/or mortality on the West Coast (e.g., California counties, especially Los Angeles), that this input alone would introduce a disproportional large, unquantifiable uncertainty if the estimated health effects from the analysis were extrapolated to the rest of the population. Therefore, the results of this analysis must be viewed in this context when drawing comparisons with other studies which consider the continuous United States (e.g., Lutter and Wolz, 1997).

1.12. Uncertainty in AHEF Modeling

AHEF modeling contributes uncertainties to the estimates of human health effects—resulting from a change in NAAQS standards—in two major areas:

1) the dose-response relationships (expressed as a BAF) for the three endpoints of concern (i.e., BCC, SCC, and CMM), and

2) the future size, behavior, and distribution of the populations that will be affected (see Section 4.4. Uncertainty in Population Adjustments).

It should be noted that for this analysis, only estimated uncertainty in the BAF parameter is quantifiable.

1.12.1. Uncertainties in Selected Derived Dose-Response Relationships

The AHEF model (described in Section 2.4) incorporates information on the dose-response relationships for BCC, SCC, and CMM through the use of a BAF (i.e., the slope of the dose-response relationship). . The estimate of BAF and associated standard error generated for CMM incidence/mortality using the SCUP-h action spectrum is 0.5846 ± 0.02 for males, 0.5047 ± 0.02 for females which yields an uncertainty range of approximately 3 % for changes in these health effects estimates; the BAF and associated standard errors generated for NMSC mortality 0.7094 ± 0.03 for males, 0.4574 ± 0.03 for females which yields an uncertainty range of approximately 4 and 7 % respectively; and BAFs and associated standard errors generated for BCC and SCC are 1.5 ± 0.5 for males, 1.3 ± 0.4 for females and 2.6 ± 0.7 for males, 2.6 ± 0.8, respectively (deGruijl and Forbes, 1995) which yields an uncertainty range of approximately 30% for changes in these health effects estimates.

1.12.2. Behavioral Uncertainties

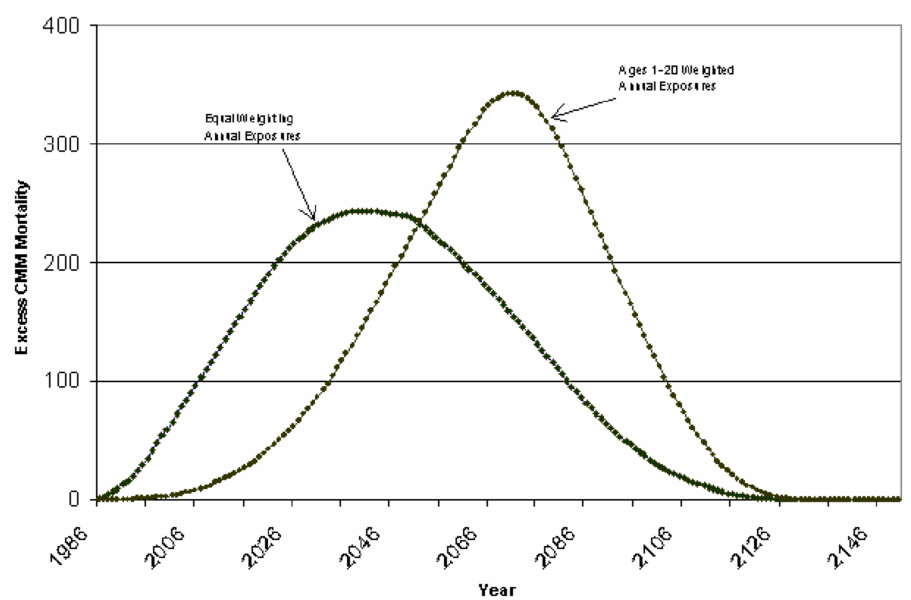
While the AHEF assumes that human exposure behavior remains constant over time, changes in human behavior affect the amount of UV radiation exposure received. For example, changes in (1) the amount of time spent outdoors, (2) in socioeconomic profiles that impact travel to areas where high UV exposure can be expected (i.e., the beach), or (3) in the use and/or efficacy of sun protection technologies such as sunglasses and sunscreens can impact the extent of UV exposure received.

A number of recent studies have examined UV exposure behaviors in the U.S. Godar et al. (2003) found that Americans get about 23 % of their lifetime UV dose by the age of 18, 46 % by the age of 40, and about 74 % by the age of 59, assuming that individuals live up to the age of 78. Among U.S. youth ages 11–18, Cokinnides et al. (2001) found that about 10 % reported practicing three or more sun protection behaviors regularly and nearly 60 % practiced one or two routinely; however, about one-third of the youth overall did not practice any recommended sun protection behaviors.

1.12.3. Latency

Another source of uncertainty in the AHEF health effects estimate is associated with the exposure period over a person's lifetime that is most likely to be the cause of UV-related health effects. This is especially relevant for CMM, since it has been hypothesized that CMM is largely the product of intense exposures early in life (e.g., through age 20) rather than cumulative lifetime exposure. The AHEF uses whole life exposure for all skin cancer types as the default assumption. Using early life exposure for CMM is not the same as evaluating a latency effect, but can be used as a proxy for latency in this health end point. Figure 10 shows the effect of this proxy measure for latency on CMM mortality changes by ≈ 10 percent when the exposure assumptions (early life *versus* whole life) are changed (U.S. EPA, 2003), with uncertainty concerning the appropriate exposure dose manifesting itself less in the total incremental risks predicted, than in *when* those incremental effects are predicted to occur, and *who* will bear them (i.e., shifting the risk to future generations). Modeling this lag time further is difficult given the current state of knowledge about latency and its mechanisms (Madronich, 1999).

Figure 10: Excess CMM mortality for the Montreal Adjustment scenario for equal-age exposure weighting and weighting for exposures only for ages 1–20: cumulative annual exposure (U.S. EPA/NASA, 2001).



1.13. Uncertainty in Valuation of Human Health Effects

An extensive literature review was conducted to determine the best medical cost estimates for NMSC for the Economic Evaluation of the U.S. Environmental Protection Agency's SunWise Program: Sun Protection Education for Young Children (Kyle et al., forthcoming). Values were taken from Chen et al. (2001), considered to be the best available source of data for these health endpoints; however, the authors did not include uncertainty bands around their central estimates.

The national mean annual wage for 2005 (U.S. BLS, 2007) is $37, 870 (mean annual wage for all occupations) which has a mean relative standard error of 0.1%.

1.14. Unquantified Sources of Uncertainty

There are a number of other sources of uncertainty in the analysis' health effects predictions. Some of these sources of uncertainty are possible to quantify, but are not central to the structure of the analysis. Others cannot be quantified because any assumptions or estimates would be simply speculative. These other sources of uncertainty include:

- Composition of the future atmosphere;
- Future conditions of the ozone column;
- Effect of climate change;
- Compliance with modeled policy scenarios;
- Laboratory techniques and instrumentation for deriving action spectra;
- Improvements in medical care/increased longevity; and
- Baseline information.

These uncertainties are described qualitatively in more detail below.

Composition of the Future Atmosphere

The exact composition of the future atmosphere as a result of compliance with different policies (i.e., ODS phaseout under the Montreal Adjustments to the Montreal Protocol) is unknown. As levels of atmospheric chlorine are reduced, the impact of ozone depletion from chlorine and bromine radical species generated from ODS would change. In addition, long-term systematic changes in atmospheric opacity (e.g., clouds, aerosols, other pollutants) will also impact the ability to model changes in ozone. Likewise, future changes in climate could result in changes in the atmospheric circulation patterns and therefore could change cloud cover. The impacts of such changes on the predicted recovery of the ozone layer and subsequently tropospheric ozone are unknown. All of these uncertainties could influence the ability to model atmospheric processes accurately.

Future Conditions of the Ozone Column

Uncertainties also can be contributed by assumptions regarding the future conditions of the ozone column in response to the phaseout of ODS. Some computer models predict that the phaseout of ODS will slow and eventually stop the rate of ozone depletion, and suggest that natural ozone-making processes will enable stratospheric ozone to return to 1979–1980 ozone conditions. These models also predict that the recovery will eventually result in increased concentrations beyond 1979–1980 levels[7] (see Chapter 12 in WMO 1999 for more detail). Because there is incomplete knowledge about the behavior of ozone prior to the satellite measurements taken in 1979–1980, the AHEF imposes a limit on future ozone recovery to the conditions observed in 1979–1980.

Effect of Climate Change

The effects of global climate variations on stratospheric temperature and, in turn, on ozone depletion, are not well understood, and have therefore not been assessed in the analysis. While this effect is not typically incorporated into models used to assess future ozone depletion, it does represent a modeling constraint that should be noted.

Compliance with Modeled Policy Scenarios

This analysis assumes compliance with each of the modeled NAAQS policy scenarios. To the extent that these limitations are not adhered to, future ozone column conditions could be different.

Laboratory Techniques and Instrumentation

Additional uncertainty can be contributed by the laboratory techniques and instrumentation used for deriving the action spectra used to weight UV exposure. Discrepancies between the wavelengths of UV radiation intended to be administered and the wavelengths actually received by the test organism can result in orders of magnitude differences in the measured response. In

[7] Whether this recovery scenario, called "ozone superabundance," is likely to occur is open to debate, particularly because of the potential for complex interactions between global climate change and stratospheric ozone dynamics. Model computations have predicted both higher and lower amounts of ozone in the future.

addition, many action spectra are derived using monochromatic light sources that do not fully simulate the polychromatic light received directly from the sun.

Improvements in medical care/increased longevity

Improvements in medical care and predictions of increased longevity for many population subgroups could affect estimates of future skin cancer incidence and mortality significantly.

Changes in socioeconomic factors

Changes in socioeconomic factors (e.g., demographics and human behavioral changes) that could affect the accuracy of the analysis include:

- Changes in human UV exposure behavior: This evaluation assumes that human exposure behavior remains constant through time, and does not take into account innovations in sun protection technology (e.g., improved sunglasses and sunscreens), increased public awareness of the effects of overexposure to UV, and increased sensitization to the need for early treatment of suspicious lesions.

- Changes in socioeconomic profiles: Socioeconomic profiles can impact a variety of factors, ranging from demand for air travel to areas where high UV exposure is expected (i.e., the beach), to the types of skin cancer most commonly observed.

- Changes in population composition and size: Population composition changes such as the expected increase in Hispanic populations, whose more pigmented skin is thought to decrease skin cancer risk, could have significant effects on future U.S. skin cancer rates.

The above factors are either not easily quantified (e.g., human behavior; see Section 4.5.2. Behavioral Uncertainties), or they are not central to the analysis (e.g., improvements in medical care), and are therefore not addressed further in this evaluation.

Baseline Information

It is possible that error is introduced to the AHEF's results through misreporting of skin cancer incidence and mortality data (i.e., the AHEF's baseline estimates). With disease data, under-, over-, and misreporting are not uncommon. For example, a studies have revealed that the incidence of CMM has been systematically under-reported in the SEER data (Clegg et al. 2002).[8] The original SEER data indicated that CMM rates in white males were relatively flat or even falling (ranging from -11.1 percent to 3.3 percent annually after 1996). However, after adjusting for underreporting, CMM rates were actually found to have increased between 3.8 to 4.4 percent annually since 1981 (Clegg et al. 2002). Underreporting of CMM incidence is largely attributable to diagnosis in doctors' offices, as opposed to hospitals and other treatment centers with better reporting accuracy. However, the AHEF results are not significantly affected by this underreporting because CMM incidence estimates in the AHEF are not based directly on SEER incidence data. Rather, because the AHEF estimates CMM incidence based on the ratio of SEER

[8] There is little reason to believe that the SEER CMM incidence under-reporting extends to the NCI-based CMM mortality input information.

incidence data to projected annual mortality estimates, and because underreporting would affect both baseline and scenario estimates, the effects on incremental changes in CMM incidence would be second order.

1.15. Summary of Quantified and Unquantified Sources of Uncertainty

Of the major sources of uncertainty associated with the analysis, the total quantified uncertainty is roughly 32 percent, as summarized in Table 10.

Table 10: Major Sources of Quantified Uncertainty

Source of Uncertainty	Quantified Uncertainty
Translating column ozone to ground-level UV	
TUV Model	≈ 5 %
Translating UV exposure to human health effects	
Uncertainty in BAFs	≤ 30 %
▪ CMM mortality (3 %)	
▪ NMSC mortality (4–7 %)	
▪ NMSC incidence (30 %)	
Early life exposure *versus* whole life exposure	≈ 10 %
Total $\sqrt{(5^2 + 30^2 + 10^2)}$	**≈ 32 %**

There are a variety of other unquantified sources of uncertainty that may contribute to overall analytical uncertainty associated with modeled ozone changes, changes in UV radiation, and changes in health effects. Table 11 summarizes the parameters that relate to these unquantified uncertainties.

Table 11: Factors with unknown contributions to uncertainty

Factor	Parameter
Changes in ozone estimates	Composition of future atmosphere
	Ability to model atmospheric processes accurately
	Response of tropospheric ozone to ozone layer recovery
	Effect of climate change
	Compliance with modeled NAAQS policy scenarios
Change in UV radiation estimates	Long-term systematic changes in atmospheric opacity (e.g., clouds, aerosols, other pollutants)
Change in health effect estimates	Changes in human UV exposure behavior
	Laboratory techniques and instrumentation for deriving an action spectrum
	Uncertainty with choice of action spectra
	Improvements in medical care/increased longevity
	Changes in socioeconomic factors (e.g., demographics and human behavioral changes)
	Baseline information (e.g., misreporting of skin cancer incidence and mortality data)
	Changes in population composition and size (including truncation of CMAQ model analysis area)

Accurate prediction of future changes in human health effects would require consideration of the net effect of all the factors described above. This challenge is beyond the ability of the current state of atmospheric and epidemiological science. In addition, direct measurements (e.g., of future UV levels or skin cancer incidence) cannot attribute explicitly observed changes to any specific factor, unless that factor is far more important than all the others combined. However, the principle of superposition can be used to examine the NAAQS impact (i.e., one effect in isolation) under the assumption that the other factors remain constant at current conditions. The validity of this principle is based on the assumption that the NAAQS impacts are independent of the other factors (e.g., behavioral changes will occur regardless of whether a new NAAQS standard is in place).

References

American Cancer Society: Cancer Facts and Figures 2007. Atlanta: American Cancer Society; 2007.

Bais, A., S. Madronich, J. Crawford, S. R. Hall, B. Mayer, M. VanWeele, J. Lenoble, J. G. Calvert, C. A. Cantrell, R. E. Shetter, A. Hofzumahaus, P. Koepke, P. S. Monks, G. Frost, R. McKenzie, N. Krotkov, A. Kylling, S. Lloyd, W. H. Swartz, G. Pfister, T. J. Martin, E.-P. Roeth, E. Griffioen, A. Ruggaber, M. Krol, A. Kraus, G. D. Edwards, M. Mueller, B. L. Lefer, P. Johnston, H. Schwander, D. Flittner, B. G. Gardiner, J. Barrick, R. Schmitt, International Photolysis Frequency Measurement and Model Intercomparison: Spectral actinic solar flux measurements and modeling, *J. Geophys. Res.*, 108, 8543, doi:1029/2002/JD002891, 2003.

Bruhl, C. and P. J. Crutzen , On the disproportionate role of tropospheric ozone as a filter against solar UV-B radiation, *Geophys. Res. Lett.*, 16, 703-706, 1989.

Chen J.G., A. B. Fleischer, Jr, E. D. Smith, .C. Kancler, N. D. Goldman, P.M. Williford, S. R. Feldman. Cost of nonmelanoma skin cancer treatment in the United States. *Dermatol Surg.* 2001; 27(12): 1035-8

Cokkinides VE, Johnston-Davis K, Weinstock M, O'Connell MC, Kalsbeek W, Thun MJ, Wingo PA. Sun exposure and sun-protection behaviors and attitudes among US youth 11 to 18 years of age. Preventive Medicine, 2001, 33:141-151.

de Gruijl F.R. and J.C. van der Leun, Estimate of the wavelength dependency of ultraviolet carcinogenesis and its relevance to the risk assessment of a stratospheric ozone depletion, *Health Phys*,. **4**, 317–323, 1994.

de Gruijl, F.R. and P.D. Forbes (1995), "UV-induced skin cancer in a hairless mouse model," *BioEssays* 17:651-660.

Eder, B, and S. Yu (2006). A performance evaluation of the 2004 release of Model-3 CMAQ. Atmospheric Environment 40(26):4811–4824.

Godar DE, Urbach F, Gasparro FP, van der Leun JC. UV doses of young adults. Photochemistry and Photobiology, 2003, 77(4):43-457.

Joseph, J. H., W. J. Wiscombe and J. A. Weinman, The delta-Eddington approximation for radiative flux transfer, *J. Atmos. Sci.* **33**, 2452-2459, 1976.

Koepke et al., Comparison of models used for UV Index calculations, Photochemistry and Photobiology, 67 (6) 657-662, 1998.

Kyle JW, Hammitt JK, Lim HW, Geller AC, Hall-Jordan LH, Maibach EW, De Fabo EC, Wagner MC. Economic Evaluation of the U.S. Environmental Protection Agency’s SunWise Program: Sun Protection Education for Young Children. Forthcoming in Pediatrics Electronic Pages, May 2008.

Longstreth J.D. (1998), “Melanoma genesis: putative causes and possible mechanisms,” in *Cutaneous Melanoma*, C.M. Balch, A.N. Houghton, A.J. Sober, and S-J. Soong (eds.), St. Louis: Quality Medical Publishing, Inc.

Madronich, S. and F. R. de Gruijl (1994), “Stratospheric ozone depletion between 1979 and 1992: Implications for biologically-active ultraviolet-B radiation and non-melanoma skin cancer incidence,” Photochemistry and Photobiology 59:541-546.

Madronich, S. and G. Weller, Numerical integration errors in calculated tropospheric photodissociation rate coefficients, J. Atmos. Chem., 10, 289-300, 1990.

Madronich, S. and S. Flocke. The role of solar radiation in atmospheric chemistry. In *Handbook of Environmental Chemistry, Volume 2 Part L: Environmental Photochemistry* (Edited by P. Boule), pp. 1-26. Springer-Verlag, Heidelberg, 1999.

Madronich, S., R. E. McKenzie, L. O Björn, and M. M. Caldwell, Changes in biologically active ultraviolet radiation reaching the Earth’s surface, in *Environmental Effects of Stratospheric Ozone Depletion* - 1998 Update (J. van der Leun, M. Tevini, and X. Tang, eds.), United Nations Environmental Programme, Nairobi, November 1998.

Madronich, S. (1999). Some comments on the methods used to estimate the effects of HSCTs on atmospheric ozone, surface UV radiation, and skin cancer incidence. Paper presented at a workshop held by EPA, “Meeting on Next Generational Supersonic Transport Risk Assessment Methods,” November 18–19, 1999 at ICF Consulting, Washington, DC.

Matthews, T.J. and B.E. Hamilton. (2005). Trend Analysis the Sex Ratio at Birth in the United States. *National Vital Statistics Reports 53:20.* Available online at: http://www.cdc.gov/nchs/data/nvsr/nvsr53/nvsr53_20.pdf

McKinlay, A. F. and Diffey, B. L., A reference action spectrum for ultraviolet induced erythema in human skin. In *Human Exposure to Ultraviolet Radiation: Risks and Regulations* (Edited by W. R. Passchier and B. F. M. Bosnjakovic), pp. 83-87. Elsevier, Amsterdam, 1987.

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

Nack, M. L. and A. E. S. Green, Influence of clouds, haze, and smog on the middle ultraviolet reaching the ground., 12, 2405-2415, 1974.

National Center for Health Statistics (2007). *Bridged-race Vintage 2006 Postcensal Population Estimates for July 1, 2000–July 1, 2006*. Available online at: http://www.cdc.gov/nchs/about/major/dvs/popbridge/datadoc.htm

Petropavlovskikh, I. *Evaluation of Photodissociation Coefficient Calculations for Use in Atmospheric Chemical Models*, Ph.D. thesis, U. of Brussels/NCAR Cooperative Thesis No. 159, National Center for Atmospheric Research, Boulder, 1995.

Pitcher, H.M., and J.D. Longstreth (1991), "Melanoma mortality and exposure to ultraviolet radiation: An empirical relationship," Environment International 17:7-21.

Toon, O. B., C. P. McKay, T. P. Ackerman, and K. Santhanam, *J. Geophys. Res*., **94**, 16287, 1989.

