REGULATORY IMPACT ANALYSES

FOR THE PARTICULATE MATTER

AND OZONE

NATIONAL AMBIENT AIR QUALITY STANDARDS

AND PROPOSED REGIONAL HAZE RULE

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SELECTED LIST OF ACRONYMS

ACT	Alternative Control Techniques
AIRS	Aerometric Information Retrieval System
AIRCOST	utility SO_2 control cost model (E.H.Pechan & Associates)
AF	air/fuel adjustment
ALAPCO	Association of Local Air Pollution Control Officers
AP-42	compilation of air pollutant emissions factors
AQSSD	Air Quality Strategies and Standards Division
AV	annualized value
BARCT	best available retrofit control technology
BEA	Bureau of Economic Analysis
BOOS	burners out-of-service
CAA	Clean Air Act
CAAAC	Clean Air Act Advisory Committee
CAM	Compliance Assurance Monitoring
CASAC	Clean Air Scientific Advisory Committee
CD	Criteria Document
CFC	chlorofluorocarbons
CFR	Code of Federal Regulations
CRDM	Climatological Regional Dispersion Model
CARB	California Air Resources Board
CARM	California Air Resources Management
CO	carbon monoxide
CS-C	control strategy-cost
CTG	control technique guideline
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
E.O.	Executive Order
EP	environmental protection
EPA	Environmental Protection Agency
EIA	Energy Information Administration
ERCAM	Emission Reductions and Cost Analysis Models
ERCAM NOx	Enhancements to the Emission Reduction and Cost Analysis Models for NOx
ERCAM VOC	Enhancements to the Emission Reduction and Cost Analysis Models for VOC
ESP	electrostatic precipitator
FAC	aerosol coefficients
FACA	Federal Advisory Committee Act
FGD	flue gas desulfurization
FGR	flue gas recirculation
FIP	Federal implementation plan
FLM	Federal Land Manager

SELECTED LIST OF ACRONYMS (continued)

FMVCP	Federal Motor Vehicle Control Program
FR	Federal Register
FTE	full time equivalent
GCVTC	Grand Canyon Visibility Transport Commission
GDP	gross domestic product
GNP	gross national product
GSP	gross State product
ICI	industrial, commercial, and institutional
ICR	Information Collection Request
ISCST	Industrial Source Complex Short Term
I/M	inspection/maintenance
I-O	input-output
IPM	Integrated Planning Model
IR	ignition timing retardation
LAER	lowest achievable emission rate
LEA	low excess air
LEV	low emission vehicle
LMOS	Lake Michigan Ozone Study Group
LNB	low-NO_x burner
MACT	maximum achievable control technology
MSA	metropolitan statistical area
MW	megawatts
NAAQS	national ambient air quality standards
NAMS	National Air Monitoring Stations
NAPAP	National Acid Precipitation Assessment Program
NAS	nonattainment areas
NEI	National Emissions Inventory
NH_3	ammonia
NPV	net present value
NSR	New Source Review
NGR	natural gas recirculation
NO_X	oxides of nitrogen
NPI	National Particulate Inventory
NSCR	non-selective catalytic reduction
NSPS	New Source Performance Standard
O&M	operating and maintenance
OAQPS	Office of Air Quality Planning and Standards
OCS	outer continental shelf
OFA	overfire air
OMB	Office of Management and Budget
OMS	Office of Mobile Sources
OMTG	open market trading guidelines

SELECTED LIST OF ACRONYMS (continued)

OTAG	Ozone Transport Assessment Group
OTC Ozone Transport Commission	
OXYFIRING	firing of glass furnaces with oxygen-enriched combustion air
PAMS	Photochemical Assessment Monitoring Stations
PM	Particulate Matter
PRA	Paperwork Reduction Act
P-V valves	pressure-vacuum valves
RACT	reasonably available control technology
RADM	Regional Acid Deposition Model
RAMP	Regional Air Management Plan
REMI	Regional Economic Model
REMSAD	Regulatory Modeling System for Aerosols and Deposition
RFA	Regulatory Flexibility Analysis
RH	Regional Haze
RIA	Regulatory Impact Analysis
RIS	Regulatory Impact Statement
RNA	residual nonattainment area
ROM	Regional Oxidant Modeling
RVP	Reid Vapor Pressure
S-R	source-receptor
SBREFA	Small Business Regulatory Enforcement Fairness Act
SCAQMD	South Coast Air Quality Management District
SCC	Source Classification Code
SCR	selective catalytic reduction
SIC	Standard Industrial Classification
SIP	State implementation plan
SLAMS	State and Local Air Monitoring Stations
SNCR	selective non-catalytic reduction
SOA	secondary organic aerosols
SOCMI	Synthetic Organic Chemical Manufacturing Industry
SO_2	sulfur dioxide
SOx	sulfur oxides
SBA	Small Business Administration
SP	Staff Paper
SPMS	special purpose monitors
STAPPA	State and Territorial Air Pollution Program Administration
TAC	total annual costs
TCI	total capital investment
TSP	total suspended particulate
TVA	Tennessee Valley Authority
ULNB	ultra low-NO_x burner
UMRA	Unfunded Mandates Reform Act