U.S. Bureau of Labor Statistics, Department of Labor. Occupational Employment Statistics (OES) Survey: May 2005 National OES Estimates. [cited 2007 Dec 26]. Available from: http://www.bls.gov/oes/.

U.S. Census Bureau (2000). *Component Assumptions of the Resident Population by Age, Sex, Race, and Hispanic Origin*. Available online at: http://www.census.gov/population/www/projections/natdet-D5.html

U.S. Census Bureau (2005). *State Interim Population Projections by Age and Sex: 2004–2030*. Available online at: http://www.census.gov/population/www/projections/projectionsagesex.html

U.S. Environmental Protection Agency. EPA Guidelines for Preparing Economic Analyses. Washington, DC: Office of the Administrator, U.S. Environmental Protection Agency; 2001. Report No. 240-R-00-003.

U.S. EPA (2003). Human Health Benefits of Stratospheric Ozone Protection. Global Programs Division, Office of Air and Radiation, U.S. EPA, Washington, DC.

U.S. EPA and NASA (2001). Human Health Effects of Ozone Depletion From Stratospheric Aircraft. U.S. EPA, Washington, DC

U.S. EPA (2008). Personal communication.

U.S. Environmental Protection Agency. Regulatory Impact Analysis: Protection of Stratospheric Ozone, E. Final Report. 1988.

USSA, *US Standard Atmosphere* National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, United States Air Force, Washington D.C., 1976.

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

Appendix A: Ground Level SCUP-h UV with 70 and 84 ppb by Day

This Appendix will provide a series of maps showing ground level SCUP-h UV levels under 70 and 84 ppb NAAQS for ozone for several specific days in the summer months – June 1, June 20, July 1, and August 1.

Figure A-1: Ground Level SCUP UV, June 1; 70 ppb Scenario

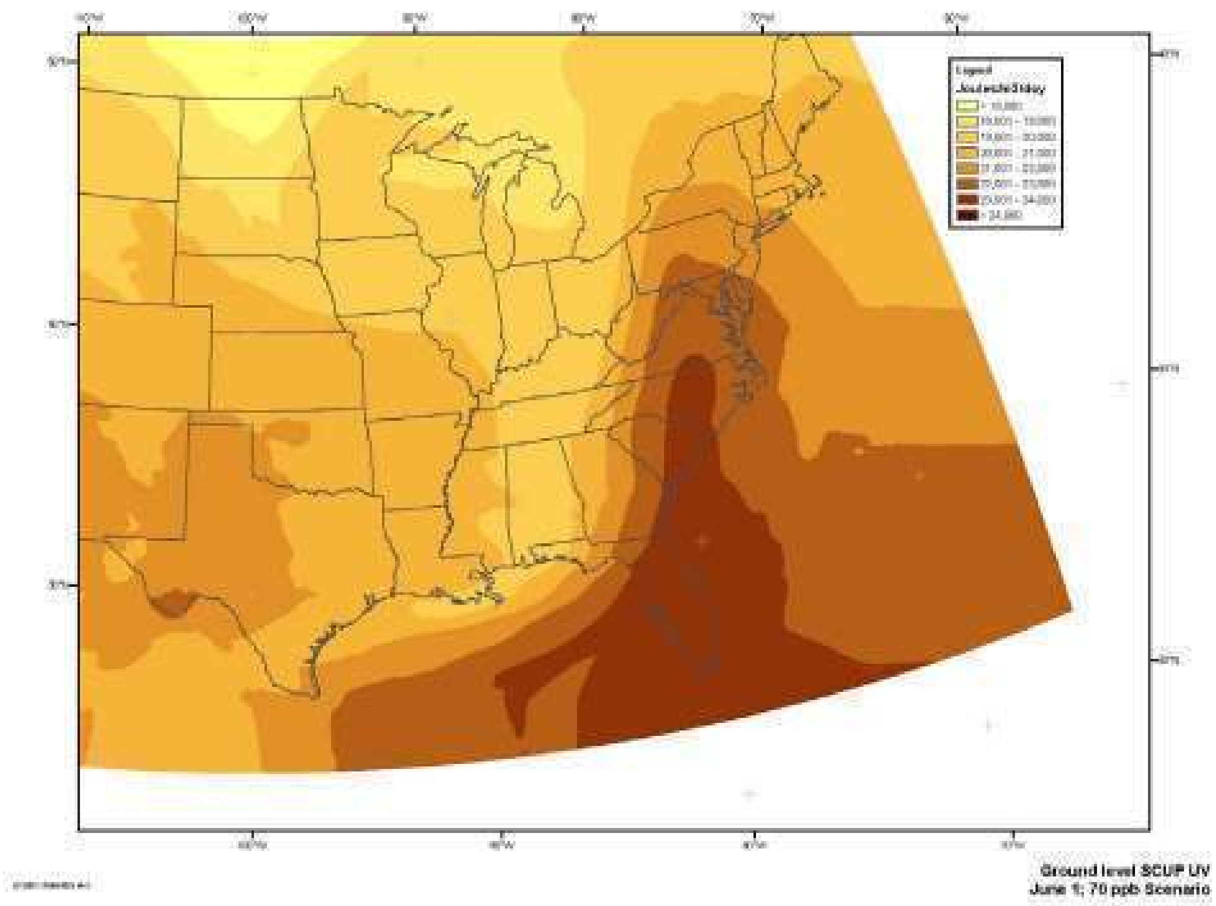


Figure A-2: Ground Level SCUP UV, June 1; 84 ppb Scenario

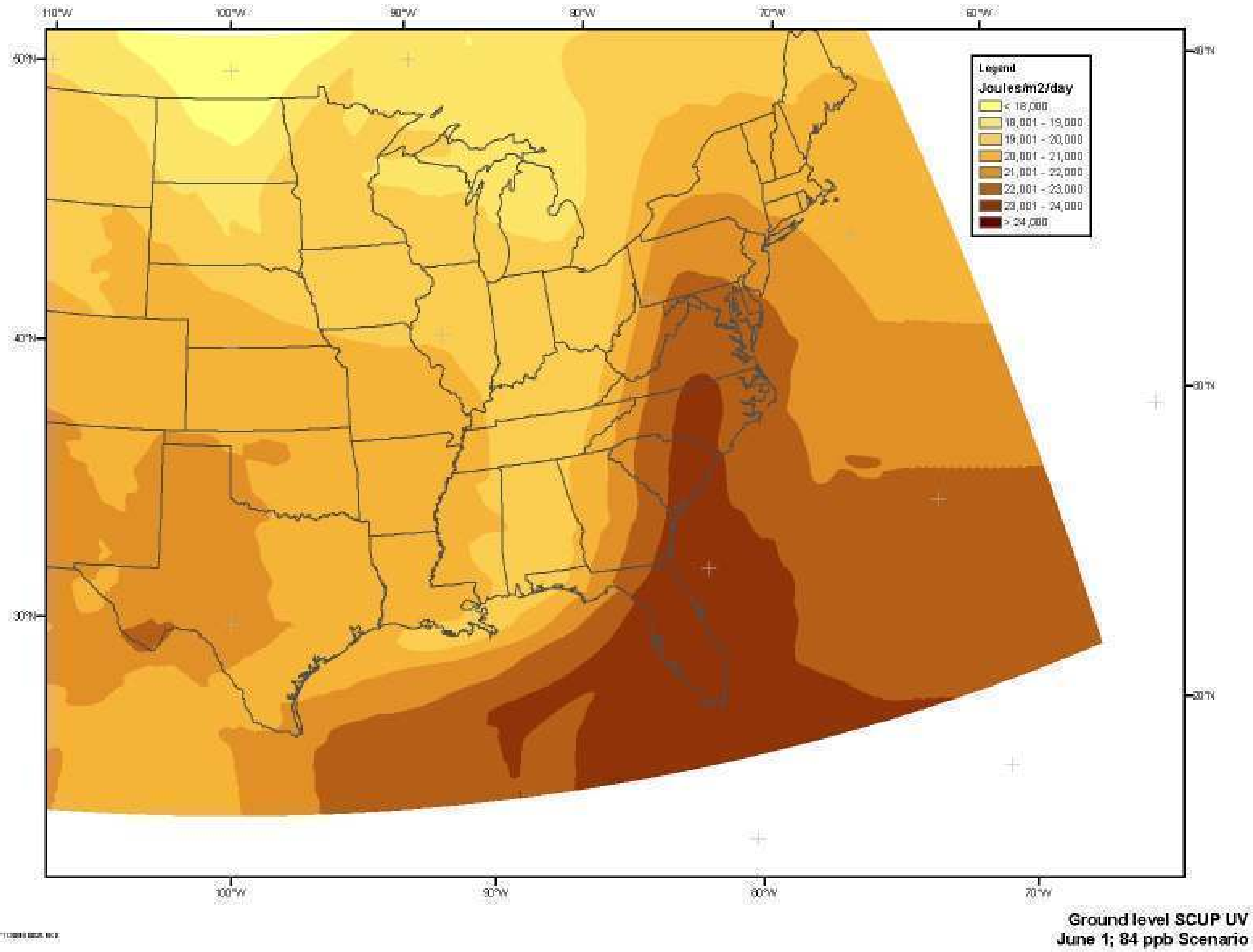


Figure A-3: Ground Level SCUP UV, June 20; 70 ppb Scenario

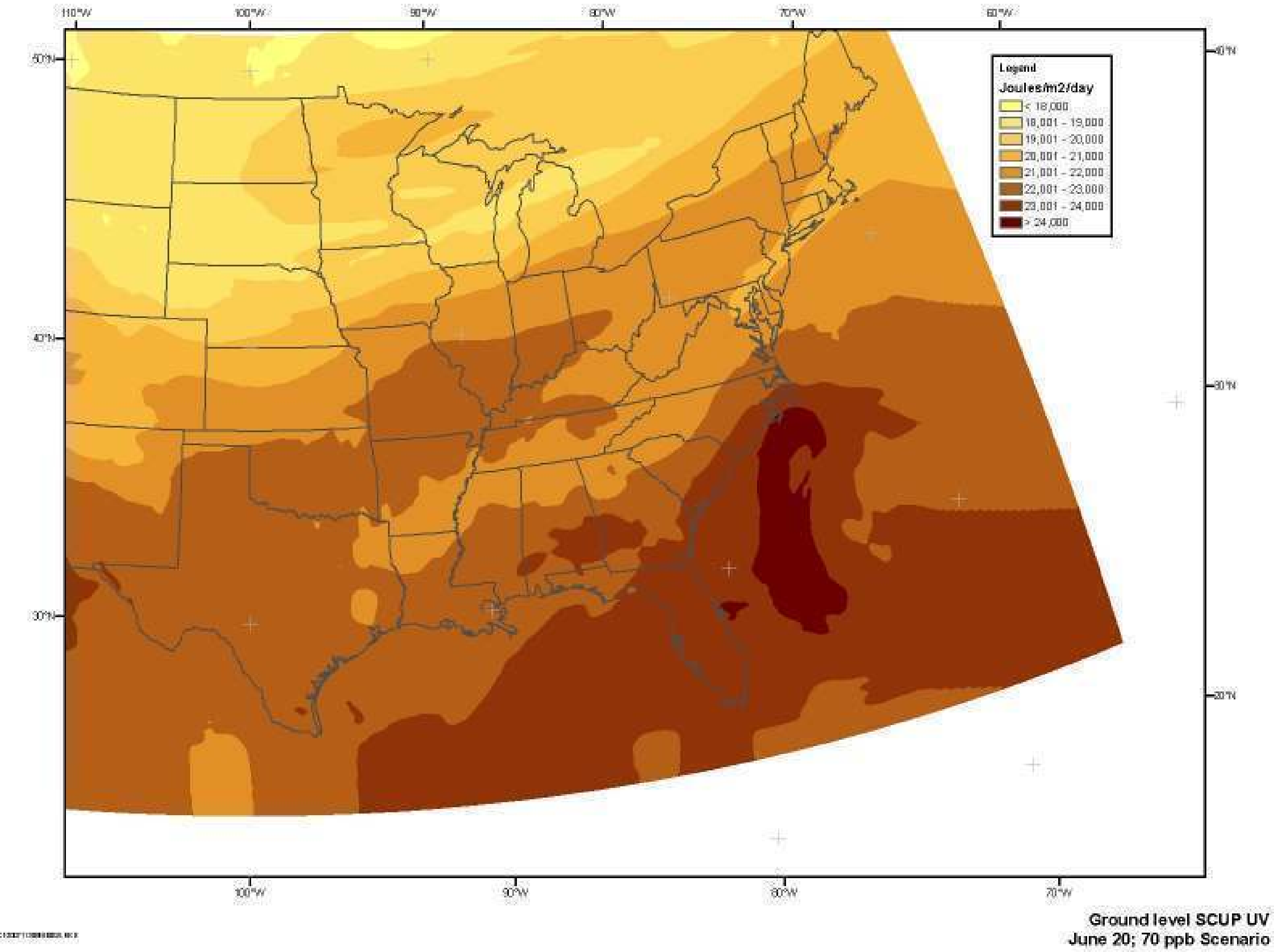


Figure A-4: Ground Level SCUP UV, June 20; 84 ppb Scenario

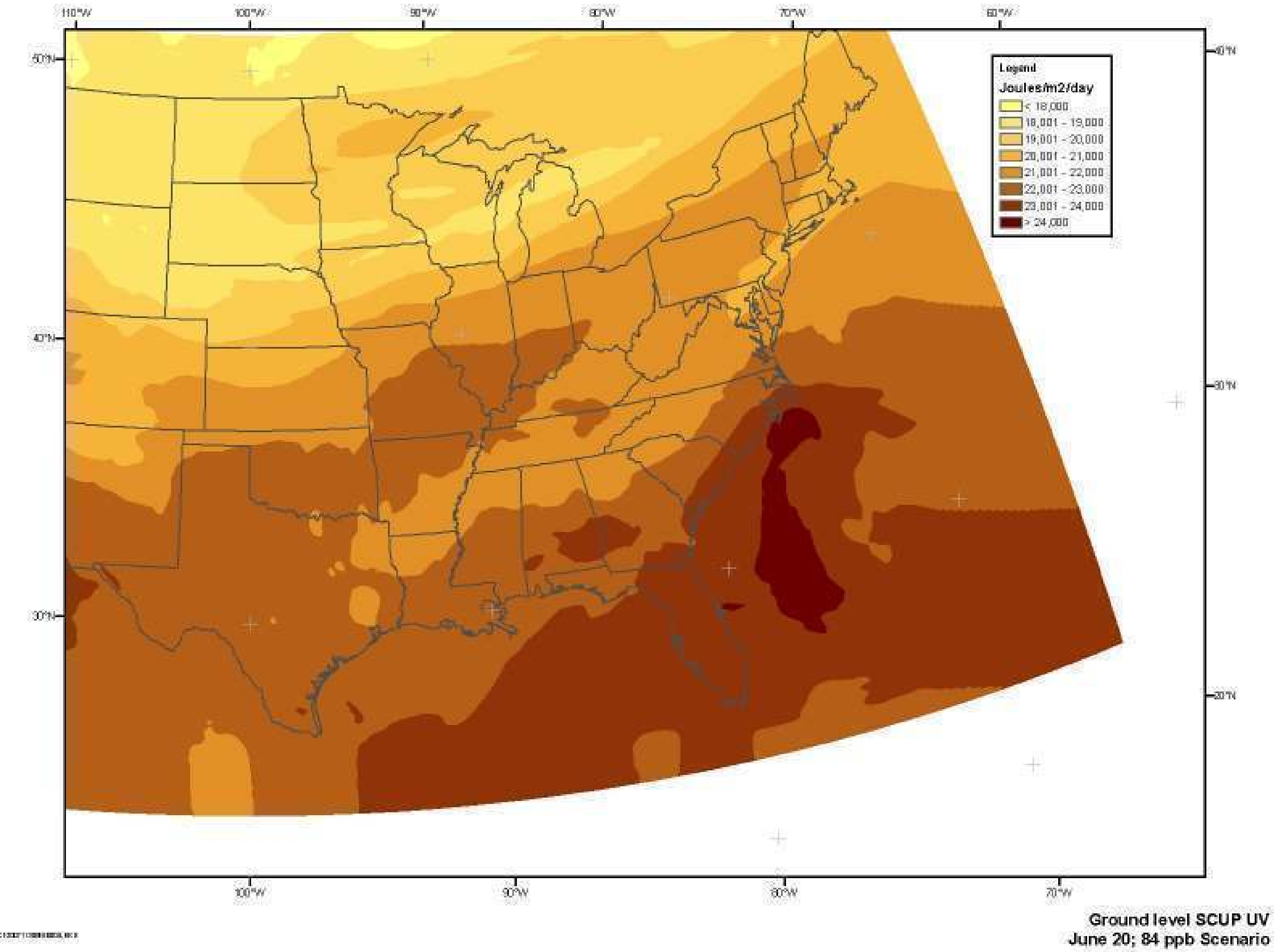


Figure A-5: Ground Level SCUP UV, July 1; 70 ppb Scenario

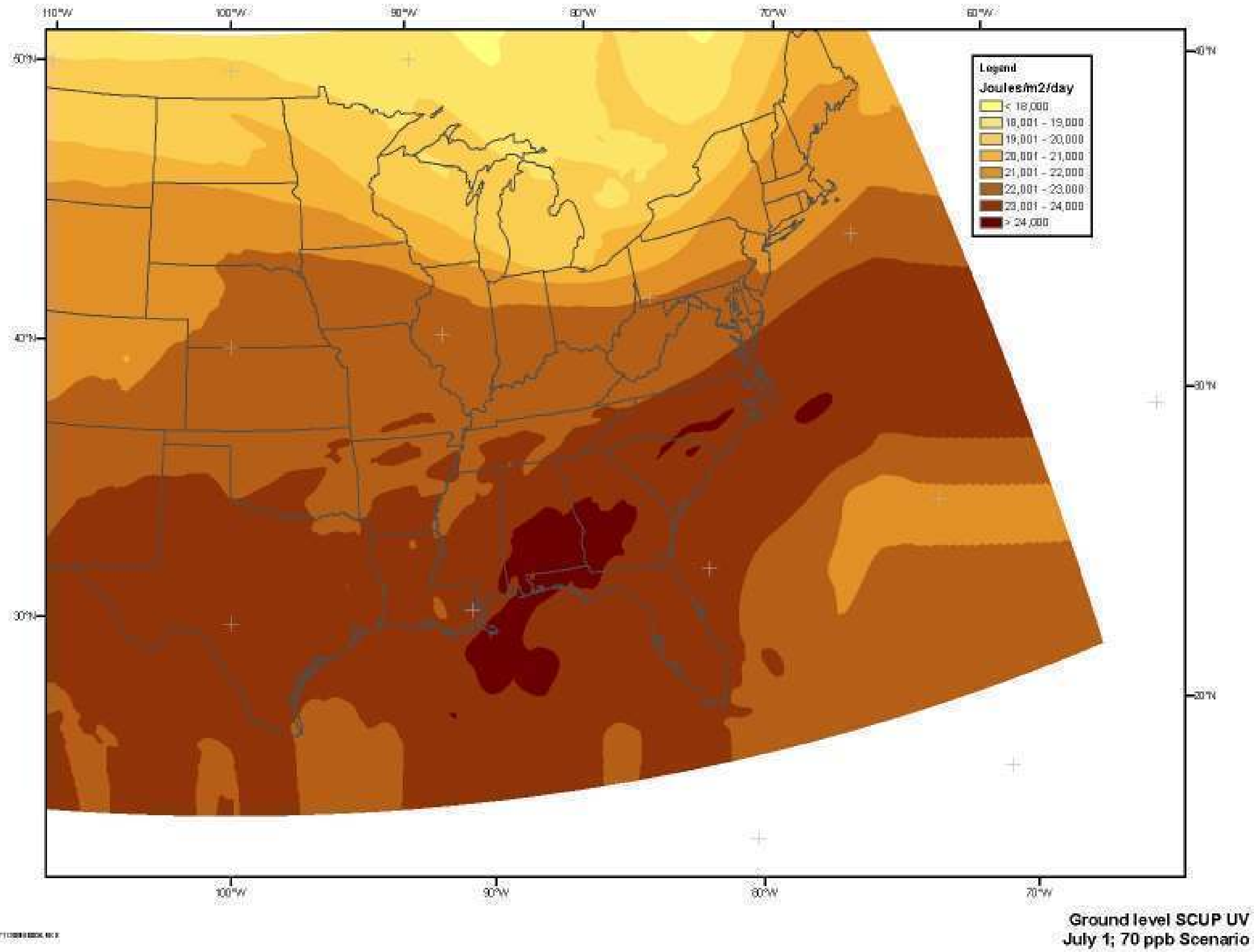


Figure A-6: Ground Level SCUP UV, July 1; 85 ppb Scenario

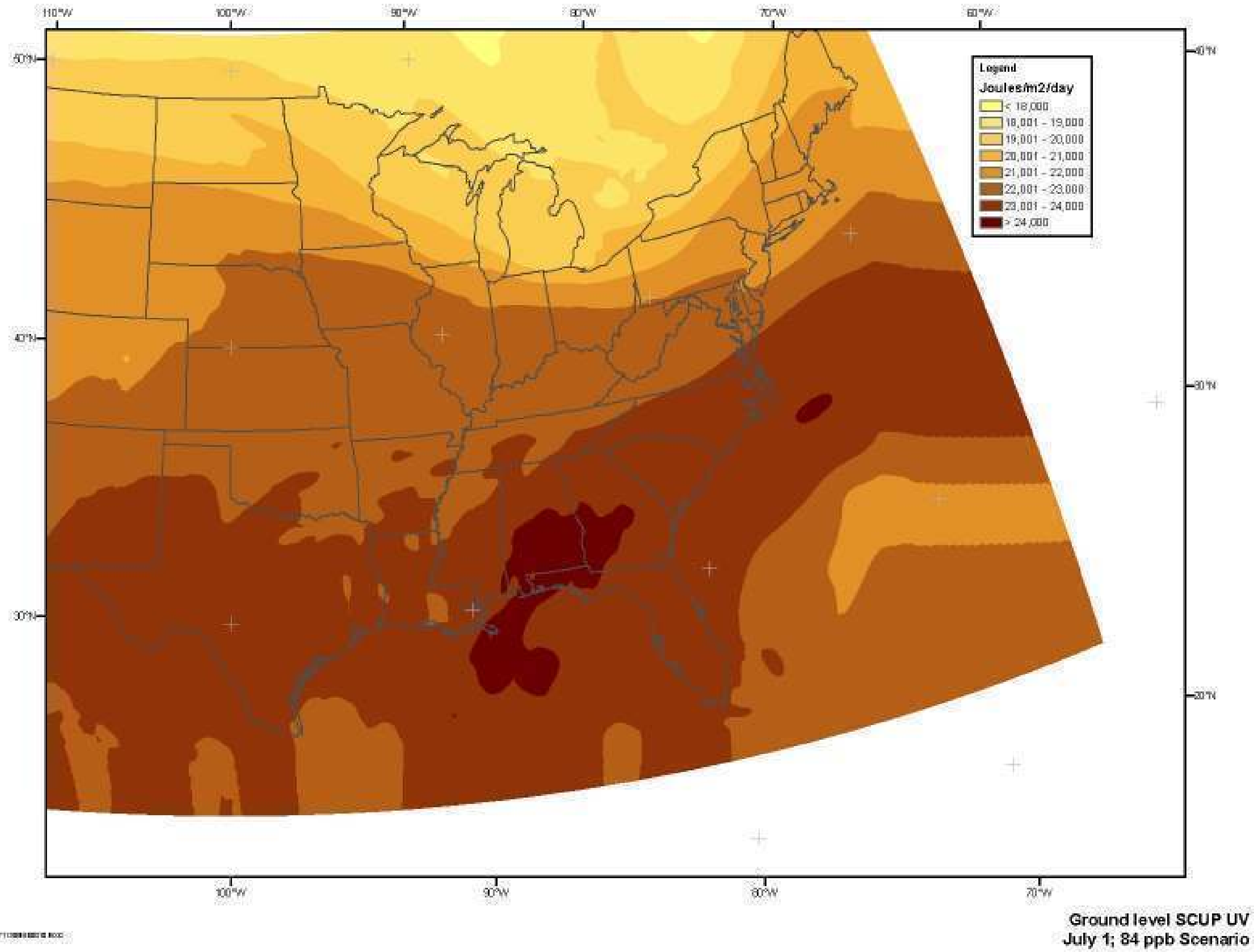


Figure A-7: Ground Level SCUP UV, August 1; 70 ppb Scenario

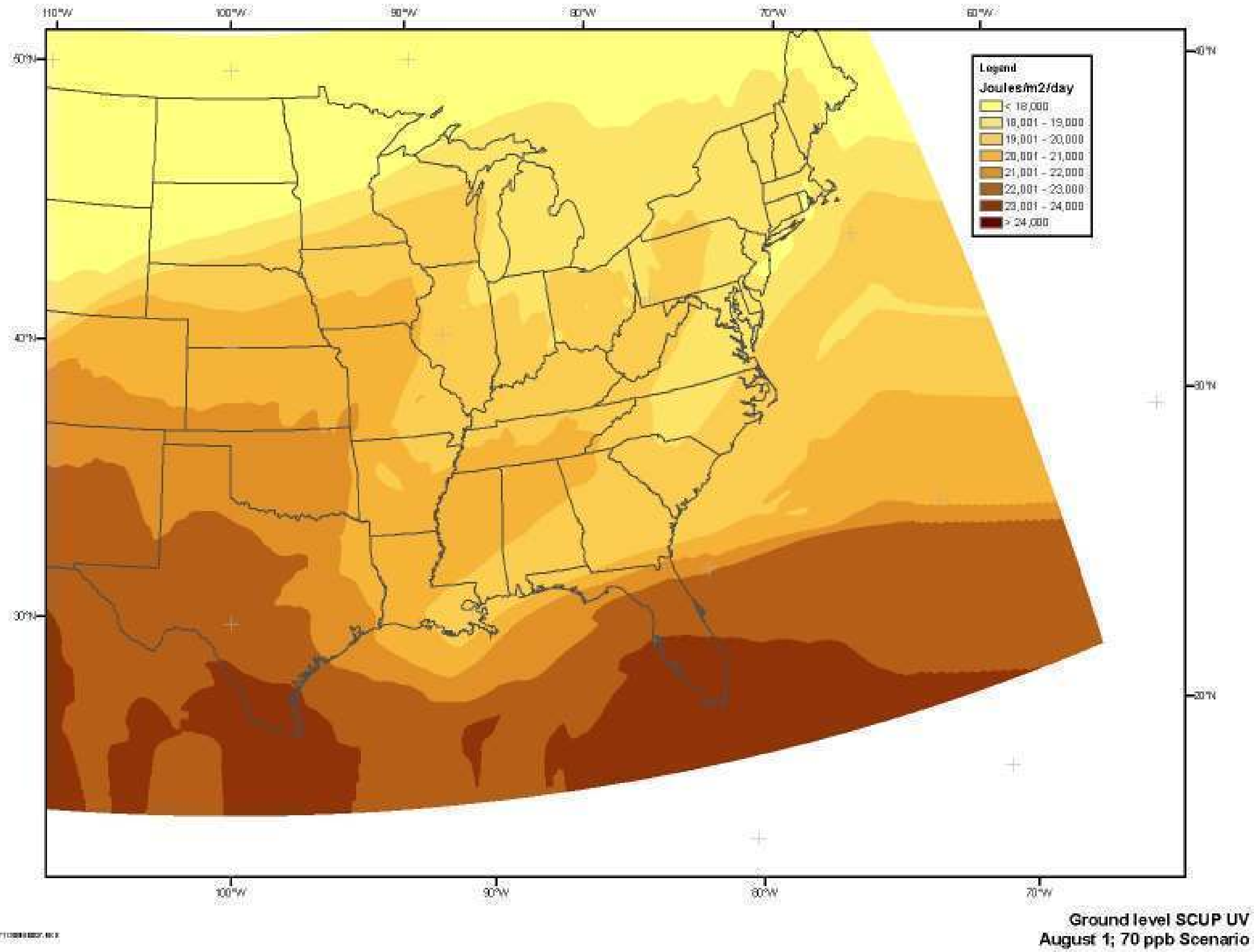
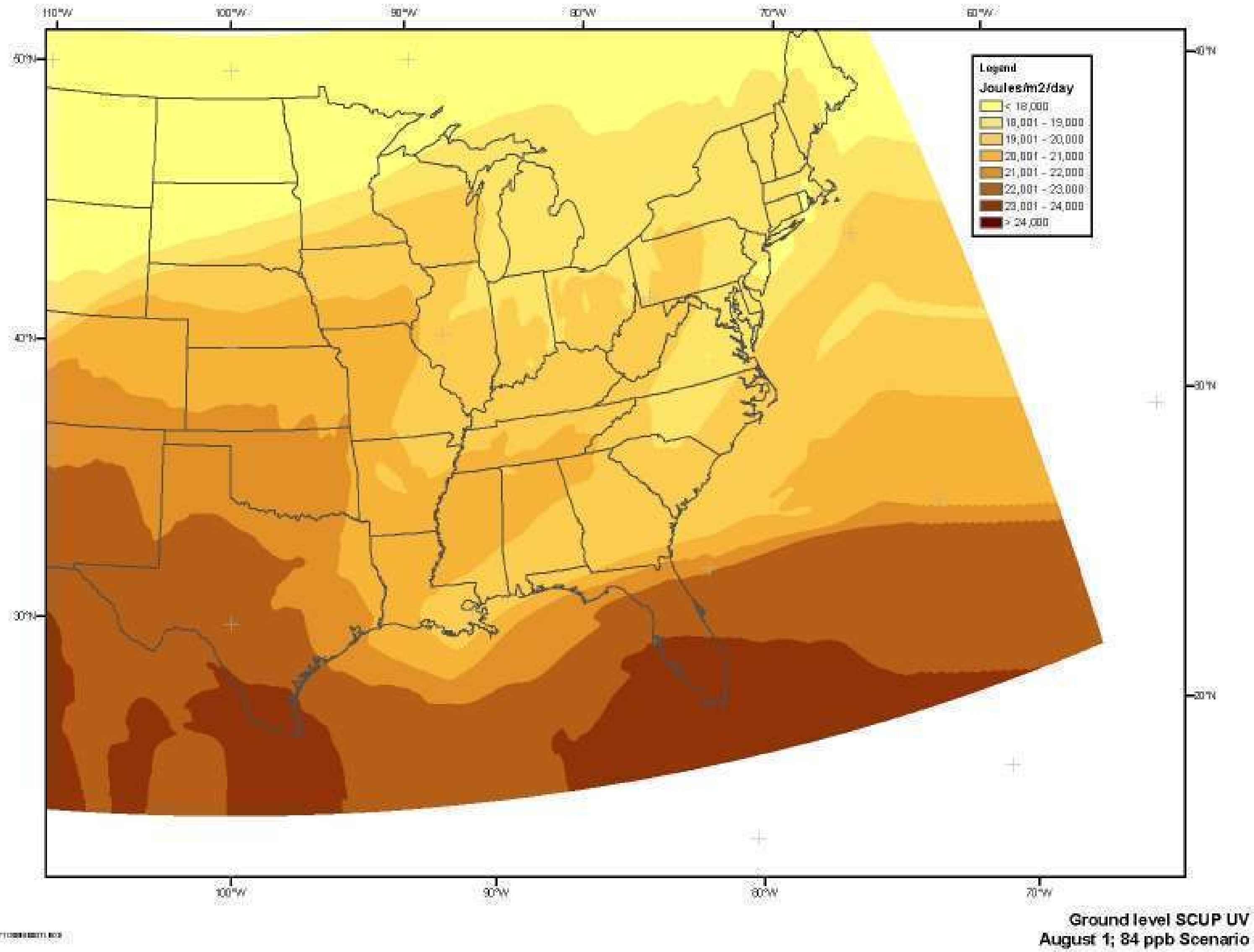
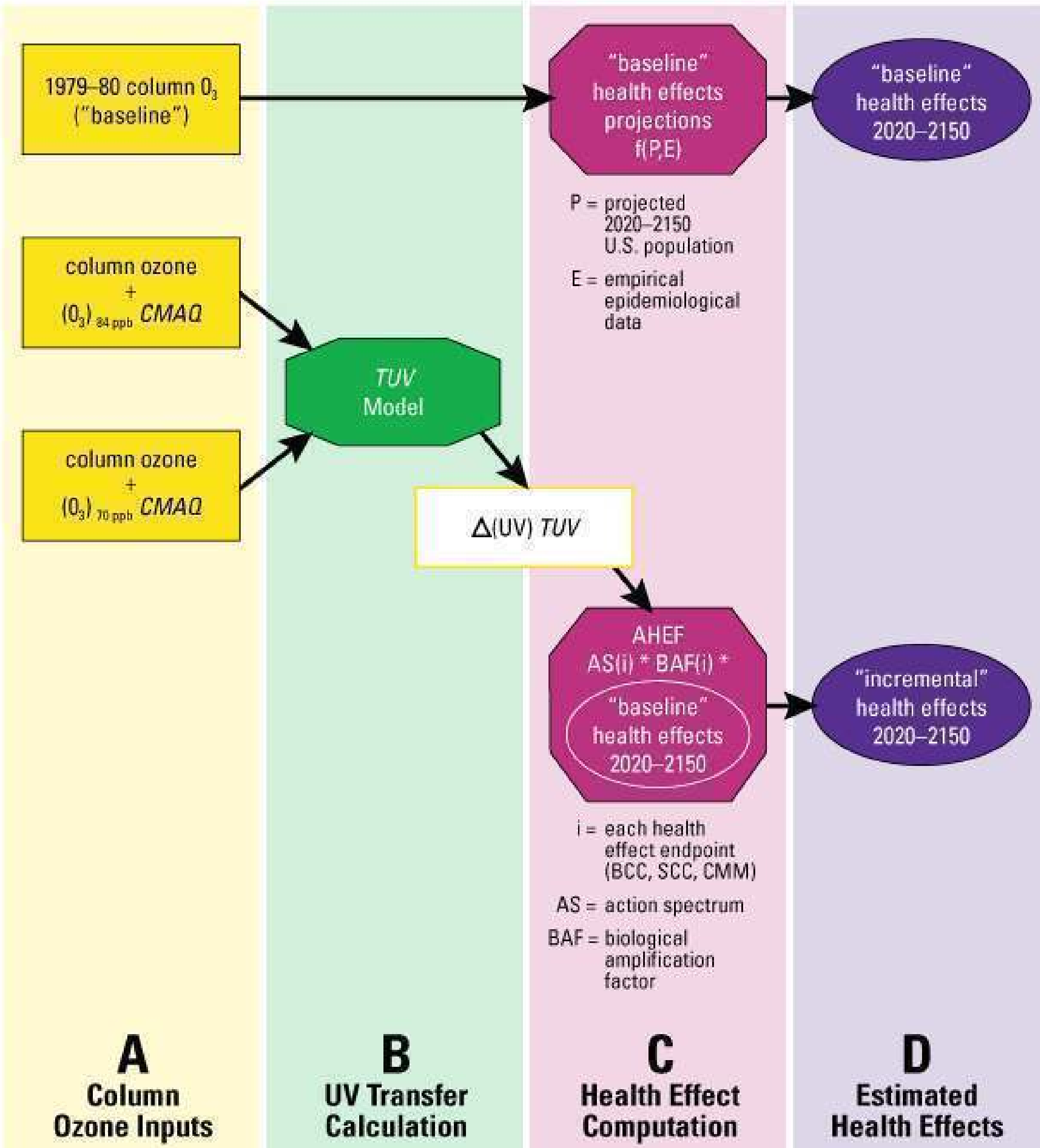


Figure A-8: Ground Level SCUP UV, August 1; 84 ppb Scenario



Appendix B: Overview of Evaluation Methodology

The schematic presented below provides a graphical summary of the method used in this evaluation. Atmospheric inputs to the process are listed along the left-hand side and the various process stages are described along the bottom.



Glossary

AHEF	Atmospheric and Health Effects Framework
BAF	Biological Amplification Factor
BAU	Business as Usual
BCC	Basal Cell Carcinoma
BLS	Bureau of Labor Statistics
CDC	Centers for Disease Control and Prevention
CMAQ	Community Multiscale Air Quality
CMM	Cutaneous Malignant Melanoma
DU	Dobson Units
EPA	United States Environmental Protection Agency
NAAQS	National Ambient Air Quality Standard
NCEE	National Center for Environmental Economics
NCI	National Cancer Institute
OAR	Office of Air and Radiation
SCC	Squamous Cell Carcinoma
SCUP-h	Skin Cancer Utrecht-Philadelphia-human
sza	solar zenith angle
TOCOR	Task Order Contracting Representative
USSA	United States Standard Atmosphere

Chapter 7: Conclusions and Implications of the Illustrative Benefit-Cost Analysis

7.1 Synopsis

EPA has performed an illustrative analysis to estimate the costs and human health benefits of nationally attaining alternative 0.075 ppm ozone standard. We have also considered 3 alternative standards incremental to attaining the current ozone standard: 0.079 ppm, 0.070 ppm, and 0.065 ppm. This chapter summarizes these results and discusses the implications of the analysis. This analysis serves both to satisfy the requirements of E.O. 12866 and to provide the public with an estimate of the potential costs and benefits of attaining alternative ozone standards. 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 full attainment of the current standards for ozone and PM NAAQS (including the hypothetical control strategy developed in the RIA for full attainment of the PM NAAQS 15/35 promulgated in September, 2006). This RIA presents the costs and benefits of full attainment in all locations except two areas of California, which would not be required to meet an alternate primary standard until 2024. Estimates for these two areas are presented in Appendix 7b. This chapter provides additional context for the RIA analysis and a discussion of limitations and uncertainties.

7.2 Results

7.2.1 Presentation of Results

For analytical purposes explained previously, we assume that almost all areas of the country will meet each alternate primary standard in 2020 through the development of technologies at least as effective as the hypothetical strategies used in this illustration. It is expected that benefits and costs will begin occurring earlier, as states begin implementing control measures to attain earlier or to show progress towards attainment. Some areas with very high levels of ozone do not plan to meet even the current standard until 2024; specifically, two California areas have adopted plans for post-2020 attainment as noted above. To perform an analysis beyond 2020 involves the use of highly speculative assumptions that introduce a much higher level of uncertainty to the results. Thus, in these locations, we provide estimates of the costs and benefits of fully attaining the alternate primary standards at a later date (2030) in Appendix 7b. It is important to note that, as a result, the 2020 results presented here do not represent a complete "full attainment" scenario for the entire nation. Due to the differences in attainment year and other assumptions underlying 2020 analysis presented here and the 2030 analysis in the appendix, it is not appropriate to add the results together to get a national "full attainment" scenario. Finally, Appendix 6b contains a health-based cost effectiveness analysis that complements the results found below.

The following two tables summarize the costs and benefits of attaining the alternate primary standards in 2020 for all places except South Coast and San Joaquin. For purposes of this analysis, we assume attainment by 2020 for all areas except San Joaquin Valley and South Coast air basins in California. The state has submitted plans to EPA for implementing the current ozone standard which propose that these two areas of California meet that standard by 2024. We have assumed for analytical purposes that the San Joaquin Valley and South Coast air basin would attain a new standard in 2030. There are many uncertainties associated with the year 2030 analysis. Between 2020 and 2030 several federal air quality rules are likely to further reduce emissions of NOx and VOC, such as, but not limited to National rules for Diesel Locomotives, Diesel Marine Vessels, and Small Nonroad Gasoline Engines. These emission reductions should lower ambient levels of ozone in California between 2020 and 2030. Complete emissions inventories as well as air quality modeling were not available for this year 2030 analysis. Due to these limitations, it is not possible to adequately model 2030 air quality changes that are required to develop robust controls strategies with associated costs and benefits. In order to provide a rough approximation of the costs and benefits of attaining 0.075 ppm and the alternate standards in San Joaquin and South Coast air basins, we have relied on the available data. Available data includes emission inventories, which do not include any changes in stationary source emissions beyond 2020, and 2020 supplemental air quality modeling. This data was used to develop extrapolated costs and benefits of 2030 attainment. To view the complete analysis for the San Joaquin Valley and South Coast air basins see Appendix 7b.

The costs presented here are based on reducing emissions primarily within 200 km of counties projected to fail to attain a particular standard. Changes in emissions translate into changes in ozone within and beyond the 200 km control areas. Air quality modeling is used to estimate where the changes in ozone resulting from emission changes takes place. Benefits are then estimated based on the modeled changes in ozone.

Tables 7.1a-d present benefits and costs. Table 7.2 provides the estimated reductions in premature mortality and morbidity.