SELECTED LIST OF ACRONYMS (continued)

USDA	U.S. Department of Agriculture
VOC	volatile organic compounds
VMT	vehicle miles traveled

EXECUTIVE SUMMARY

Purpose

The Clean Air Act (CAA) directs the Environmental Protection Agency (EPA) to identify and set national standards for pollutants which cause adverse effects to public health and the environment. The EPA is also required to review these health and welfare-based standards at least once every five years to determine whether, based on new research, revisions to the standards are necessary to continue to protect public health and the environment. Recent evidence indicates that two pollutants, ground level ozone and particulate matter (PM), (specifically fine particles which are smaller than 2.5µm in diameter, termed $PM_{2.5}$) are associated with significant health and welfare effects below current regulated levels. As a result of the most recent review process, EPA is revising the primary (health-based) and secondary (welfare-based) National Ambient Air Quality Standards (NAAQS) for both of these pollutants. In addition, in the final action on PM, EPA recognized that visibility impairment is an important effect of PM on public welfare. The EPA concluded that the most appropriate approach for addressing visibility impairment is the establishment of secondary standards for PM identical to the suite of primary standards, in conjunction with a revised visibility protection program to address regional haze in certain large national parks and wilderness areas.

To some degree, the problems of ground level ozone, PM and regional haze all result from commonly shared elements. Pollutants which are precursors to ozone formation are also precursors to the formation of fine PM. Both ozone and fine PM are components of regional haze. These similarities clearly provide management opportunities for optimizing and coordinating monitoring networks, emission inventories and air quality models, and for creating opportunities for coordinating and minimizing the regulatory burden for sources that would otherwise be required to comply with separate controls for each of these pollutants. Thus, these new standards are likely to be considered jointly by the various authorities responsible for their implementation. With this in mind, EPA has developed an economic impact analysis which looks at the coordinated implementation of all of these new rules. Pursuant to Executive Order

12866, this Regulatory Impact Analysis (RIA) assesses the potential costs, economic impacts, and benefits associated with illustrative implementation scenarios of these NAAQS for ozone and PM, including monitoring for these pollutants. It also assesses the costs, economic impacts, and benefits associated with the implementation of alternative regional haze programs.

In setting the primary air quality standards, EPA's first responsibility under the law is to select standards that protect public health. In the words of the CAA, for each criteria pollutant EPA is required to set a standard that protects public health with "an adequate margin of safety." As interpreted by the Agency and the courts, this decision is a *health-based* decision that specifically is *not* to be based on cost or other economic considerations. However, under the CAA, cost can be considered in establishing an alternative regional haze program.

This reliance on science and prohibition against the consideration of cost in setting of the primary air quality standard does not mean that cost or other economic considerations are not important or should be ignored. The Agency believes that consideration of cost is an essential decision making tool for the cost-effective <u>implementation</u> of these standards. Over time, EPA will continue to update this economic analysis as more information on the implementation strategies becomes known. However, under the health-based approach required by the CAA, the appropriate place for cost and efficiency considerations is during the development of implementation strategies, strategies that will allow communities, over time, to meet the health-based standards. The implementation process is where decisions are made -- both nationally and within each community -- affecting how much progress can be made, and what time lines, strategies and policies make the most sense. For example, the implementation process includes the development of national emissions standards for cars, trucks, fuels, large industrial sources and power plants, and through the development of appropriately tailored state and local implementation plans.