Table 7.1a: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.075 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	2.6 – 17	2.4 – 16	7.6 – 8.8	–6.3 – 9.5	–6.4 – 7.9
Meta-analysis	Bell et al. 2005	3.8 – 18	3.6 – 17	7.6 – 8.8	–5.0 – 11	–5.2 – 9.1
	Ito et al. 2005	4.4 – 19	4.3 – 17	7.6 – 8.8	–4.4 – 11	–4.5 – 9.8
	Levy et al. 2005	4.5 – 19	4.4 – 17	7.6 – 8.8	–4.3 – 11	–4.5 – 9.9
Assumption that association is not causal****		2.0 – 17	1.8 – 15	7.6 – 8.8	–6.8 – 9	–7.0 – 7.4

Table 7.1b: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.079 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	1.4 – 11	1.3 – 9.9	2.4 – 2.9	–1.5 – 8.5	–1.6 – 7.5
Meta-analysis	Bell et al. 2005	1.9 – 11	1.8 – 10	2.4 – 2.9	–1.1 – 8.9	–1.2 – 7.9
	Ito et al. 2005	2.1 – 12	2.0 – 11	2.4 – 2.9	–0.83 – 9.2	–0.9 – 8.1
	Levy et al. 2005	2.1 – 12	2.0 – 11	2.4 – 2.9	–0.80 – 9.2	–0.9 – 8.2
Assumption that association is not causal****		1.2 – 11	1.1 – 9.7	2.4 – 2.9	–1.7 – 8.3	–1.8 – 7.3

Table 7.1c: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.070 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	5.4 – 29	5.1 – 27	19 – 25	–20 – 10	–20 – 7.6
Meta-analysis	Bell et al. 2005	9.7 – 34	9.5 – 31	19 – 25	–15 – 15	–16 – 12
	Ito et al. 2005	12 – 36	12 – 33	19 – 25	–13 – 17	–13 – 14
	Levy et al. 2005	12 – 36	12 – 33	19 – 25	–13 – 17	–13 – 14
Assumption that association is not causal****		3.5 – 27	3.2 – 25	19 – 25	–22 – 8	–22 – 5.7

Table 7.1d: Estimated Range of Annual Monetized Costs and Ozone Benefits and $PM_{2.5}$ Co-Benefits: 0.065 ppm Standard in 2020 in Billions of 2006$*

Ozone Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs*** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	9.0 – 46	8.6 – 42	32 – 44	–35 – 14	–35 – 9.7
Meta-analysis	Bell et al. 2005	17 – 54	16 – 50	32 – 44	–27 – 22	–28 – 18
	Ito et al. 2005	21 – 58	21 – 54	32 – 44	–23 – 26	–23 – 22
	Levy et al. 2005	21 – 58	21 – 54	32 – 44	–23 – 26	–23 – 22
Assumption that association is not causal****		5.5 – 42	5.1 – 38	32 – 44	–39 – 10	–39 – 6.2

*All estimates rounded to two significant figures. As such, they may not sum across columns. These estimates do not include visibility benefits. Only includes areas required to meet the current standard by 2020, does not include San Joaquin and South Coast areas in California. Appendix 7b shows the costs and benefits of attaining alternate standards in San Joaquin and South Coast California.

**Includes ozone benefits, and PM 2.5 co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. Tables exclude unquantified and nonmonetized benefits.

***Range reflects lower and upper bound cost estimates. Data for calculating costs at a 3% discount rate was not available for all sectors, and therefore total annualized costs at 3% are not presented here. Additionally, these estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

****Total includes ozone morbidity benefits and total PM co-benefits only.

The individual row estimates for benefits reflect the variability in the functions available for estimating a major source of benefits—avoided ozone premature mortality. Ranges within the total benefits column reflect variability in the estimates of PM premature mortality co-benefits across the available effect estimates. Ranges in the total costs column reflect different assumptions about the extrapolation of costs. The low end of the range of net benefits is constructed by subtracting the highest cost from the lowest benefit, while the high end of the range is constructed by subtracting the lowest cost from the highest benefit. Following these tables is a discussion of the implications of these estimates, as well as the uncertainties and limitations that should be considered in interpreting the estimates. These tables do not include visibility benefits, which are estimated at $160 million/yr.

Below are three graphs illustrating the net benefits of the selected and alternative standards. Figures 7.1 and 7.2 provide visual depictions of all available net benefit estimates. Figure 7.3 contains a subset of estimates from the graphic above, displaying four combinations of ozone and PM benefits estimates with the two primary cost estimates for each alternative. These figures depict the richness and variability in the estimates of costs and benefits that may not be captured by the truncated summary tables above.

Figure 7.1 displays all possible combinations of net benefits, utilizing the five different ozone functions, the fourteen different PM functions, and the two cost methods. Each of the 140 bars in each graph represents an independent and equally probability point estimate of net benefits under a certain combination of cost and benefit estimation methods. Thus it is not possible to infer the likelihood of any single net benefit estimate. The blue bars indicate combinations where the net benefits are negative, whereas the green bars indicate combinations where net benefits are positive.

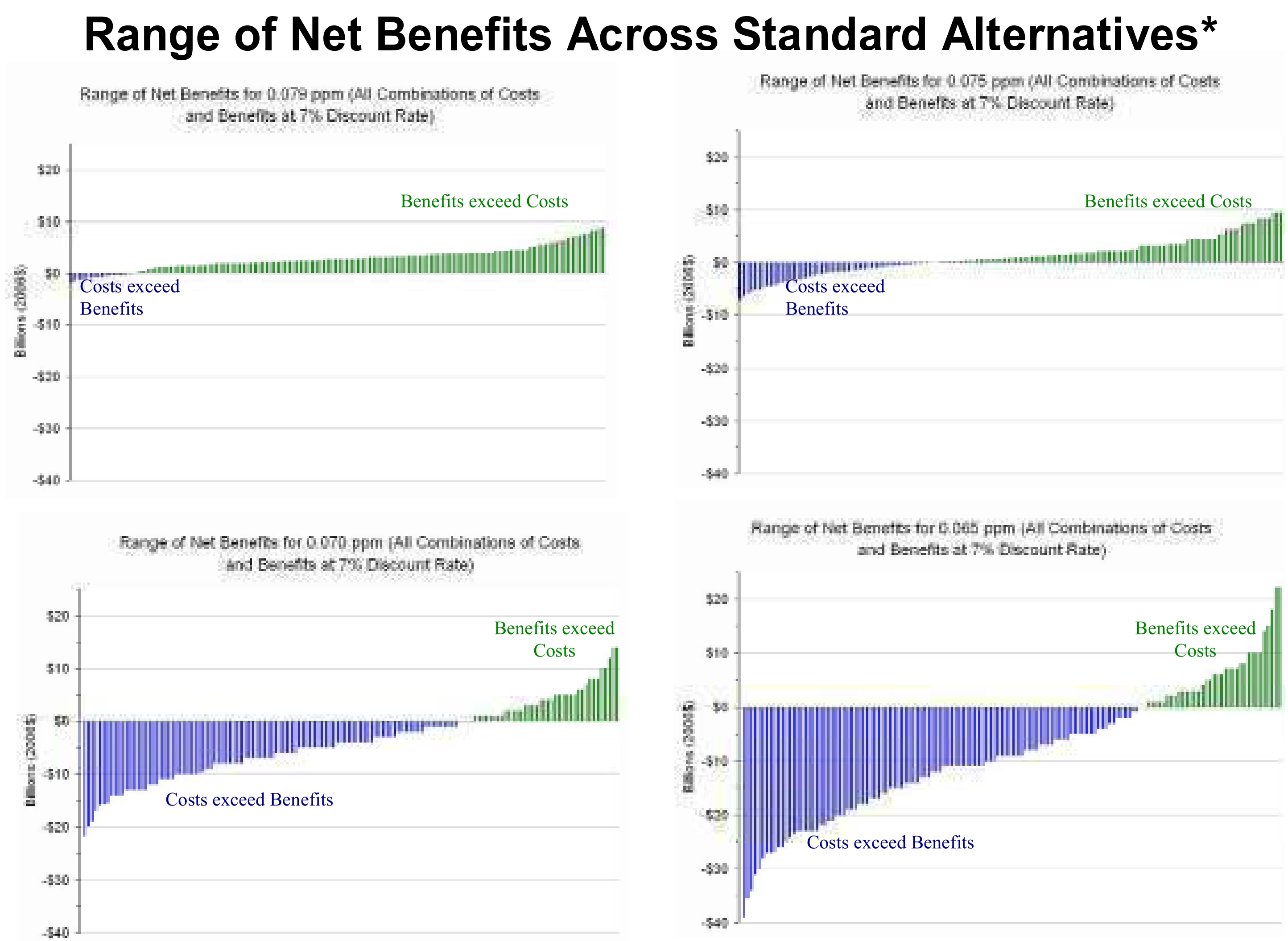
Figure 7.2 displays a close-up view of the range of net benefits for the selected standard. For the selected standard of 0.075 ppm, the median value of all of the independent point estimates is $0.8 billion, and the majority (64%) of the combinations indicate positive net benefits for this standard.

Figure 7.3 illustrates a subset of the net benefit estimates shown in Figure 7.1. While we treat each combination of costs and benefit estimates as being equally probable in our model, here we select a series of combinations of an ozone benefits estimate, a $PM_{2.5}$ co-benefit estimate, and a cost estimate. Consistent with the distribution shown in Figure 7.1 above, the net benefits estimate is very sensitive to the choice of ozone mortality function, $PM_{2.5}$ mortality function, and cost estimation approach. These intermediate combinations (which are discussed more completely in the benefits chapter) represent reference points:

- Bell 2004 is the epidemiological study that underlies the ozone NAAQS risk assessment and Pope is the PM mortality function that was in several EPA RIAs, and
- Bell 2005 is one of three ozone meta-analyses and Laden is a more recent PM epidemiological study that was used as an alternative in the PM NAAQS RIA

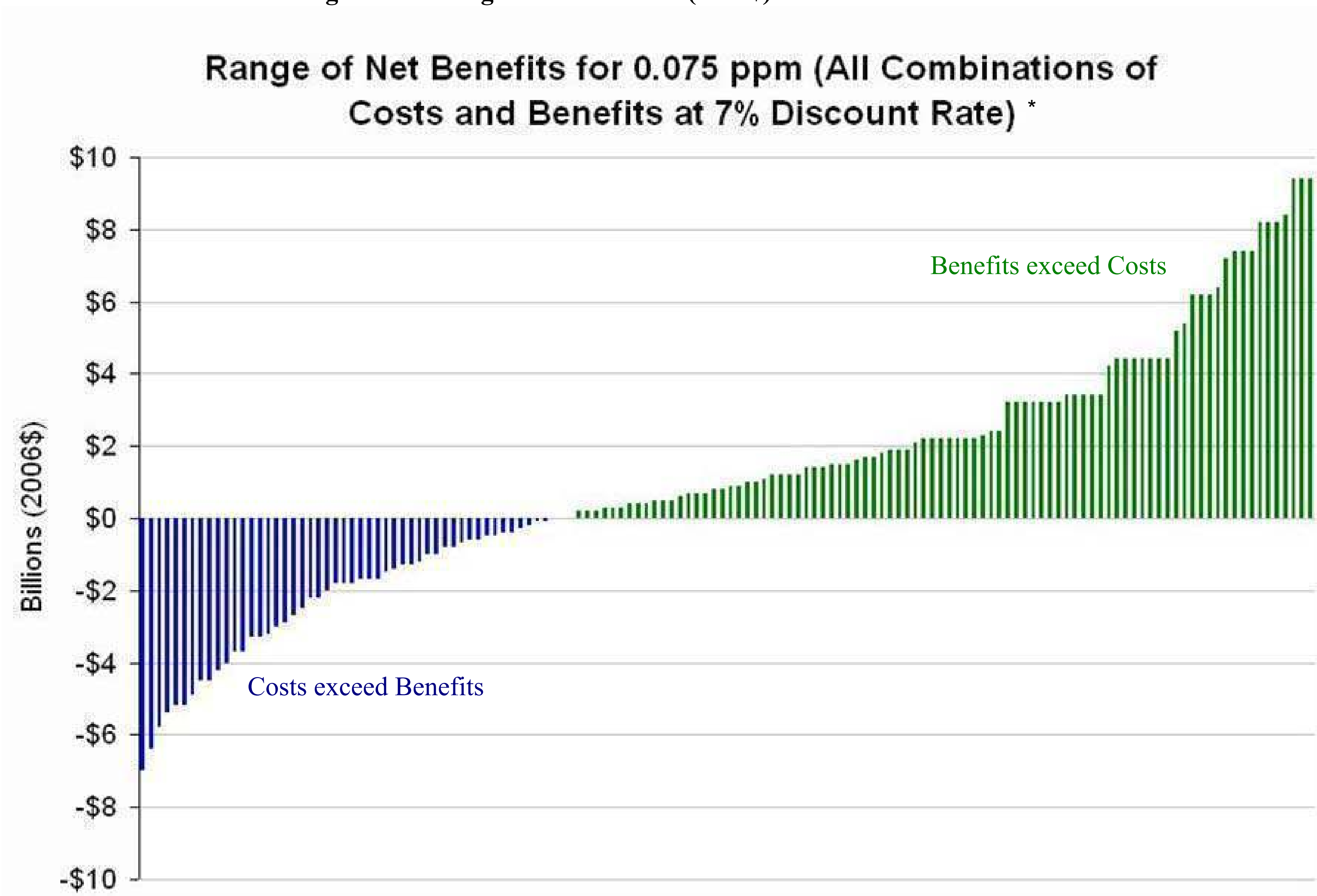
These figures show that for the intermediate points on the distribution the costs and benefits of the selected standard are slightly positive or slightly negative. The tails of the distribution, depending on the specific combination of assumptions, show that benefits are either significantly higher than costs (over $10 billion in net benefits) or that the benefits are significantly lower than costs (roughly negative $6 billion in net benefits).

Figure 7.1: Range of Net Benefits (2006$) for All Standard Alternatives (7% discount)



* This graph shows all 140 combinations of the 5 different ozone mortality functions and assumptions, the 14 different PM mortality functions, and the 2 cost methods. All combinations are treated as independent and equally probable. These estimates do not include visibility benefits, which are estimated at $160 million/yr. Only includes areas required to meet the current standard by 2020, does not include San Joaquin and South Coast areas in California.

Figure 7.2: Range of Net Benefits (2006$) for Selected Standard

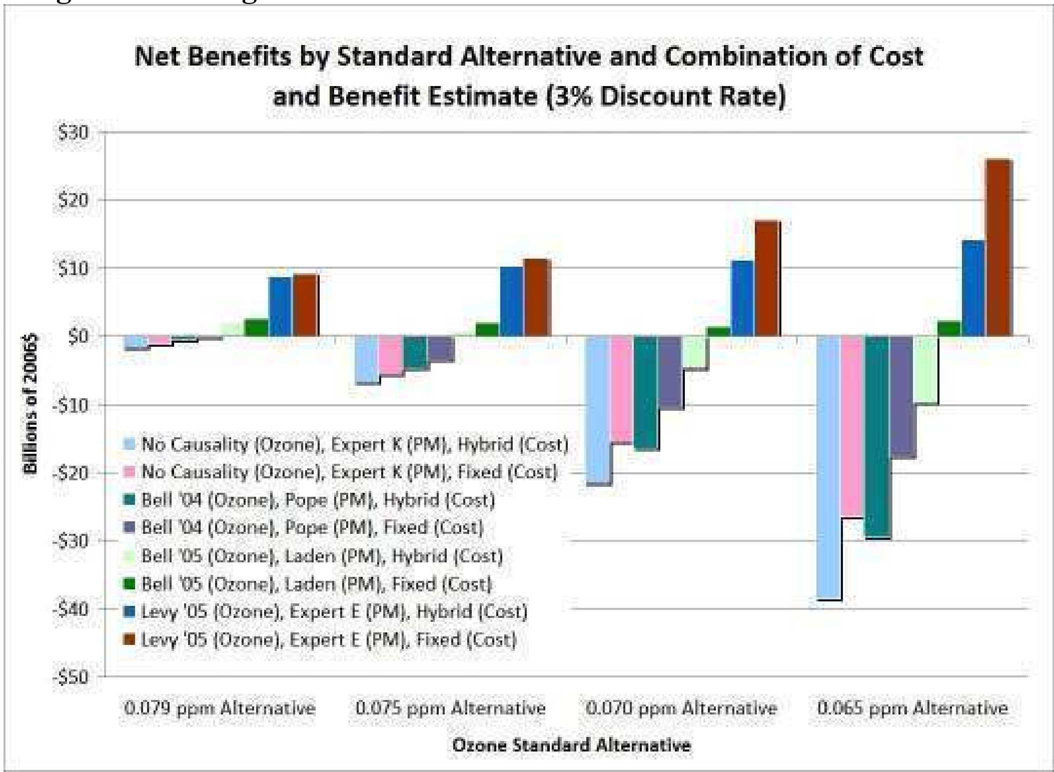


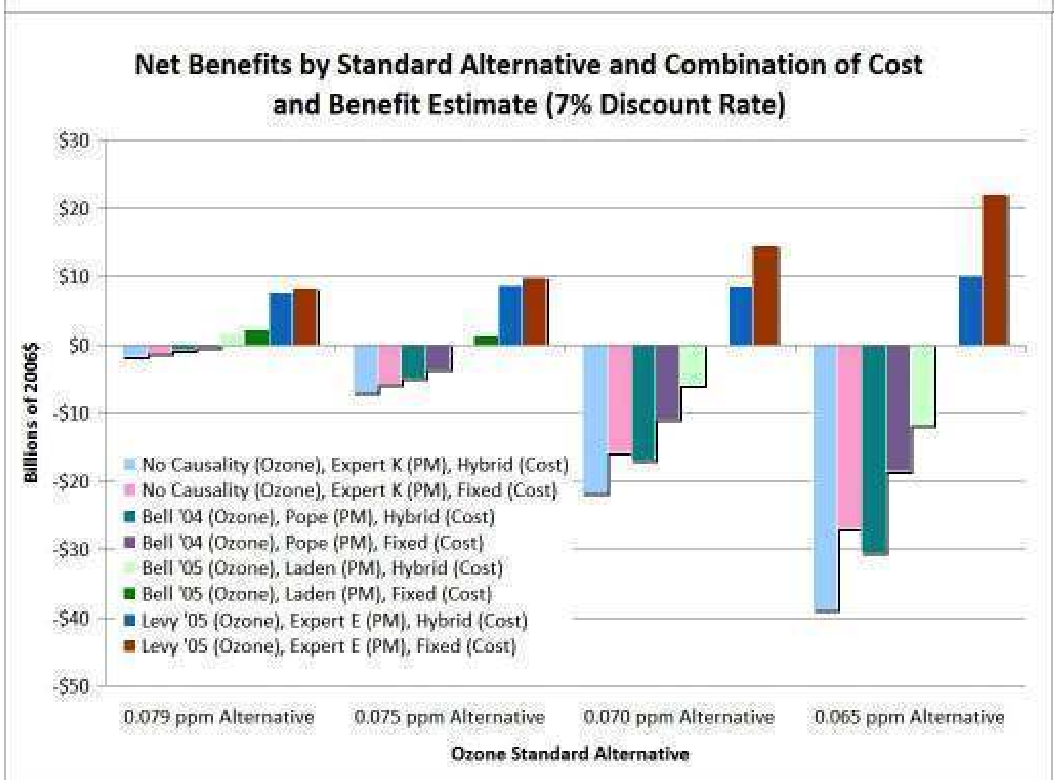
* This graph shows all 140 combinations of the 5 different ozone mortality functions and assumptions, the 14 different PM mortality functions, and the 2 cost methods. All combinations are treated as independent and equally probable.

For the selected standard of 0.075 ppm, the median value of all of the independent point estimates is $0.8 billion, and the majority (64%) of the combinations indicate positive net benefits for this standard.

These estimates do not include visibility benefits, which are estimated at $160 million/yr. Only includes areas required to meet the current standard by 2020, does not include San Joaquin and South Coast areas in California.

Figure 7.3: Range of Net Benefits for Select Combinations at 3% and 7%*





*See Section 7.3 for discussion of the ozone and PM premature mortality estimates. See Section 5.2 for discussion of the hybrid and fixed cost estimates.

Table 7.2: Summary of Total Number of Annual Ozone and $PM_{2.5}$-Related Premature Mortalities and Premature Morbidity Avoided: 2020 National Benefits*

Combined Estimate of Mortality Standard Alternative and Model or Assumption		Combined Range of Ozone Benefits and $PM_{2.5}$ Co-Benefits**			
		0.079 ppm	0.075 ppm	0.070 ppm	0.065 ppm
NMMAPS	Bell (2004)	140 – 1,300	260 – 2,000	560 – 3,500	940 – 5,500
Meta-Analysis	Bell (2005)	200 – 1,300	420 – 2,200	560 – 4,100	2,000 – 6,500
	Ito (2005)	230 – 1,300	500 – 2,300	1,100 – 4,300	2,500 – 7,000
	Levy (2005)	230 – 1,400	510 – 2,300	1,400 – 4,400	2,500 – 7,100
Assumption that association is not causal		120 – 1,200	190 – 2,000	310 – 3,200	490 – 5,000
Combined Estimate of Morbidity					
Acute Myocardial Infarction		570	890	1,500	2,300
Upper Respiratory Symptoms		3,100	4,900	8,100	13,000
Lower Respiratory Symptoms		4,200	6,700	11,000	17,000
Chronic Bronchitis		240	380	630	970
Acute Bronchitis		640	1,000	1,700	2,600
Asthma Exacerbation		3,900	6,100	10,000	16,000
Work Loss Days		28,000	43,000	72,000	110,000
School Loss Days		72,000	200,000	640,000	1,100,000
Hospital and ER Visits		890	1,900	5,100	9,400
Minor Restricted Activity Days		340,000	750,000	2,100,000	3,500,000

*Only includes areas required to meet the current standard by 2020, does not include San Joaquin Valley and South Coast air basins in California. Appendix 7b shows the costs and benefits of attaining alternate standards in San Joaquin and South Coast California.

**Includes ozone benefits, and PM 2.5 co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation described in Chapter 6.

7.3 Discussion of Results

7.3.1 Sensitivity of Changes to Costs and Benefits Under an Alternate Baseline Scenario

Circular A-4 of the Office of Management and Budget's (OMB) guidance under Executive Order 12866 defines a no-action baseline as "what the world will be like if the proposed rule is not adopted". The illustrative analysis in this RIA assesses the costs and benefits of moving from this "no-action" baseline to a suite of possible new standards. Circular A-4 states that the choice of an appropriate baseline may require consideration of a wide range of potential factors, including:

- evolution of the market,
- changes in external factors affecting expected benefits and costs,
- changes in regulations promulgated by the agency or other government entities, and
- the degree of compliance by regulated entities with other regulations. (OMB 2003)

Circular A-4 also recommends that…

> When more than one baseline is reasonable and the choice of baseline will significantly affect estimated benefits and costs, you should consider measuring benefits and costs against alternative baselines. In doing so you can analyze the effects on benefits and costs of making different assumptions about other agencies' regulations, or the degree of compliance with your own existing rules. (OMB 2003)

This sensitivity analysis is intended to provide information about how the no-action baseline would differ under different assumptions about mobile technologies. It also assesses nationally what the change would be to costs and benefits of all standards. Cost for all standards would increase by $1.8[1] billion and benefits for all standards would increase by $360 million to $3.1 billion using 2006$ and a 3% discount rate, and $330 million to $2.8 billion when using a 7% discount rate.

The primary analysis baseline included some mobile controls characterized as additional technology changes in the onroad transportation sector. The application of these controls to the baseline assumes an optimistic future where reductions in emissions are achieved through the implementation nationally of cutting-edge mobile technologies. This sensitivity analysis estimates nationally how the costs and benefits of attaining 0.075 and the alternate primary standards would change if these technology changes were not implemented to meet the current standard, but were instead implemented as part of the strategy for attaining a new tighter standard.

In this sensitivity analysis scenario, 169,000 tons of NOx would not be reduced prior to the benefit/cost analysis. The alternate baseline or starting point for assessing the costs and benefits of the standard of 0.075 and the alternate primary standards would be higher across the board. Benefits from improved ozone and co-controlled PM2.5 air quality would increase. The costs of control would increase, as well The air quality improvements would be accomplished by including additional onroad transportation control measures in the control scenario, equivalent to the reductions 'removed' from the alternate baseline. The value in benefits of those improvements is estimated on a $/ton emissions reduced basis derived from the Locomotive Marine Diesel Rule.

It should be noted that these benefits are only a partial accounting of the total benefits associated with the mobile controls included in this sensitivity analysis. The sensitivity analysis does not estimate the benefits of other co-controlled emission reductions achieved by the mobile controls, such as VOCs (a precursor to ozone formation) and direct PM. The benefits presented here are therefore an underestimate of total benefits. Furthermore, these estimates are highly uncertain and are purely illustrative estimates of the potential costs and benefits of these mobile source

[1] This cost could be offset in states that choose to replace existing periodic physical inspection of vehicles with remote onboard diagnostic device inspection in I/M programs. As explained in Appendix 9a, Remote OBD eliminates the need for periodic inspections of OBD-equipped vehicles by car owners. EPA estimates that the nationwide installation of Remote OBD would save the nation's motorists about $16 to $22 billion in inspection and convenience costs over a 10 year period.

control strategies. We present them only as screening-level estimates to provide a bounding estimate of the costs and benefits of including these emissions controls in the ozone NAAQS baseline. As such, it would be inappropriate to apply these benefit per-ton estimates to other policy contexts, including other regulatory impact analyses. For more details on the baseline sensitivity analysis, please reference Appendix 7a.

7.3.2 Relative Contribution of PM Benefits to Total Benefits

Because of the relatively strong relationship between $PM_{2.5}$ concentrations and premature mortality, PM co-benefits resulting from reductions in NO_x emissions can make up a large fraction of total montetized benefits, depending on the specific PM mortality impact function used, and on the relative magnitude of ozone benefits, which is dependent on the specific ozone mortality function assumed. PM co-benefits based on daily average concentrations are calculated over the entire year, while ozone related benefits are calculated only during the summer ozone season. Because the control strategies evaluated in this RIA are assumed to operate year round rather than only during the ozone season, this means that PM benefits will accumulate during both the ozone season and the rest of the year.

For the 0.075ppm alternative, PM2.5 co-benefits account for between 42 and 99 percent of total benefits. The lower end of the range assumes a combination of Levy et al. (2005) & Expert K. The upper end of the range assumes a combination of the assumption of no causality & Expert E.

7.3.3 Challenges to Modeling Full Attainment in All Areas

Because of relatively higher ozone levels in several large urban areas (Southern California, Chicago, Houston, and the Northeastern urban corridor) and because of limitations on the available database of currently known emissions control technologies, EPA recognized from the outset that known and reasonably anticipated emissions controls would likely be insufficient to bring some areas into attainment with either the current or alternative, more stringent ozone standards. Therefore, we designed this analysis in two stages: the first stage focused on analyzing the air quality improvements that could be achieved through application of documented, well-characterized emissions controls, and the costs and benefits associated with those controls. The second stage utilized extrapolation methods to estimate the costs and benefits of additional emissions reductions needed to bring all areas into full attainment with the standards. Clearly, the second stage analysis is a highly speculative exercise, because it is based on estimating emission reductions and air quality improvements without any information about the specific controls that would be available to do so.

The structure of the RIA reflects this 2-stage analytical approach. Separate chapters are provided for the cost, emissions and air quality impacts of modeled controls and for extrapolated costs and air quality impacts. We have used the information currently available to develop reasonable approximations of the costs and benefits of the extrapolated portion of the emissions reductions necessary to reach attainment. However, due to the high level of uncertainty in all aspects of the extrapolation, we judged it appropriate to provide separate estimates of the costs and benefits for the modeled stage and the extrapolated stage, as well as an overall estimate for reaching full attainment. There is a single chapter on benefits, because the methodology for estimating benefits does not change between stages. However, in that chapter, we again provide separate estimates of the benefits associated with the modeled control scenario which provides the foundation upon which benefits for full attainment are extrapolated for all four alternate primary standards (0.079, 0.075, 0.070, and 0.065 ppm).

In both stages of the analysis, it should be recognized that all estimates of future costs and benefits are not intended to be forecasts of the actual costs and benefits of implementing revised standards. Ultimately, states and urban areas will be responsible for developing and implementing emissions control programs to reach attainment of the ozone NAAQS, with the timing of attainment being determined by future decisions by states and EPA. Our estimates are intended to provide information on the general magnitude of the costs and benefits of alternative standards, rather than precise predictions of control measures, costs, or benefits. With these caveats, we expect that this analysis can provide a reasonable picture of the types of emissions controls that are currently available, the direct costs of those controls, the levels of emissions reductions that may be achieved with these controls, the air quality impact that can be expected to result from reducing emissions, and the public health benefits of reductions in ambient ozone levels. This analysis identifies those areas of the U.S. where our existing knowledge of control strategies is not sufficient to allow us to model attainment, and where additional data or research may be needed to develop strategies for attainment.

The ozone NAAQS RIA provided great challenges when compared to previous RIAs. Why was this so? Primarily because as we tighten standards across multiple pollutants with overlapping precursors (e.g., the recent tightening of the $PM_{2.5}$ standards), we move further down the list of cost-effective known and available controls. As we deplete our database of available choices of known controls, we are left with background emissions and remaining anthropogenic emissions for which we do not have enough knowledge to determine how and at what cost reductions can be achieved in the future when attainment would be required. With the more stringent NAAQS, more areas will need to find ways of reducing emissions, and as existing technologies are either inadequate to achieve desired reductions, or as the stock of low-cost existing technologies is depleted (causing the cost per ton of pollution reduced to increase), there will be pressure to develop new technologies to fill these needs. While we can speculate on what some of these technologies might look like based on current research and development and model programs being evaluated by states and localities, the actual technological path is highly uncertain.

Because of the lack of knowledge regarding the development of future emissions control technologies, a significant portion of our analysis is based on extrapolated tons generated from air quality sensitivity modeling necessary to reach full attainment of an alternative ozone NAAQS and the resulting costs and benefits. 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, such as the time allowed for areas with high levels of ozone pollution to meet the ozone NAAQS, the opportunity for technical advances is greater (see Chapter 5 for details).

Our estimates of costs of attainment in 2020 assume a particular trajectory of aggressive technological change. This trajectory leads to a particular level of emissions reductions and costs which we have estimated based on two different approaches, the fixed cost and hybrid approaches. An alternative storyline might hypothesize a much less optimistic technological change path, such that emissions reductions technologies for industrial sources would be more expensive or would be unavailable, so that emissions reductions from many smaller sources might be required for 2020 attainment, at a potentially greater cost per ton. Under this alternative storyline, two outcomes are hypothetically possible: Under one scenario, total costs associated with full attainment might be substantially higher. Under the second scenario, states may choose to take advantage of flexibility in the Clean Air Act to adopt plan with later attainment dates to allow for additional technologies to be developed and for existing programs like EPA's Onroad Diesel, CAIR, Nonroad Diesel, and Locomotive and Marine rules to be fully implemented. If states were to submit plans with attainment dates beyond our 2020 analysis year, benefits would clearly be lower than we have estimated under our analytical storyline. However, in this case, state decision makers, seeking to maximize economic efficiency, would not impose costs, including potential opportunity costs of not meeting their attainment date, when they exceed the expected health benefits that states would realize from meeting their modeled 2020 attainment date. In this case, upper bound costs are difficult to estimate because we do not have an estimate of the point where marginal costs are equal to marginal benefits plus the costs of nonattainment.

Due to the nature of the extrapolation method for benefits (which focuses on reductions in ozone only at monitors that exceed the NAAQS), we generally understate the total benefits that would result from implementing additional emissions controls to fully attain the ozone NAAQS (i.e., assuming that the application of control strategies would result in ozone reductions both at nonattaining and attaining monitors). On the other hand, the possibility also exists that benefits are overestimated, both because it is possible that new technologies might not meet the specifications, development time lines, or cost estimates provided in this analysis and because the analysis assumes there are quantifiable benefits to reducing ambient ozone below each of the alternative standards.

Estimated benefits and costs may reflect both bias and uncertainty. While we strive to avoid bias and characterize uncertainty to the extent possible, we note that in some cases, biased estimates were used due to data and/or methodological limitations. In these cases we have tried to identify the direction and potential magnitude of the bias. These extrapolated benefits are uncertain, but the relative uncertainty compared to the modeled benefits is similar, once the underestimation bias has been taken into account. The emissions and cost extrapolations do not have a clear directional bias, however, they are much more uncertain relative to the modeled emissions and cost estimates, because of the lack of refined information about the relationship between emissions reductions and ozone changes in specific locations, and because of the difficulties in extrapolating costs well beyond the observed data. Of course, these benefits and costs will only be realized if the emission reductions projected in this extrapolated approach actually occur in the future.

7.4 What Did We Learn through this Analysis?

1. As in our analysis for the PM NAAQS RIA, in selecting controls, we focused more on the ozone cost-effectiveness (measured as $/ppb) than on the NO_x or VOC cost-effectiveness (measured as $/ton). When compared on a $/ton basis, many VOC controls appear cost-effective relative to NO_x reductions (see Figures 5.1 and 5.2). However, the air quality sensitivity analysis showed that NOx reductions were more effective than

VOC reductions in reducing Ozone concentrations except in urban areas which are VOC limited. In those locations, NO_x reductions can actually result in increases in ozone, and as such, VOC reductions can be cost-effective relative to NO_x on a $/ppb basis.

2. *Our knowledge of technologies that might achieve NO_x and VOC reductions to attain alternative ozone NAAQS is insufficient.* In some areas of the U.S., our existing controls database was insufficient to meet even the current ozone standard. After applying existing rules and the hypothetical controls applied in the PM NAAQS RIA across the nation we were able to identify controls that reduced overall NO_x emissions nationwide by 6 percent and VOC by 2 percent. After these reductions, remaining emissions were still substantial, with over 9 million tons of NO_x and 12 million tons of VOCs remaining nationwide. The large remaining inventories of NO_x and VOC emissions suggests that additional control measures need to be developed, with appropriate consideration of the relative effectiveness of NO_x and VOC in achieving ozone reductions.

3. *Most of the overall reductions in NO_x achieved in our illustrative control strategy were from nonEGU point sources.* This was due to the fact that: 1) EGUs have been heavily controlled under the recent NO_x SIP call and Clean Air Interstate Rules. The EGU program we included in our strategy for meeting the alternative ozone standards was not intended to achieve overall reductions in NO_x beyond the CAIR caps, but instead to obtain NO_x emission reductions in areas where they would more effectively reduce ozone concentrations in downwind nonattainment areas; and 2) mobile sources are already subject to ongoing emission reduction programs through the Tier 2 highway, onroad diesel and nonroad diesel rules. Thus, the opportunities for controlling NO_x emissions were much greater in the nonEGU point sector than in the mobile or EGU sectors. However, the remaining uncontrolled NO_x emissions from EGU and mobile sectors are still greater than nonEGU point sources[2], and additional reductions from these sectors may need to be considered in developing strategies to achieve full attainment. Exploratory analyses indicate that there are opportunities to achieve emission reductions from EGU peaking units on High Energy Demand Days (HEDD) with targeted strategies. Another area under analysis is the energy efficiency/clean distributed generation based emission reductions.

4. *Tightening the ozone standards can provide significant, but not uniform, health benefits*. The magnitude of the benefits is highly uncertain, <u>and is not expected to be uniform throughout the nation</u>. While our illustrative analyses showed that the benefits of implementing a tighter standard will likely result in reduced health impacts for the nation as a whole, the particular scenarios that we modeled show that some areas of the U.S. will see ozone (and $PM_{2.5}$) levels increase. This is due to two reasons. The first reason is that the complexities involved in the atmospheric processes which govern the transformation of emissions into ozone result in some locations and times when reducing NO_x emissions can actually increase ozone levels on some days (see Chapter 2 for more discussion). For most locations, these days are few relative to the days when ozone levels are decreased. However, in some urban areas the net effect of implementing NO_x controls

[2] NonEGU point source emission projections currently do not include estimated activity or economic growth.

is to increase overall ozone levels and increase the health effects associated with ozone. This same phenomenon results in some areas also seeing increases in $PM_{2.5}$ formation. The second reason is that the particular control strategy that we modeled for EGU sources is a modification to controls on sources within the overall cap and trade program in the Eastern U.S., established under the CAIR. As with any cap and trade program, changes in requirements at particular sources will result in shifts in power generation and emissions at other sources. Because under our chosen EGU control scenario the overall emissions cap for the CAIR region remains the same, some areas of the country will see a decrease in emissions, while others will see an increase. This is not unexpected, and is an essential element of the cap and trade program. Our goal in selecting the EGU control strategy was to focus the emissions reductions in areas likely to benefit the most from EGU NO_x emissions reductions, with emissions increases largely occurring in areas in attainment with the ozone NAAQS. However, this necessarily means that in those areas where emissions increases occurred, ozone levels would also be expected to increase, with commensurate increases in health impacts. On a national level, however, we expected overall health benefits of the modeled EGU strategy to be positive. In addition, our air quality modeling analysis showed that while ozone levels did increase in some areas, none of these increases resulted in an attaining area moving into nonattainment. Adjustments to our control scenario might achieve a pattern of reductions that achieves further air quality improvement.

5. *The 0.079 ppm and 0.075 ppm benefits estimates reflect special uncertainties.* EPA interpolated the benefits of the 0.070 ppm alternative to estimate the full attainment benefits of the less stringent 0.075 ppm and 0.079 ppm alternatives. These two interpolated benefits estimates are subject to two sources of uncertainty: (1) the uncertainties inherent in the original 0.070 ppm benefits analysis that was the basis for the interpolation; (2) the incremental uncertainty added through the interpolation approach. A chief source of uncertainty in the 0.070 ppm analysis was the use of the monitor rollback technique to estimate full attainment benefits. This approach likely understates the benefits that would result from state implementation of emissions controls because controls implemented to reduce ozone concentrations at the highest monitor would likely result in some reductions in ozone concentrations at nearby attaining monitors. Therefore, air quality improvements and resulting health benefits from full attainment would be more widespread than we estimated in our rollback analysis for the 0.070 ppm alternative. The interpolation approach adds its own uncertainties. We made a reasonable judgment regarding the geographic area within which to interpolate benefits. However, this area may not match the ultimate geographic distribution of air quality improvements under a state-implemented control strategy to attain either the 0.075 ppm or 0.079 ppm alternative; this could result in an under- or over-estimate of benefits. The complexity of the various uncertainties makes it challenging to draw conclusions about their combined directional influence on the benefits estimates.

6. *Tightening the ozone standards can incur significant, but uncertain, costs*. An engineering cost comparison demonstrates that the cost of the 0.070 ppm Ozone NAAQS

known control costs ($3.3 billion per year[3] (2006$)) is only slightly lower than the Clean Air Interstate Rule (approximately $4 billion per year (2006$)) and roughly one and half to just over four times higher than the PM NAAQS 15/35 control strategy with annual engineering costs of $1.0 billion (2006$). It should be noted that for the Ozone NAAQS $3.3 billion represent the engineering cost of partial attainment. Full attainment using extrapolation methods are expected to increase total costs significantly. For example, total costs for the 0.070 ppm standard are significant at $19 to $25 billion (2006$). Yet, the magnitude and distribution of costs across sectors and areas is highly uncertain. Our estimates of costs for a set of modeled NO_x and VOC controls comprise only a small part of the estimated costs of full attainment. These estimated costs for the modeled set of controls are still uncertain, but they are based on the best available information on control technologies, and have their basis in real, tested technologies. Estimating costs of full attainment required several techniques for extrapolation of the costs based upon the degree of difficulty to reach attainment Based on air quality supplemental modeling, there is clearly significant spatial variability in the relationship between local and regional NO_x emission reductions and ozone levels across urban areas. For some locations, the extrapolation requires only a modest reduction beyond known controls. In these cases, the extrapolation is likely reasonable and not as prone to uncertainties. However, for areas where the bulk of air quality improvements were derived from extrapolated emissions reductions that go well beyond the area of the known controls, the uncertainty associated with costs increases.

7. *NonEGU point source controls dominate the estimated costs.* These costs account for about 54 percent of modeled control costs. The average cost per ton for these reductions is approximately $3,800 (2006$) and the highest marginal cost for the last known control applied is $22,000 (2006$). Mobile source controls were also significant contributors to overall costs, accounting for over 23 percent of total modeled control costs.

8. *Costs and benefits will depend on implementation timeframes.* States will ultimately select the specific timelines for implementation as part of their State Implementation Plans. To the extent that states seek classification as extreme nonattainment areas, the timeline for implementation may be extended beyond 2020, meaning that the amount of emissions reductions that will be required in 2020 will be less, and costs and benefits in 2020 will also be lowered.

7.5 References

U.S. Office of Management and Budget. September 2003. Circular A-4, Regulatory Analysis Guidance sent to the Heads of Executive Agencies and Establishments. Washington, DC. http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf.

[3] Known controls include the modeled control strategy ($2.8 billion dollars per year (2006$)) as well as any supplemental and giveback controls applied (Appendix 5a.4).