In summary, this RIA and associated analyses are intended to generally inform the public about the potential costs and benefits that may result when the promulgated revisions to the ozone and PM NAAQS are implemented by the States, but are not relevant to establishing the standards themselves. This RIA also presents the benefits and costs of alternative regional haze goals which may be relevant to establishing provisions of the regional haze rule.

General Limitations of this Analysis

Cost-benefit analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, cost-benefit analysis helps illuminate important potential effects of changes in policy and helps set priorities for closing information gaps and reducing uncertainty. However, nonmonetized benefits are not included here. Executive Order 12866 is clear that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. It is particularly important to note that there are many unquantifiable and nonmonetizable benefits categories. Including many health and welfare effects.

Several specific limitations need to be mentioned. The state of atmospheric modeling is not sufficiently advanced to adequately account for all the interactions between these pollutants and the implementation strategies which may be used to control them. Additionally, significant shortcomings exist as to the data available for these analyses. While containing uncertainties, the models used by EPA and the assumptions in the analysis are thought to be reasonable based on the available evidence.

Another major limitation is the illustrative implementation scenario which EPA uses in this analysis to measure the cost of meeting the new standards. The strategies used are limited in part because of our inability to predict the breadth and depth of the creative approaches to implementing these new NAAQS, and in part by technical limitations in modeling capabilities. These limitations, in effect, force costs to be developed based on compliance strategies that may reflect suboptimal approaches to implementation, and therefore, may reflect higher potential costs for attaining the new standards. This approach renders the result specifically useful as an incentive to pursue lower cost options, but not as a precise indicator of likely costs.

Another dimension adding to the uncertainty of this analysis is time. In the case of air pollution control, thirteen years is a very long time over which to carry assumptions. Pollution control technology has advanced considerably in the last thirteen years and can be expected to continue to advance in the future. Yet there is no clear way model this advance for use in this analysis.

Furthermore, using 2010 as the analytical year for our analysis may not allow sufficient time for all areas to reach attainment. This analysis recognizes this by not arbitrarily assuming all areas reach attainment in 2010. Because 2010 is earlier than many areas are likely to be required to attain, especially for $PM_{2.5}$, the result is a snapshot in time, reflecting progress and partial attainment but not complete attainment.

What we know about 2010 is limited by several factors. This is because EPA's modeling was not able to identify specific measures sufficient to attain the standards in all areas by the analytical year. Further, in EPA's effort to realistically model control measures which might actually be put into practice, our analysis excludes control measures which historically have been seen to be cost-ineffective.

However, even though the control measures identified in our models may be insufficient to reduce pollutants to reach the standards in all areas, there is sufficient evidence to predict that technological innovation and innovative policy mechanisms over the 13 years will make substantial progress towards improving techniques to remove pollutants in these areas in a cost-effective fashion. Chapter 9 of the RIA provides examples of how technological innovation has improved air pollution control measures over the last 10 years and lists emerging technologies which may be available in the year 2010. It also provides a rough estimate of full attainment costs that might result from the implementation of these and other control technologies yet to be developed.