Appendix 7a: National Baseline Sensitivity Analysis

7a.1 Synopsis

Circular A-4 of the Office of Management and Budget's (OMB) guidance under Executive Order 12866 defines a no-action baseline as "what the world will be like if the proposed rule is not adopted." The illustrative analysis in this RIA assesses the costs and benefits of moving from this "no-action" baseline to a suite of possible new standards. Circular A-4 states that the choice of an appropriate baseline may require consideration of a wide range of potential factors, including:

- evolution of the market,
- changes in external factors affecting expected benefits and costs,
- changes in regulations promulgated by the agency or other government entities, and
- the degree of compliance by regulated entities with other regulations. (OMB 2003)

Circular A-4 also recommends that…

> When more than one baseline is reasonable and the choice of baseline will significantly affect estimated benefits and costs, you should consider measuring benefits and costs against alternative baselines. In doing so you can analyze the effects on benefits and costs of making different assumptions about other agencies' regulations, or the degree of compliance with your own existing rules. (OMB, 2003)

This sensitivity analysis is intended to provide information about how the no-action baseline would differ under different assumptions about mobile technologies. It also assesses nationally what the change would be to costs and benefits of a new standard of 0.075 ppm and alternate primary standards of 0.079, 0.070, and 0.065 ppm. Cost for all standards would increase by \$1.8 billion[1] and benefits for all standards would increase by

[1] This cost could be offset in states that choose to replace existing periodic physical inspection of vehicles with remote onboard diagnostic device inspection in Inspection and Maintenance programs. As explained in the Appendix to Chapter 3, Remote On Board Diagnostics (OBD) eliminates the need for periodic inspections of OBD-equipped vehicles by car owners. EPA estimates that the nationwide installation of Remote OBD would save the nation's motorists about \$16 to \$22 billion in inspection and convenience costs over a 10 year period. Refer to the Appendix 5a for more details on the cost savings of remote OBD.

$360 million to $3.1 billion using 2006$ and a 3% discount rate, and $330 million to $2.8 billion when using a 7% discount rate.[2]

The process of analysis of costs and benefits of attaining 0.075 and the alternate primary standard is, in some ways, an incremental building exercise. EPA begins with a Base Case (that includes promulgated rules, consent decrees, existing promulgated programs) and layers onto that illustrative control strategies from previous NAAQS RIA analyses, and finally, a simulated control strategy for attaining the current NAAQS in question (O3 at 0.084 ppm). This is the point at which the "no-action baseline" is established.

Once the no-action baseline is established, EPA begins assessing the costs and benefits of moving to a tighter standard. EPA does not assess the costs and benefits of reaching the no-action baseline. Decisions about what is in the baseline affect the starting point of the assessment of costs and benefits, and thus affect the total incremental cost and benefit estimates.

The primary analysis baseline included some mobile controls characterized as additional technology changes in the onroad transportation sector. The application of these controls to the baseline assumes an optimistic future where reductions in emissions are achieved through the implementation nationally of cutting-edge mobile technologies. This sensitivity analysis estimates nationally how the costs and benefits of attaining 0.075 and the alternate primary standards would change if these technology changes were not implemented to meet the current standard, but were instead implemented as part of the strategy for attaining a new tighter standard.

In this sensitivity analysis scenario, 169,000 tons of NOx would not be reduced prior to the benefit/cost analysis. The alternate baseline or starting point for assessing the costs and benefits of the standard of 0.075 and the alternate primary standards would be higher across the board. Benefits from improved ozone and co-controlled PM2.5 air quality would increase. The costs of control would increase, as well. The air quality improvements would be accomplished by including additional onroad transportation control measures in the control scenario, equivalent to the reductions 'removed' from the alternate baseline. The value in benefits of those improvements is estimated on a $/ton emissions reduced basis derived from the Locomotive Marine Diesel Rule.

A description of the control measures added to the alternate control scenario for this sensitivity analysis follows.

[2] These estimates are highly uncertain and are purely illustrative estimates of the potential costs and benefits of these mobile control strategies. We present them only as screening-level estimates to provide a bounding estimate of the costs and benefits of including these emissions controls in the ozone NAAQS control case for all standards. As such, it would be inappropriate to apply these benefit per-ton estimates to other policy contexts, including other regulatory impact analyses. Furthermore, the benefits only reflect a partial accounting of the total benefits associated with emission reductions related to the mobile controls included in this sensitivity analysis.

7a.2 Control Details

7a.2.1 Improved Catalyst Design

Improved Catalyst Design is a nationwide strategy that results in tailpipe emission reductions for new vehicles. The principle technologies used to achieve the Improved Catalyst Design standards are improved catalysts and increased use of electronically controlled air injection, reducing NOx and VOC emissions for new light duty gasoline vehicles.

We modeled a program that would achieve Bin 2[3] emission levels (see Table 7a.1) for a program starting in 2013 and fully phased in by 2015.

Phase-in Scenario	Cars:	50% in 2013 100% in 2014	Trucks:	100% in 2015

Table 7a.1: Emission Standards

	NOx	NMOG
Bin 2	0.02	0.01
Bin 5 (reference)	0.07	0.09

Table 7a.2: Nationwide 2020 Tailpipe Emission Reductions (tons(%))

	2020 NOx	2020 HC
Bin 2	87,705 (7%)	93,676 (6%)

In comparison, Tier 2 reduced NOx by about 2.2 million tons in 2020 and nearly 3 million tons in 2030, a 74% reduction.

The above results are modeled relative to a Bin 5 baseline

- Modeled difference in level of the standards: Bin 5 vs. Bin 2.
- In reality, new standards would likely provide fewer benefits because many Bin 5 vehicles are certified well below the standard, and many are in fact 50-state vehicles certified in California as ULEVs.
- The costs are also modeled relative to a Bin 5 baseline, so the fact that many vehicles are actually cleaner today will also result in lower total costs.

[3] For information on Bin emission levels, see: http://www.epa.gov/greenvehicles/summarychart.pdf

The technology is described as follows:

- The technology relies on catalyst improvements—adding Rhodium, improved substrate/washcoat, and 900 cpsi density (all vehicles are assumed to need these changes)

- All vehicles are assumed to have close-coupled catalysts (1 or 2)

- Increased use of electronically controlled air injection—100% implementation on everything except 4-cylinder engines

Engineering costs for this program are estimated to be approximately $90-250 per vehicle for LDVs to LDT4s.

- Based on an analysis similar to that done for Tier 2 and LEV-II, estimating penetration rates of emission control technologies, coupled with estimated costs for each technology.

- A significant driver of costs is the market price of Rhodium, which has varied in the last 5 years from below $1000 to above $6000 per Troy ounce. We used the 5-year average of $2200.

- These costs are the result of a preliminary analysis intended to achieve rough estimates. An in-depth bottom-up detailed cost analysis would need to be done to support an actual Improved Catalyst Design regulatory program.

- Most of the costs are for catalyst improvements—adding Rhodium, improved substrate/washcoat, and 900 cpsi density (all vehicles are assumed to need these changes)

Cost-effectiveness is $8,400 per ton for HC+NOx, and $17,500 per ton for NOx alone. Based on assumptions and variables in the analysis, these numbers can vary +/- 30%.

7a.2.2 Plug-In Hybrid Electric Vehicles

Plug-In Hybrid Electric Vehicles (PHEVs) are very similar to Hybrid Electric Vehicles, but with three significant functional differences. The first is the addition of a means to charge the battery pack from an outside source of electricity (usually the electric grid). Second, a PHEV would have a larger battery pack with more energy storage, and a greater capability to be discharged. Finally, a PHEV would have a control system that allows the battery pack to be significantly depleted during normal operation.

PHEVs offer a significant opportunity to replace petroleum used for transportation energy with domestically-produced electricity. The reduction in petroleum usage does, of course, depend on the amount of electric drive the vehicle is capable of under its duty cycle. PHEVs can lower localized emissions of criteria pollutants and air toxics especially in urban areas by operating on electric power. The emissions with this technology occur more from power generation outside the urban area at the power generation plant rather than from the vehicle tailpipe, which may provide health benefits for residents of the more densely populated urban areas. Unlike most other oil-saving technologies, PHEVs also use existing infrastructure for fueling with gasoline and electricity so large investments in fueling infrastructure are not required. Since emissions from utilities are capped by existing programs, increases in power generation are generally not expected to impact attainment of air quality standards.

For this analysis, we assumed that PHEVs would be available as passenger cars and as light trucks in all light truck weight classes by 2012. We assumed the following phase-in schedule for PHEVs (Table 7a.3) as a fraction of new vehicle sales for the period from 2012 to 2020. This is an illustrative example of what could be feasible for the market penetration of PHEVs based on reductions that are needed for attainment of the revised ozone NAAQS and EPA's internal expertise and judgment. Recent announcements by Toyota and General Motors that they plan to introduce PHEVs by 2010 provide additional support for these assumptions.

Table 7a.3: Plug-In Hybrid Percentage of Total Sales of New Vehicles by Year

Year	Percentage of New Vehicles
2012	1%
2013	3%
2014	7%
2015	12%
2016	18%
2017	25%
2018	30%
2019	30%
2020	30%

We believe that the first consumers of PHEVs are likely to be the ones who can take best advantage of the PHEV while still operating on an overnight charge, i.e., urban and suburban residents with shorter commutes. We also assume continuing improvements in the range of PEHVs while operating on the overnight charge. For this analysis, we assumed that 70% of the VMT of PHEVs would be powered by the overnight charge rather than the vehicle engine and would have no direct exhaust emissions.[4] We used that estimate, and the assumptions of vehicle sales given above, to adjust the travel fractions in EPA's MOBILE6.2 emission model to account for the impact of reduced emissions for each model year of PHEVs.

All light-duty gasoline vehicles and trucks: Affected SCC:

- 2201001000 Light Duty Gasoline Vehicles (LDGV), Total: All Road Types

[4] Note that this assumption is different than the assumption used in the payback analysis used to determine costs of PHEVs in: *Interim Report: New Powertrain Technologies and Their Projected Costs*. U.S. E.P.A, October 2005. http://epa.gov/otaq/technology/420r05012.pdf. That study assumes that only 30% of PHEV VMT is powered by overnight charge, but still shows a positive payback potential.

- 2201020000 Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
- 2201040000 Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types

Using the assumptions and methods described above, we estimated that HC emissions would be reduced by a range of 2.4% to 3.9% for passenger cars and light trucks (reductions vary by vehicle class). For NOx, we estimate reductions in the range of 1.6% to 2.5% for passenger cars and light trucks.

For purposes of this RIA, we identified this measure as a no cost strategy i.e., $0/ton NOx. Plug-in hybrids have upfront capital costs, but these costs can be fully recovered by the fuel savings during the life of the vehicle. According to research conducted by the EPA, the potential consumer payback for the hypothetical PHEV midsize car and large SUV can be calculated from the modeled fuel economy and projected cost of the vehicle package[5]. Using a retail price markup factor of 1.26 from the projected cost, the additional cost of a PHEV midsize car over the base vehicle is $6,072. The large SUV is projected to cost $7,884 more than the comparable base vehicle.

Appling these costs, the modeled fuel economy, and the standard economic assumptions used in this analysis of $2.50 per gallon gasoline price, 7% discount rate, and a 14 year life with annual VMT taken from the MOBILE6 model, results in consumer payback shown below. The payback period for the midsize car is 10.7 years, and 7.5 years for the large SUV.

Table 7a.4: Cost Effectiveness of PHEV Midsize Car and SUV

	Midsize Car	**Large SUV**
Incremental Vehicle Price	$5,646	$8,577
Fuel Economy Gain	126%	92%
Tailpipe CO2 decrease	56%	48%
Discounted Fuel Savings	$6,493	$11,751
Discounted Electricity Cost	$929	$1,346
Discounted Brake Savings	$376	$533
Reduced Fueling Time Savings	$395	$428
Lifetime Savings	$688	$2,789
Payback Period	10.7 years	7.5 years

Improved After-Market Catalysts

Both EPA and CARB have standards in place for aftermarket catalysts. CARB now requires higher quality replacement catalysts for OBDII vehicles and is considering expanding that requirement to pre-OBDII vehicles as well. (Even though higher quality, these replacement catalysts do not constitute a new standard for the vehicle—they just bring it closer to its original as-new performance level.) CARB has done testing and has

[5] Draft Revision to: *Interim Report: New Powertrain Technologies and Their Projected Costs*. U.S. E.P.A., October 2005. http://epa.gov/otaq/technology/420r05012.pdf

found that substantial emission reductions can be had by upgrading the quality of aftermarket catalysts.

Applying the proposed aftermarket catalyst requirements to the national fleet would bring about nationwide reductions. According to the Manufacturers of Emission Controls Association (MECA), approximately 3 million aftermarket catalysts are sold each year.

Estimated benefits are derived by comparing performance of existing replacement catalysts to that of the proposed catalysts. The difference is applied to the 3 million vehicles in the fleet that get aftermarket replacement catalysts.

All light-duty gasoline vehicles and trucks: Affected SCC:

- 2201001000 Light Duty Gasoline Vehicles (LDGV), Total: All Road Types
- 2201020000 Light Duty Gasoline Trucks 1 (LDGT1), Total: All Road Types
- 2201040000 Light Duty Gasoline Trucks 2 (LDGT2), Total: All Road Types

The table below (Table 7a.5) shows the emissions of the current aftermarket catalysts at 25,000 miles and the performance of the OBDII-type aftermarket catalysts at the same mileage. The emission reductions from improved aftermarket catalysts are substantial, even for Tier 0 vehicles.

Table 7a.5: Emissions of Aftermarket Catalysts

	Current Aftermarket Catalysts		Proposed Aftermarket Catalysts		Percent Reduction	
Category	**HC**	**NOx**	**HC**	**NOx**	**HC**	**NOx**
Tier 0	0.600	2.4	0.1750	0.20	71%	92%
Tier 1	0.600	2.4	0.1350	0.15	78%	94%
TLEV	0.600	1.6	0.0580	0.20	90%	88%
LEV	0.600	1.6	0.0250	0.05	96%	97%
ULEV	0.450	1.2	0.0125	0.07	97%	94%
LEV II LEV	0.450	1.2	0.0300	0.07	93%	94%
LEV II ULEV	0.450	0.8	0.0125	0.07	97%	91%
LEV II SULEV	0.375	0.8	0.0100	0.02	97%	98%

Based on this information, if starting in 2010 we required the 3 million replacement catalysts installed each year to meet these standards, by 2020 there would be 15 million vehicles with such catalysts left in the fleet (the other 15 million are assumed to be scrapped during this time period). In 2020, the emission reductions we calculate are as follows:

Table 7a.6: Emission Reductions from Replacement Catalysts

	HC	NOx
LDGV	3.5%	7.1%
LDGT1	3.4%	7.0%
LDGT2	3.6%	7.1%
LDGT3	3.7%	7.2%
LDGT4	3.9%	7.3%

Both EPA and CARB have standards in place for aftermarket catalysts. CARB now requires higher quality replacement catalysts for OBDII vehicles and is considering expanding that requirement to pre-OBDII vehicles as well. (Even though higher quality, these replacement catalysts do not constitute a new standard for the vehicle—they just bring it closer to its original as-new performance level.) CARB has done testing and has found that substantial emission reductions can be had by upgrading the quality of aftermarket catalysts.

Estimated engineering cost of the proposed replacement catalyst is $275, compared to approximately $100 for current replacement catalysts. These cost numbers are based on a review of prices published on the internet for OBDII and pre-OBDII replacement catalysts.[6]

Table 7a.7: CARB Cost Effectiveness for Improved After Market Catalysts

Category	NOx + HC	NOx only	HC only
Tier 0	$1,423	$1,722	$8,187
Tier 1	$1,353	$1,665	$7,238
TLEV	$1,889	$2,774	$5,917
LEV	$1,659	$2,378	$5,488
ULEV	$2,275	$3,329	$7,186
LEV II LEV	$2,090	$2,887	$7,567
LEV II ULEV	$2,736	$4,419	$7,186
LEV II SULEV	$2,782	$4,232	$8,120

For the O3 RIA, we used an average cost of $3,700/ton NOx reduced.

7a.2.3 Summary of Emission Reductions and Costs

Total emission reductions and costs for the 3 control measures included in the alternative baseline analysis are presented in Table 7a.8:

Table 7a.8: NOx Emission Reductions and Costs for Alternative Baseline Analysis

Sector	Control Measure	Annual Emission Reductions (Tons)	Total Cost (M$)
Onroad	Improved Catalyst Design	77,000	$1,600
	Plug-In Hybrid	22,000	$---

[6] See: www.discountconverters.com and autopartswharehouse.com

Improved After-market Catalyst	70,000	$260
TOTAL	**169,000**	**$1,900**

7a.3 Methods for Estimation of Benefits ($/ton NOx reduced)

We estimated the monetary value of the 169,000 tons of mobile source NOx emission reductions in our baseline through a benefit per ton approach. Because NOx is both an ozone and PM2.5 precursor, these reductions will yield both reductions in the ambient levels of these pollutants as well as monetized benefits. Because these reductions occur in the mobile source sector, we decided to estimate total ozone benefits by imputing an ozone benefit per-ton estimate from the soon-to-be-promulgated Locomotive and Marine Diesel Rule. While this rule does not affect an identical set of sources, it is a reasonable representation of the benefits of emission reductions in mobile source emissions, which is the sector of interest. We have included these benefit per-ton calculations in a separate Technical Support Document (TSD). To estimate the PM2.5 co-benefits we used a set of benefit per-ton estimates consistent with the main analysis. The process for deriving these estimates can be found in the same TSD.

The range of total combined ozone and PM2.5-related 2020 benefits associated with the emission reductions are between $360 million to $3.1 billion in 2006$ using a 3% discount rate. The lower-end of this range represents the combination of the assumption of no causality for ozone benefits and the Expert K PM mortality function for PM2.5 co-benefits (US EPA, 2006; US EPA, 2005). Using these same two combinations of studies, the range changes to between $330 million to $2.8 billion when using a 7% discount rate. It should be noted that these benefits are only a partial accounting of the total benefits associated with the mobile controls included in this sensitivity analysis. The sensitivity analysis does not estimate the benefits of other co-controlled emission reductions achieved by the mobile controls, such as VOCs (a precursor to ozone formation) and direct PM. The benefits presented here are therefore an underestimate of total benefits. Furthermore, these estimates are highly uncertain and are purely illustrative estimates of the potential costs and benefits of these mobile control strategies. We present them only as screening-level estimates to provide a bounding estimate of the costs and benefits of including these emissions controls in the ozone NAAQS control case for all standards. As such, it would be inappropriate to apply these benefit per-ton estimates to other policy contexts, including other regulatory impact analyses.

7a.4 References

U.S. Office of Management and Budget. September 2003. Circular A-4, Regulatory Analysis Guidance sent to the Heads of Executive Agencies and Establishments. Washington, DC. http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf.

Draft Revision to: *Interim Report: New Powertrain Technologies and Their Projected Costs*. U.S. E.P.A. October 2005. http://epa.gov/otaq/technology/420r05012.pdf

U.S. Environmental Protection Agency Science Advisory Board. 2005. EPA's Review of the National Ambient Air Quality Standards for Particulate Matter (Second Draft PM Staff Paper, January 2005). EPA-SAB-CASAC-05-007. June.

U.S. Environmental Protection Agency, 2006. Air Quality Criteria for Ozone and Related Photochemical Oxidants Volume I of III. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC EPA 600/R-05/004aF

Industrial Economics, Incorporated (IEc). April 2004. "Expert Judgment Assessment of the Relationship Between $PM_{2.5}$ Exposure and Mortality." Available at <www.epa.gov/ttn/ecas/benefits.html>.

Appendix 7b: Post 2020 Attainment Analysis

7b.1 Uncertainties of Post 2020 Attainment Analysis

Attainment dates will be determined in the future through the SIP process based on criteria in the CAA, future air quality data, and future rulemakings and are not knowable at this time. For analytical simplicity, and in keeping with the proposal analysis, we have chosen to use an analysis year of 2020 and generally assume attainment in that year. The exception is the San Joaquin and South Coast California areas where SIP submittals for the current standard show that they would have current standard attainment dates later than 2020. For these two areas in California, we are assuming a new standard attainment date of 2030. Estimates of the benefits and costs of attaining .075 and the alternate air quality standards for these two areas in 2030 are included below.

There are many uncertainties associated with the year 2030 analysis. Between 2020 and 2030 several onroad mobile and nonroad mobile source federal air quality rules are expected to further reduce emissions of NOx and VOC. Because mobile source rules affect new vehicles and equipment, they reduce inventories over a long period of time, as older vehicles and equipment are gradually scrapped and are replaced by new, regulated, lower-emitting vehicles and equipment. Among the onroad rules that contribute to the expected decline in mobile-source emissions between 2020 and 2030 are the Tier 2 Rule (light-duty cars and trucks) that went into effect in 2004, the 2007 Onroad Heavy-Duty Rule, and the Mobile Source Air Toxics Rule ("MSAT Final", EPA, 2007a and EPA, 2007b) that goes into effect in 2011. Major nonroad rules also contribute to this decline, including the Locomotive Emissions Final Rulemaking (EPA, 1998), the Locomotive-Marine Final Rule (EPA, 2007c), the Clean Air Nonroad Diesel Final Rule—Tier 4 (EPA, 2004), and Control of Air Pollution from Aircraft (EPA, 2005), among others. California has also regulated most of these same categories, often more stringently than the Federal government, resulting in substantial expected inventory decreases between 2020 and 2030. The emission reductions from these programs should lower ambient levels of ozone between 2020 and 2030 across the state of California; this would facilitate the process of reaching attainment with a revised ozone standard in San Joaquin and South Coast by 2030. In addition, activity data beyond 2025 does not exist for aircraft data; therefore, 2030 aircraft emissions are held at year 2025 levels.

However, the onroad mobile and nonroad mobile sectors are the only sectors projected to 2030 in our emission inventories; we do not have 2030 inventories for any stationary sources and therefore do not have a comprehensive estimate of Ozone precursor emissions around which to craft control strategies to determine costs. All stationary source emissions are held at year 2020 levels because of uncertainties in how to project stationary emissions beyond 2020, and the lack of consistent projection methodologies beyond 2020 (e.g., the model used to create future year EGU emissions does not project to year 2030). Without a complete set of future 2030 emission inventories and control strategies, it is not possible to adequately model either baseline air quality or changes from control strategies. Without modeled changes in Ozone ambient concentrations, it is not possible to perform a sophisticated benefits analysis. In order to provide some idea of costs and benefits of attaining 0.075 and the alternate standards in San Joaquin and

South Coast air basins, we've relied on the available data. Due to the previously mentioned limitations, these analysis results do not capture potential economic growth, or changes in emissions beyond 2020.

7b.2 Post 2020 Attainment Analysis

7b.2.1 Air Quality and Emissions Targets

We have used the 2020-based supplemental air quality modeling as a rough indicator of the percent control needed to meet the four alternate standards by 2030. Table 7b.1 shows the NOx targets estimated to get the Los Angeles and San Joaquin Valley areas into attainment by 2030. The supplemental air quality modeling showed (see Fig4-2d) that there was a sharp dropoff in ozone between the 60% and 90% additional NOx control cases. This may be due to the South Coast region transitioning from VOC-limited to NOx-limited conditions at this level of NOx emissions reductions.

Table 7b.1: Estimated Percentage Reductions of NOx beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in Los Angeles and the San Joaquin Valley in 2030

All 2030 Extrapolated Cost Areas (NOx only)	2020 Design Value after RIA Control Scenario (ppm)	Additional local control needed to meet various standards				
		0.065	0.070	0.075	0.079	0.084
Los Angeles South Coast Air Basin, CA	0.122	> 90%	88%	83%	79%	75%
San Joaquin Valley, CA	0.096	76%	67%	59%	49%	37%

Table 7b.2 shows the NOx reductions needed to get the Los Angeles and San Joaquin Valley areas, into attainment by 2030. These reductions are based on the NOx targets for Los Angeles South Coast Air Basin in Table 7b.1. The higher reductions for Los Angeles compared to the San Joaquin Valley should enable all of California to attain, even after transport effects. Inventory reductions in 2030 from the onroad mobile, nonroad mobile, and aircraft/locomotive/commercial marine sources were credited to the estimates prior to creating the estimated extrapolated reductions needed in Table 7b.2. This table reveals that the majority of emission reductions are needed for these areas to reach the current ozone standard The reductions also include the Final Loco-Marine controls for 2030 (EPA, 2008). Overall, the loco-marine 2030 inventory contains about 120,000 fewer tons of NOx than the 2020 loco-marines inventory for the geographic area in California being analyzed.

Table 7b.2: Estimated Extrapolated Emissions Reductions of NOx Beyond the RIA Control Scenario Necessary to Meet the Various Ozone Standards in Los Angeles and the San Joaquin Valley in 2030

All 2030 Extrapolated Cost Areas (NOx only)	Additional local emissions reductions [annual tons/year] needed to meet various standards (ppm)				
	0.065	0.070	0.075	0.079	0.084
Los Angeles-San Joaquin Valley, CA[a]	390,000	380,000	350,000	330,000	300,000

[a] The Los Angeles South Coast Air Basin and San Joaquin Valley are included in the Sacramento Metro buffer.

To calculate the incremental costs of attainment for the Los Angeles and San Joaquin Valley areas the reductions to meet the current standard are removed from the reductions needed for the various standards.[1] Table 7b.3 contains the remaining 2030 emissions reductions needed for Los Angeles and the San Joaquin Valley.

Table 7b.3: Additional Local Emissions Reductions [annual tons/year] Needed to Meet Various Standards (ppm) Incremental to the Current Standard

All 2030 Extrapolated Cost Areas (NOx only)	Additional local emissions reductions [annual tons/year] needed to meet various standards (ppm) incremental to the current standard			
	0.065[a]	0.070	0.075	0.079
Los Angeles-San Joaquin Valley, CA[b]	78,000	73,000	45,000	23,000

[a] The 0.065 ppm emission reductions required are incremental to the reductions achieved by Sacramento in 2020 (see Table 4.6a).

[b] The Los Angeles South Coast Air Basin and San Joaquin Valley are included in the Sacramento Metro buffer.

The additional tons of reductions needed to attain the various standards may appear relatively low at first glance. It is important to note that these are incremental to progress made in San Joaquin and South Coast air basins toward attainment of the various standards in Sacramento. Additionally, between 2020 and 2030 other rules are expected to reduce emissions. Among these are the Tier 2 Rule (light-duty cars and trucks) that went into effect in 2004, the 2007 Onroad Heavy-Duty Rule, and the Mobile Source Air Toxics Rule ("MSAT Final", EPA, 2007a and EPA, 2007b) that goes into effect in 2011. Major nonroad rules also contribute to this decline, including the Locomotive Emissions Final Rulemaking (EPA, 1998), the Locomotive-Marine Final Rule (EPA, 2007c), the Clean Air Nonroad Diesel Final Rule—Tier 4 (EPA, 2004), and Control of Air Pollution from Aircraft (EPA, 2005), among others. California has also regulated most of these same categories, often more stringently than the Federal government, resulting in substantial expected inventory decreases between 2020 and 2030. A final factor that influences the total number of tons needed to attain in 2030 is the relatively greater effectiveness in California of NOx reductions that happen in the higher range of percentage reduced from the total NOx inventory. For example, a ton reduced when 80% of the total NOx inventory has already been controlled and reduced has a greater effect on ozone concentrations than a ton reduced when only 30% of the total NOx inventory has been thus far reduced.

7b.2.2 Extrapolated Costs

The same two methodologies (fixed and hybrid) were used to estimate the costs of the additional local emission reductions for this 2030 analysis as were used in the national 2020 analysis. There is even more uncertainty associated with this analysis because there is more time for all types of change. Technological change, change in energy policy, changes in the sources of emissions are all expected to be more important for 2030 than for 2020. Because the South Coast and San

[1] In one case, the 0.065 ppm alternate standard, the reductions for the Sacramento Metro area in 2020 (again, includes Los Angeles and the San Joaquin Valley areas that do not require attainment in 2020) are greater than the reductions required to meet the current standard, and these reductions are the subtracted from the increment needed for California to meet the 0.065 ppm standard..

Joaquin Valley cost area has historically had a difficult time attaining air quality standards, it might be expected that the 2020 cost methodologies might underestimate the costs of the additional local emission reductions. However, the additional time for technological change between 2020 and 2030 might be expected to lower costs and result in an overestimate of costs from using the 2020 methodologies. The net bias of using the methodology employed for 2020 in the 2030 analysis is unknown. Additionally it is important to note, most of the air quality improvement needed for these areas is to reach the 0.08 ozone standard. The cost analysis below represents the incremental costs of attaining alternate ozone standards.

7b.2.2.1 Fixed Cost Approach Results

Table 7b.4 shows the estimated costs using the fixed cost methodology with a $15,000 a ton cost applied to the local emission reductions from Table 7b.3

Table 7b.4: Extrapolated Cost to Meet Various Alternate Standards Using Fixed Cost Approach ($15,000/ton) [a]

All 2030 Extrapolated Cost Areas (NOx only)	Fixed Cost Approach Extrapolated Cost (M 2006$).			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
Los Angeles-San Joaquin Valley, CA	$1,200	$1,100	$680	$340

[a] All estimates rounded to two significant figures.

7b.2.2.2 Hybrid Approach Results

Table 7b.6 shows the estimated costs using the fixed cost methodology with the hybrid approach using the average costs shown in Table 7b.5 applied to the local emission reductions from Table 7b.3. The calculations for average cost used for Los Angeles and San Joaquin Valley use the same formulas presented in the Appendix 5a. There are large uncertainties when extrapolating to 2030, therefore keeping the approach consistent yielded the average cost numbers seen in Table 7b.5.

Table 7b.5: Hybrid Approach (Mid) Parameter Values for Various Standards [a, b]

All 2030 Extrapolated Cost Areas (NOx only)	0.065 ppm		0.070 ppm		0.075 ppm		0.079 ppm	
Los Angeles-San Joaquin Valley, CA	R [c]	Average Cost/Ton (2006$)	R [d]	Average Cost/Ton (2006$)	R [d]	Average Cost/Ton (2006$)	R [d]	Average Cost/Ton (2006$)
	1.42	$24,000	1.37	$24,000	1.27	$23,000	1.19	$ 23,000

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

[c] Los Angeles-San Joaquin Valley, CA did not meet the baseline and therefore has an addition R to reach the current standard of 1.11.

[d] Los Angeles-San Joaquin Valley, CA have an R of 1.13 for the 0.65 ppm standard only, due to the emission reductions from Sacramento being limiting.

Table 7b.6: Extrapolated Cost to Meet Various Standards Using Hybrid Approach (Mid) [a, b]

All 2030 Extrapolated Cost Areas (NOx only)	Hybrid Approach Extrapolated Cost (M 2006$).			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
Los Angeles-San Joaquin Valley, CA	$1,900	$1,700	$1,000	$520

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

7b.2.2.3 Sensitivity Analysis Results

Extrapolated cost ensitivity results for the fixed cost approach using a lower ($10,000/ton) and a higher ($20,000/ton) are presented in Table 7b.7 and Table 7b.8. Tables 7b.9 and 7b.11 present the average cost/ton for a higher and lower value of M (0.47 for the high and 0.12 for the low in place of the 0.24 used in the mid estimate). The total extrapolated costs for the Hybrid (Low) and Hybrid (High) are presented in Tables 7b.10 and 7b.12.

Table 7b.7: Extrapolated Cost to Meet Various Alternate Standards Using Fixed Cost Approach ($10,000/ton) [a]

All 2030 Extrapolated Cost Areas (NOx only)	Fixed Cost Approach Extrapolated Cost (M 2006$).			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
Los Angeles-San Joaquin Valley, CA	$780	$730	$450	$230

[a] All estimates rounded to two significant figures.

Table 7b.8: Extrapolated Cost to Meet Various Alternate Standards Using Fixed Cost Approach ($20,000/ton) [a]

All 2030 Extrapolated Cost Areas (NOx only)	Fixed Cost Approach Extrapolated Cost (M 2006$).			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
Los Angeles-San Joaquin Valley, CA	$1,600	$1,500	$900	$450

[a] All estimates rounded to two significant figures.

Table 7b.9: Hybrid Approach (Low) Average Cost/Ton for Various Standards [a, b]

All 2030 Extrapolated Cost Areas (NOx only)	Hybrid Approach Average Cost/Ton (2006$)			
	0.065 ppm	0.070 ppm	0.075 ppm	0.079 ppm
Los Angeles-San Joaquin Valley, CA	$19,000	$19,000	$19,000	$19,000

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 7b.10: Extrapolated Cost to Meet Various Standards Using Hybrid Approach (Low)[a, b]

All 2030 Extrapolated Cost Areas (NOx only)	Hybrid Approach Extrapolated Cost (M 2006$)			
	0.065 ppm	**0.070 ppm**	**0.075 ppm**	**0.079 ppm**
Los Angeles-San Joaquin Valley, CA	$1,500	$1,400	$860	$430

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 7b.11: Hybrid Approach (High) Average Cost/Ton for Various Standards [a, b]

All 2030 Extrapolated Cost Areas (NOx only)	Hybrid Approach Average Cost/Ton (2006$)			
	0.065 ppm	**0.070 ppm**	**0.075 ppm**	**0.079 ppm**
Los Angeles-San Joaquin Valley, CA[A]	$33,000	$33,000	$32,000	$31,000

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

Table 7b.12: Extrapolated Cost to Meet Various Standards Using Hybrid Approach (High)[a, b]

All 2030 Extrapolated Cost Areas (NOx only)	Hybrid Approach Extrapolated Cost (M 2006$)			
	0.065 ppm	**0.070 ppm**	**0.075 ppm**	**0.079 ppm**
Los Angeles-San Joaquin Valley, CA[A]	$2,600	$2,400	$1,400	$700

[a] All estimates rounded to two significant figures.

[b] These estimates assume a particular trajectory of aggressive technological change. An alternative storyline might hypothesize a much less optimistic technological trajectory, with increased costs, or with decreased benefits in 2020 due to a later attainment date.

7b.2.3 Benefits

The Estimated Benefits of 2030 Attainment with Alternate Ozone Standards

The ozone analysis for San Joaquin and South Coast applies the same methods described elsewhere in the benefits chapter with the exception of: (1) the population year and (2) the year for the income growth adjustment. We updated both to 2030 to be consistent with the attainment year. Table 7b.13 below summarizes the updated benefits estimates.

Table 7b.13: Total Estimated Ozone Benefits of Attaining Alternate Ozone Standards in 2030 in San Joaquin and South Coast (2006$)

Mortality Function or Assumption	*Valuation Estimate*
0.079 ppm	
No Causality	$13,000,000
Bell et al. (2004)	$130,000,000
Bell et al. (2005)	$380,000,000
Ito et al. (2005)	$520,000,000
Levy et al. (2005)	$530,000,000
0.075 ppm	
No Causality	$25,000,000
Bell et al. (2004)	$250,000,000
Bell et al. (2005)	$770,000,000
Ito et al. (2005)	$1,000,000,000
Levy et al. (2005)	$1,100,000,000
0.070 ppm	
No Causality	$64,000,000
Bell et al. (2004)	$530,000,000
Bell et al. (2005)	$1,600,000,000
Ito et al. (2005)	$2,100,000,000
Levy et al. (2005)	$2,200,000,000
0.065 ppm	
No Causality	$97,000,000
Bell et al. (2004)	$800,000,000
Bell et al. (2005)	$2,400,000,000
Ito et al. (2005)	$3,100,000,000
Levy et al. (2005)	$3,300,000,000

Estimating the Monetized Benefit per ton of $PM_{2.5}$ Precursor Reduced

The NOx emission reductions necessary to reach attainment with an alternate revised standard would also reduce levels of $PM_{2.5}$. The process for estimating the $PM_{2.5}$ co-benefit for these two airsheds is very similar to the national co-benefit analysis described in the body of the RIA, with a single exception noted further below. The steps are as follows:

1. *Estimate the number of tons of NOx necessary to attain a baseline of 0.08 ppm*. As noted above, Table 7b.2 includes the estimate of extrapolated NOx tons necessary to attain each standard alternative.

2. *Calculate the benefits of attaining 0.08 ppm incremental to partial attainment of 0.08 ppm.* To estimate the benefits of fully attaining 0.08 ppm incremental to partial attainment of 0.08 ppm, the relevant benefit per ton is simply multiplied by the total number of extrapolated NOx tons abated. Note that this calculation step allows us to net

out the benefits of attaining the current standard, so that all subsequent benefits are incremental to the full attainment of 0.080 ppm.

3. *Calculate the benefits of partially attaining 0.070 ppm incremental to full attainment of 0.08 ppm.* Subtract the benefits of fully attaining 0.080 ppm incremental to the partial attainment of 0.08 ppm to create a new estimate of incremental 0.070 ppm partial attainment.

4. *Calculate the $PM_{2.5}$ benefits of fully attaining 0.070 ppm*. Multiplying the estimate of the extrapolated NOx tons necessary to attain 0.070 ppm fully (Table 7b.3) produces an estimate of the incremental benefits of fully attaining 0.070 ppm incremental to partial attainment of 0.070 ppm. By adding this incremental benefit estimate to the benefits generated in step 3, we derived a total benefit estimate of attaining 0.070 ppm incremental to 0.08 ppm.

5. *Repeat step 4 to estimate the benefits of 0.075 ppm, 0.079 ppm and 0.065 ppm*. Step 4 may be repeated by substituting the NOx tons necessary to attain the selected alternative of 0.075 ppm and the remaining alternatives of 0.079 ppm and 0.065 ppm to produce an estimate of total $PM_{2.5}$ co-benefits.

Because this analysis estimates the $PM_{2.5}$ co-benefits of full attainment for these two airsheds in 2030, it was necessary to apply a $PM_{2.5}$ benefit per ton estimate that incorporates this population year. The Technical Support Document for this RIA describes the technique for calculating a benefit per ton estimate that reflected population growth to 2030 (EPA, 2008). Table 7b.14 below summarizes the total monetized $PM_{2.5}$ co-benefits associated with attainment of each standard alternative.

Total Estimate of Combined Ozone Benefits and $PM_{2.5}$ Co-Benefits

Table 7b.15 summarizes the total combined benefits for each standard alternative.

The following tables summarize the costs, benefits, and net benefits of attaining the alternate primary standards for South Coast and San Joaquin.