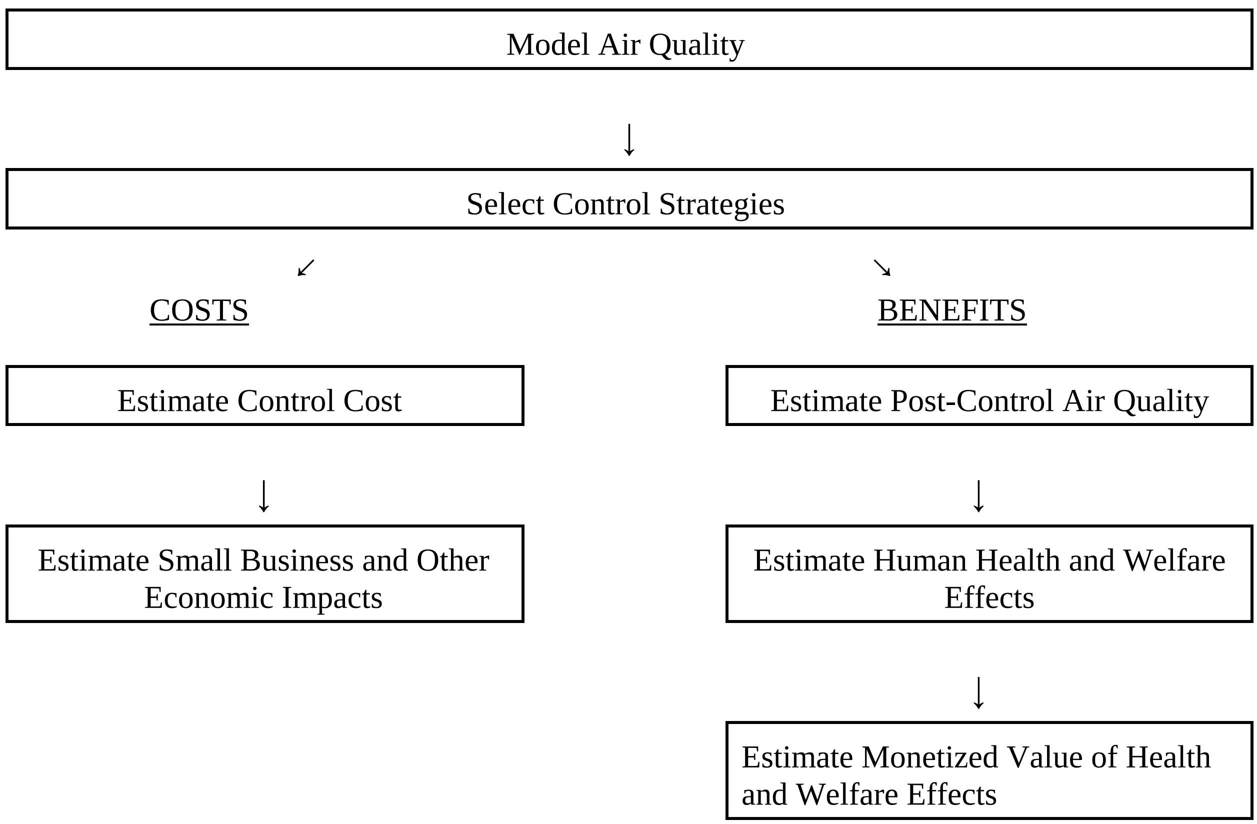
It is important to recognize that with the finalization of the new ozone and PM standards, the Act, and the implementation package accompanying the standards, allow for flexibility in the development of implementation strategies, both for control strategies as well as schedules. The actual determination of how areas or counties will meet the standards is done by States during the development of their State Implementation Plans (SIPs). These SIPs are generally based on the results from more detailed area specific models using more complete information than is available to EPA for the development of its national analysis. For this reason, while EPA believes that this RIA is a good approximation of the national costs and benefits of these rules (subject to the limitations described elsewhere), this analysis cannot accurately predict what will occur account for what happens in individual areas. In addition, this RIA does not take into account all the creativity and flexibility which a State will have when actually implementing these standards. Thus, cheaper ways of implementing the new standards and obtaining the same amount of benefits may well be found.

Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in the analysis. Where information and data exists, quantitative characterizations of these and other uncertainties are included. However, data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

Overview of RIA Methodology: Inputs and Assumptions

The potential costs, economic impacts and benefits have been estimated for each of the three rules. The flow chart below summarizes the analytical steps taken in developing the results presented in this RIA.

FIGURE ES-1: Flowchart of Analytical Steps



The assessment of costs, economic impacts and benefits consists of multiple analytical components, dependent upon emissions and air quality modeling. In order to estimate baseline air quality in the year 2010, emission inventories are developed for 1990 and then projected to 2010, based upon estimated national growth in industry earnings and other factors. Current CAA-mandated controls (e.g., Title I reasonably available control measures, Title II mobile source controls, Title III air toxics controls, Title IV acid rain sulfur dioxide (SO_2) controls) are applied to these emissions to take account of emission reductions that should be achieved in 2010 as a result of implementation of the current PM and ozone requirements. These 2010 CAA emissions in turn are input to an air quality model that relates emission sources to county-level pollutant concentrations. This modeled air quality is used to identify projected counties, based on these assumptions, that exceed the alternative pollutant concentration levels[1]. A cost optimization model is then employed to determine, based on a range of assumptions, the least cost control strategies to achieve the alternatives in violating counties. Given the estimated costs of attaining alternative standards, the potential economic impacts of these estimated costs on potentially affected industry sectors is subsequently analyzed. Potential health and welfare benefits are also estimated from modeled changes in air quality as a result of control strategies applied in the cost analysis. Finally, benefits and costs are compared.