Table 7b.14: Total Estimated PM2.5 Co-Benefits of Attaining Alternate Ozone Standards in 2030 in San Joaquin and South Coast (2006$)

	Valuation Estimate	
Mortality Function	**3% Discount Rate**	**7% Discount Rate**
0.079 ppm		
ACS Study	$120,000,000	$110,000,000
Harvard Six-City Study	$260,000,000	$240,000,000
Expert K	$54,000,000	$50,000,000
Expert E	$450,000,000	$410,000,000
0.075 ppm		
ACS Study	$240,000,000	$220,000,000
Harvard Six-City Study	$530,000,000	$480,000,000
Expert K	$110,000,000	$100,000,000
Expert E	$900,000,000	$820,000,000
0.070 ppm		
ACS Study	$400,000,000	$360,000,000
Harvard Six-City Study	$860,000,000	$780,000,000
Expert K	$180,000,000	$160,000,000
Expert E	$1,500,000,000	$1,300,000,000
0.065 ppm		
ACS Study	$420,000,000	$380,000,000
Harvard Six-City Study	$910,000,000	$820,000,000
Expert K	$190,000,000	$170,000,000
Expert E	$1,600,000,000	$1,400,000,000

Table 7b.15: Total Combined Ozone Benefits and PM2.5 Co-Benefits of Attaining Alternate Ozone Standards in 2030 in San Joaquin and South Coast (2006$, 3% Discount Rate)

	Alternative Standard and Model or Assumption				
	Bell et al. (2004)	**Bell et al. (2005)**	**Ito et al. (2005)**	**Levy et al. (2005)**	**Assumption of No Causality**
0.079 ppm Alternative					
ACS Study	$250,000,000	$510,000,000	$640,000,000	$650,000,000	$130,000,000
Harvard Six-City Study	$390,000,000	$650,000,000	$780,000,000	$800,000,000	$280,000,000
Expert K	$180,000,000	$440,000,000	$570,000,000	$590,000,000	$67,000,000
Expert E	$580,000,000	$840,000,000	$970,000,000	$990,000,000	$460,000,000
0.075 ppm Selected Alternative					
ACS Study	$500,000,000	$1,000,000,000	$1,300,000,000	$1,300,000,000	$270,000,000
Harvard Six-City Study	$780,000,000	$1,300,000,000	$1,600,000,000	$1,600,000,000	$550,000,000
Expert K	$360,000,000	$870,000,000	$1,100,000,000	$1,200,000,000	$130,000,000
Expert E	$1,200,000,000	$1,700,000,000	$1,900,000,000	$2,000,000,000	$930,000,000
0.070 ppm Alternative					
ACS Study	$930,000,000	$2,000,000,000	$2,500,000,000	$2,600,000,000	$460,000,000
Harvard Six-City Study	$1,400,000,000	$2,400,000,000	$3,000,000,000	$3,100,000,000	$920,000,000
Expert K	$710,000,000	$1,800,000,000	$2,300,000,000	$2,400,000,000	$240,000,000
Expert E	$2,000,000,000	$3,100,000,000	$3,600,000,000	$3,700,000,000	$1,500,000,000
0.065 ppm Alternative					
ACS Study	$1,200,000,000	$2,800,000,000	$3,500,000,000	$3,700,000,000	$520,000,000
Harvard Six-City Study	$1,700,000,000	$3,300,000,000	$4,000,000,000	$4,200,000,000	$1,000,000,000
Expert K	$990,000,000	$2,600,000,000	$3,300,000,000	$3,500,000,000	$280,000,000
Expert E	$2,400,000,000	$3,900,000,000	$4,700,000,000	$4,900,000,000	$1,700,000,000

Table 7b.16: Total Combined Ozone Benefits and PM2.5 Co-Benefits of Attaining Alternate Ozone Standards in 2030 in San Joaquin and South Coast (2006$, 7% Discount Rate)

	Alternative Standard and Model or Assumption				
	Bell et al. (2004)	**Bell et al. (2005)**	**Ito et al. (2005)**	**Levy et al. (2005)**	**Assumption of No Causality**
0.079 ppm Alternative					
ACS Study	$240,000,000	$490,000,000	$630,000,000	$640,000,000	$120,000,000
Harvard Six-City Study	$370,000,000	$620,000,000	$760,000,000	$770,000,000	$250,000,000
Expert K	$180,000,000	$430,000,000	$570,000,000	$580,000,000	$63,000,000
Expert E	$540,000,000	$790,000,000	$930,000,000	$940,000,000	$420,000,000
0.075 ppm Selected Alternative					
ACS Study	$480,000,000	$990,000,000	$1,300,000,000	$1,300,000,000	$250,000,000
Harvard Six-City Study	$730,000,000	$1,200,000,000	$1,500,000,000	$1,500,000,000	$500,000,000
Expert K	$350,000,000	$860,000,000	$1,100,000,000	$1,200,000,000	$130,000,000
Expert E	$1,100,000,000	$1,600,000,000	$1,900,000,000	$1,900,000,000	$840,000,000
0.070 ppm Alternative					
ACS Study					
Harvard Six-City Study	$1,300,000,000	$2,400,000,000	$2,900,000,000	$3,000,000,000	$840,000,000
Expert K	$700,000,000	$1,700,000,000	$2,300,000,000	$2,400,000,000	$230,000,000
Expert E	$1,900,000,000	$2,900,000,000	$3,500,000,000	$3,500,000,000	$1,400,000,000
0.065 ppm Alternative					
ACS Study	$1,200,000,000	$2,800,000,000	$3,500,000,000	$3,700,000,000	$480,000,000
Harvard Six-City Study	$1,600,000,000	$3,200,000,000	$3,900,000,000	$4,100,000,000	$920,000,000
Expert K	$970,000,000	$2,600,000,000	$3,300,000,000	$3,500,000,000	$270,000,000
Expert E	$2,200,000,000	$3,800,000,000	$4,500,000,000	$4,700,000,000	$1,500,000,000

Table 7b.17: Annual Monetized Costs and Benefits in 2030 in San Joaquin and South Coast: 0.075 ppm Standard in Billions of 2006$*

Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	0.36 - 1.2	0.35 - 1.1	0.68 - 1.0	-0.64 - 0.48	-0.65 - 0.39
Meta-analysis	Bell et al. 2005	0.87 - 1.7	0.86 - 1.6	0.68 - 1.0	-0.13 - 0.99	-0.14 - 0.90
	Ito et al. 2005	1.1 - 1.9	1.1 - 1.9	0.68 - 1.0	0.14 - 1.26	0.13 - 1.2
	Levy et al. 2005	1.2 - 2.0	1.2 - 1.9	0.68 - 1.0	0.17 - 1.29	0.16 - 1.20
Assumption that association is not causal***		0.13 - 0.93	0.13 - 0.84	0.68 - 1.0	-0.87 - 0.25	-0.87 - 0.16

Table7b.18: Annual Monetized Costs and Benefits in 2030 in San Joaquin and South Coast: 0.079 ppm Standard in Billions of 2006$*

Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	0.18 - 0.58	0.18 - 0.54	0.34 - 0.52	-0.34 - 0.24	-0.34 - 0.20
Meta-analysis	Bell et al. 2005	0.44 - 0.84	0.43 - 0.79	0.34 - 0.52	-0.08 - 0.50	-0.09 - 0.45
	Ito et al. 2005	0.57 - 0.97	0.57 - 0.93	0.34 - 0.52	0.05 - 0.63	0.05 - 0.59
	Levy et al. 2005	0.59 - 0.99	0.58 - 0.94	0.34 - 0.52	0.07 - 0.65	0.06 - 0.60
Assumption that association is not causal***		0.07 - 0.46	0.06 - 0.42	0.34 - 0.52	-0.45 - 0.12	-0.46 - 0.08

Table 7b.19: Annual Monetized Costs and Benefits in 2030 in San Joaquin and South Coast: 0.070 ppm Standard in Billions of 2006$*

Mortality Function or Assumption	Reference	Total Benefits** 3%	Total Benefits** 7%	Total Costs** 7%	Net Benefits 3%	Net Benefits 7%
NMMAPS	Bell et al. 2004	0.71 - 2.0	0.70 - 1.9	1.1 - 1.7	-0.99 - 0.90	-1.0 - 0.76
Meta-analysis	Bell et al. 2005	1.8 - 3.1	1.7 - 2.9	1.1 - 1.7	0.06 - 2.0	0.05 - 1.8
	Ito et al. 2005	2.3 - 3.6	2.3 - 3.5	1.1 - 1.7	0.62 - 2.5	0.60 - 2.4
	Levy et al. 2005	2.4 - 3.7	2.4 - 3.5	1.1 - 1.7	0.67 - 2.6	0.66 - 2.4
Assumption that association is not causal***		0.24 - 1.5	0.23- 1.4	1.1 - 1.7	-1.5 - 0.43	-1.5 - 0.29

Table 7b.20: Annual Monetized Costs and Benefits in 2030 in San Joaquin and South Coast: 0.065 ppm Standard in Billions of 2006$*

Mortality Function or Assumption	Reference	Total Benefits**		Total Costs**	Net Benefits	
		3%	7%	7%	3%	7%
NMMAPS	Bell et al. 2004	0.99 - 2.4	0.97 - 2.2	1.2- 1.9	-0.91 - 1.2	-0.93 - 1.0
Meta-analysis	Bell et al. 2005	2.6 - 3.9	2.6 - 3.8	1.2 - 1.9	0.67 - 2.7	0.65 - 2.6
	Ito et al. 2005	3.3 - 4.7	3.3 - 4.5	1.2 - 1.9	1.4 - 3.5	1.4 - 3.3
	Levy et al. 2005	3.5 - 4.9	3.5 - 4.7	1.2 - 1.9	1.6 - 3.7	1.6 - 3.5
Assumption that association is not causal***		0.28 - 1.7	0.27 - 1.5	1.2 - 1.9	-1.6 - 0.46	-1.63 - 0.31

*Includes ozone benefits, and PM 2.5 co-benefits. Range was developed by adding the estimate from the ozone premature mortality function to both the lower and upper ends of the range of the PM2.5 premature mortality functions characterized in the expert elicitation. Tables exclude unquantified and nonmonetized benefits. All estimates rounded to two significant figures, so totals may not sum across columns.

**Range reflects lower and upper bound cost estimates. Data for calculating costs at a 3% discount rate was not available for all sectors, and therefore total annualized costs at 3% are not presented here.

***Total includes ozone morbidity benefits only.

7b.3 References

U.S. Environmental Protection Agency (EPA). 1998. *Locomotive Emission Standards: Regulatory Support Document*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105. Available at http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/locorsd.pdf

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

U.S. Environmental Protection Agency (EPA). 2005. *Emission Standards and Test Procedures for Aircraft and Aircraft Engines: Summary and Analysis of Comments*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-05-004, November, 2005. Available at http://www.epa.gov/otaq/regs/nonroad/aviation/420r05004.pdf.

U.S. Environmental Protection Agency (EPA). 2007a. *Regulatory Impact Analysis for Final Rule: Control of Hazardous Air Pollutants from Mobile Sources*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105, EPA420-R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/420r07002.pdf.

U.S. Environmental Protection Agency (EPA). 2007b. *National Scale Modeling for the Final Mobile Source Air Toxics Rule*, Office of Air Quality Planning and Standards, Emissions Analysis and Monitoring Division, Research Triangle Park, NC 27711, EPA 454/R-07-002, February 2007. Available at http://www.epa.gov/otaq/regs/toxics/454r07002.pdf.

U.S. Environmental Protection Agency (EPA). 2007c. *Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder, Chapter 3: Emission Inventory*, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division, Ann Arbor, MI 48105. EPA420-D-07-001, March 2007. Available at http://www.epa.gov/otaq/regs/nonroad/420d07001chp3.pdf.

U.S. Environmental Projections Agency (EPA). 2008. Technical Support Document: Preparation of Emissions Inventories For the 2002-based Platform, Version 3, Criteria Air Pollutants, USEPA, January, 2008.

Chapter 8: Statutory and Executive Order Impact Analyses

Synopsis

This chapter summarizes the Statutory and Executive Order (EO) impact analyses relevant for the ozone NAAQS RIA. In general, because this RIA analyzes an illustrative attainment strategy to meet the revised NAAQS, and because States will ultimately implement the new NAAQS, the Statutory and Executive Orders below did not require additional analysis. For each EO and Statutory requirement we describe both the requirements and the way in which the RIA addresses these requirements. Further analyses of the NAAQS proposal and its impact on these statutory and executive orders are found in section VII of the NAAQS preamble.

8.1 Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order (EO) 12866 (58 FR 51735, October 4, 1993), the ozone NAAQS action is an “economically significant regulatory action” because it is likely to have an annual effect on the economy of $100 million or more. Accordingly, EPA prepared this regulatory impact analysis (RIA) of the potential costs and benefits associated with this action. The RIA estimates the costs and monetized human health benefits of attaining three alternative ozone NAAQS nationwide. Specifically, the RIA examines the alternatives of 0.079 0.075 ppm, 0.070 ppm, and 0.065 ppm. The RIA contains illustrative analyses that consider a limited number of emissions control scenarios that States and Regional Planning Organizations might implement to achieve these alternative ozone NAAQS. However, the Clean Air Act (CAA) and judicial decisions make clear that the economic and technical feasibility of attaining ambient standards are not to be considered in setting or revising NAAQS, although such factors may be considered in the development of State plans to implement the standards. Accordingly, although an RIA has been prepared, the results of the RIA have not been considered in issuing this rule.

8.2 Paperwork Reduction Act

This RIA does not impose an information collection burden under the provisions of the Paperwork Reduction Act, 44 U.S.C. 3501 et seq. There are no information collection requirements directly associated with revisions to a NAAQS under section 109 of the CAA.

Burden is defined as the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

An agency may not conduct or sponsor information collection, and a person is not required to respond to a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

8.3 Regulatory Flexibility Act

The EPA has determined that it is not necessary to prepare a regulatory flexibility analysis in connection with this RIA. For purposes of assessing the impacts of today's rule on small entities, small entity is defined as: (1) a small business that is a small industrial entity as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

After considering the economic impacts of today's rule on small entities, EPA has concluded that this action will not have a significant economic impact on a substantial number of small entities. This rule will not impose any requirements on small entities. This rule establishes national standards for allowable concentrations of ozone in ambient air, as required by section 109 of the CAA. See also *ATA I* at 1044-45 (NAAQS do not have significant impacts upon small entities because NAAQS themselves impose no regulations upon small entities).

8.4 Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), Public Law 104-4, establishes requirements for Federal agencies to assess the effects of their regulatory actions on State, local, and Tribal governments and the private sector. Under section 202 of the UMRA, EPA generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with "Federal mandates" that may result in expenditures to State, local, and Tribal governments, in the aggregate, or to the private sector, of $100 million or more in any 1 year. Before promulgating an EPA rule for which a written statement is needed, section 205 of the UMRA generally requires EPA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows EPA to adopt an alternative other than the least costly, most cost-effective or least burdensome alternative if the Administrator publishes with the final rule an explanation why that alternative was not adopted. Before EPA establishes any regulatory requirements that may significantly or uniquely affect small governments, including Tribal governments, it must have developed under section 203 of the UMRA a small government agency plan. The plan must provide for notifying potentially affected small governments, enabling officials of affected small governments to have meaningful and timely input in the development of EPA regulatory proposals with significant Federal intergovernmental mandates, and informing, educating, and advising small governments on compliance with the regulatory requirements.

This proposal contains no Federal mandates (under the regulatory provisions of Title II of the UMRA) for State, local, or Tribal governments or the private sector. The rule imposes no new expenditure or enforceable duty on any State, local or Tribal governments or the private sector, and EPA has determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments. Furthermore, as indicated previously, in setting a NAAQS, EPA cannot consider the economic or technological feasibility of attaining ambient air quality standards, although such factors may be considered to a degree in the development of State plans to implement the standards. See also *ATA I* at 1043 (noting that because EPA is precluded from considering costs of implementation in establishing NAAQS, preparation of a Regulatory Impact Analysis pursuant to the Unfunded Mandates Reform Act would not furnish any information which the court could consider in reviewing the NAAQS). Accordingly, EPA has determined that the provisions of sections 202, 203, and 205 of the UMRA do not apply to this final decision. The EPA acknowledges, however, that any corresponding revisions to associated SIP requirements and air quality surveillance requirements, 40 CFR part 51 and 40 CFR part 58, respectively, might result in such effects. Accordingly, EPA has addressed unfunded mandates in the notice that announces the revisions to 40 CFR part 58, and will, as appropriate, address unfunded mandates when it proposes any revisions to 40 CFR part 51.

8.5 Executive Order 13132: Federalism

Executive Order 13132, entitled “Federalism” (64 FR 43255, August 10, 1999), requires EPA to develop an accountable process to ensure “meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications.” “Policies that have federalism implications” is defined in the Executive Order to include regulations that have “substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government.”

At the time of the proposal, EPA concluded that the proposed rule would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132.

8.6 Executive Order 13175: Consultation and Coordination with Indian Tribal Governments

Executive Order 13175, entitled “Consultation and Coordination with Indian Tribal Governments” (65 FR 67249, November 9, 2000), requires EPA to develop an accountable process to ensure “meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications.” This rule concerns the establishment of ozone NAAQS. The Tribal Authority Rule gives Tribes the opportunity to develop and implement CAA programs such as the ozone NAAQS, but it leaves to the discretion of the Tribe whether to develop these programs and which programs, or appropriate elements of a program, they will adopt.

This rule does not have Tribal implications, as specified in Executive Order 13175. It does not have a substantial direct effect on one or more Indian Tribes, since Tribes are not obligated to adopt or implement any NAAQS. Thus, Executive Order 13175 does not apply to this rule..

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

Executive Order 13045, "Protection of Children from Environmental Health Risks and Safety Risks" (62 FR 19885, April 23, 1997) applies to any rule that: (1) is determined to be "economically significant" as defined under Executive Order 12866, and (2) concerns an environmental health or safety risk that EPA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, the Agency must evaluate the environmental health or safety effects of the rule on children, and explain why the regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the Agency. This rule is subject to Executive Order 13045 because it is an economically significant regulatory action as defined by Executive Order 12866, and we believe that the environmental health risk addressed by this action may have a disproportionate effect on children.

The NAAQS constitute uniform, national standards for ozone pollution; these standards are designed to protect public health with an adequate margin of safety, as required by CAA section 109. However, the protection offered by these standards may be especially important for children because children, along with other sensitive population subgroups such as the elderly and people with existing heart or lung disease, are potentially susceptible to health effects resulting from ozone exposure. Because children are considered a potentially susceptible population, we have carefully evaluated the environmental health effects of exposure to ozone pollution to this sub-population. These effects and the size of the population affected are summarized in section 8.7 of the Criteria Document and section 3.6 of the Staff Paper, and the results of our evaluation of the effects of ozone pollution on children are discussed in sections II.A-C of the NAAQS proposal preamble.

8.8 Executive Order 13211: Actions that Significantly Affect Energy Supply, Distribution or Use

Executive Order 13211, "Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use" (66 FR 28355 (May 22, 2001), requires EPA to prepare and submit a Statement of Energy Effects to the Administrator of the Office of Information and Regulatory Affairs, Office of Management and Budget, for certain actions identified as "significant energy actions." Section 4(b) of Executive Order 13211 defines "significant energy actions" as "any action by an agency (normally published in the Federal Register) that promulgates or is expected to lead to the promulgation of a final rule or regulation, including notices of inquiry, advance notices of proposed rulemaking, and notices of proposed rulemaking: (1)(i) that is a significant regulatory action under Executive Order 12866 or any successor order, and (ii) is likely to have a significant adverse effect on the supply, distribution, or use of energy; or (2) that is designated by the Administrator of the Office of Information and Regulatory Affairs as a significant energy action." OMB has designated this rulemaking as a significant energy action. We have prepared a Statement of Energy Effects for this action as follows.

Application of the modeled illustrative control strategy containing only known controls shown Chapter 5 of this RIA leads to an estimated decrease nationwide in 2020 in coal production of less than 0.2 percent, an estimated decrease in crude oil production of about 0.1 percent, an estimated decrease in natural gas production of less than 0.1 percent, and an estimated increase in electricity production of less than 0.1 percent. Estimates of price changes for these energy products are of the same magnitude nationwide in 2020 as the estimates of output changes. For more details on how energy impacts are modeled in this analysis and the caveats and limitations that should be understood in interpreting these impacts, please refer to Appendix 5B of this RIA. For the electricity generating sector, installation of approximately 9.4 gigawatts (GWs) of SCR and 2.4 GWs of SNCR are projected in 2020 as a result of applying the illustrative EGU control strategy mentioned earlier in this RIA. There are very small changes expected in the mix of electricity generation (i.e., the number of coal-fired EGUs compared to the number of natural gas-fired and oil-fired EGUs) as a response to the illustrative EGU control strategy. Hydro, nuclear, other, and renewable based generation are projected to remain the same. Projected retirements of both coal and oil/gas units remained the same after applying the illustrative EGU control strategy. For more details on the energy impacts estimated for EGUs, please refer to Chapter 5 of this RIA and its appendix.

We provide the energy impact results reflecting only the modeled illustrative control strategy because these results have a greater degree of certainly associated with them when compared to results associated with the other alternate primary ozone standards analyzed. This greater degree of certainty is due to the application of photochemical air quality modeling (i.e., CMAQ) to assess where precursor emission reductions are most needed to attain a particular alternate primary ozone standard. Since such CMAQ modeling was not applied for these other alternate primary ozone standards, we thus have a differing degree of certainty with regards to impacts associated with the modeled illustrative control strategy as opposed to other strategies applied for the other alternate primary ozone standards. Other caveats associated with our illustrative control strategies and results from applying them are explained in Chapter 3 of this RIA. Finally, the energy impacts reported in this RIA do not incorporate the extrapolated costs estimated for Chapter 5 of this RIA. The proportion of the engineering costs that are extrapolated can also be found in that RIA chapter.

8.9 National Technology Transfer Advancement Act

Section 12(d) of the National Technology Transfer Advancement Act of 1995 (NTTAA), Public Law No. 104-113, §12(d) (15 U.S.C. 272 note), directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (e.g., materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards. Since EPA is not changing any of the monitoring requirements as part of this proposal, there are no impacts associated with the NTTAA.

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

Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," requires Federal agencies to consider the impact of programs, policies, and activities on minority populations and low-income populations. According to EPA guidance, agencies are to assess whether minority or low-income populations face a risk or a rate of exposure to hazards that are significant and that "appreciably exceeds or is likely to appreciably exceed the risk or rate to the general population or to the appropriate comparison group" (EPA, 1998).

In accordance with Executive Order 12898, the Agency has considered whether these decisions may have disproportionate negative impacts on minority or low-income populations. This rule establishes uniform, national ambient air quality standards for ozone, and is not expected to have disproportionate negative impacts on minority or low income populations. In this NAAQS proposal, the Administrator considered the available information regarding health effects among vulnerable and susceptible populations, such as those with preexisting conditions. Thus it remains EPA's conclusion that this rule is not expected to have disproportionate negative impacts on minority or low income populations.