This RIA presents results for the coordinated implementation of these three rules as well as providing an estimate of their costs and benefits separately. Due to the lack of an integrated air quality model, it is impossible to concurrently estimate the joint impacts. In an attempt to provide as much information as possible regarding joint impacts, EPA is able to model the two NAAQS sequentially by assuming first the imposition of controls to meet the new ozone standard, followed by the new PM standard and regional haze target but was unable to sufficiently model adequately the imposition of controls to meet the new PM standard, followed by the new ozone and regional haze standards. Neither approach correctly models the actual process which would be used by decision makers trying to simultaneously develop an optimal program to control all three pollutants. The coordinated implementation national results do not show much difference from the sum of the three rules. This is thought to occur due more to model limitations than a true result.

This analysis estimates the potential costs, economic impacts and benefits for three PM standard options, three ozone standard options and two regional haze options. The alternatives analyzed include:

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1 For the purposes of this RIA, the term “attain” or “attainment” is used to indicate that the air quality level specified by the standard alternative is achieved. Because the analyses in this RIA are based on one-year of air quality data, they are only estimates of actual attainment; all standard alternatives are specified as 3-year averages.

For PM_{10}

- the promulgated PM_{10} standard set at 50µg/m^3 annual mean, and 150µg/m^3, 99th percentile 24-hour average

For $PM_{2.5}$

- the promulgated $PM_{2.5}$ standard set at 15µg/m^3, spatially averaged annual mean, and 65 µg/m^3, 98th percentile 24-hour average and two alternatives: 1) an annual standard set at 15µg/m^3, in combination with a 24-hour standard set at 50µg/m^3; and 2) an annual standard set at 16µg/m^3, in combination with a 24-hour standard set at 65µg/m^3.

For Ozone

- the promulgated ozone standard set at .08 parts per million (ppm) in an eight hour concentration based fourth highest average daily maximum form, and two alternatives: 1) .08 ppm in an eight hour concentration based third highest average daily maximum form; and 2) .08 ppm in an eight hour concentration based fifth highest average daily maximum form.

For Regional Haze

- a regional haze visibility target reduction of 0.67 and 1 deciview. These reductions are analyzed incremental to the implementation of the new $PM_{2.5}$ standard.

The RIA analyses have been constructed such that benefits and costs are estimated incremental to those derived from the combined effects of implementing both the 1990 CAA Amendments and the current PM_{10} and ozone NAAQS as of the year 2010. These analyses provide a "snapshot" of potential benefits and costs of the new NAAQS and regional haze rule in the context of (1) implementation of CAA requirements between now and 2010, (2) the effects on air quality that derive from economic and population growth, and (3) the beneficial effects on air quality that the Agency expects will result from a series of current efforts to provide regional-level strategies to manage the long range transport of NOx and SO_2. It should be kept in mind that 2010 is earlier than attainment with the new standards will be required.

This RIA does not attempt to force its models to project full attainment of the new standards in areas not predicted to achieve attainment by 2010. However, further calculations are performed to attempt to project full attainment benefits and costs in this RIA. For the benefit estimates, the same general methodology used in our base analysis is extended to derive the estimates and are reported within this RIA. For the cost estimates a limited methodology is used to predict potential costs of full attainment, with the last increment of reductions being "achieved" through the use of unspecified measures having an average emission cost-effectiveness of $10,000 per ton. It is important to recognize that EPA has much less confidence in these cost estimates because of the length of time over which full attainment would be achieved.

In that regard, the $10,000 cost estimate for these reductions is intended to provide an ample margin to account for unknown factors associated with future projections, and may tend to overestimate the final costs of attainment. In fact, EPA will encourage, and expects that States will utilize, market based approaches that would allow individual sources to avoid incurring costs greater than $10,000/ton. Chapter 9 discusses EPA's particular interest in applying the concept of a Clean Air Investment Fund that would allow individual sources to avoid incurring costs greater than $10,000 per ton. Based on this analysis, EPA believes that a large number of emissions reductions are available at under $10,000 a ton; sources facing higher control costs could finance through such a fund. Compliance strategies like this will likely lower costs of compliance through more efficient allocation, and can serve to stimulate technology innovation.

The estimation of benefits from environmental regulations poses special challenges. The include the difficulty of quantifying the incidence of health, welfare, environmental endpoints of concern, and the difficulty of assigning monetized values to these endpoints. As a result, many categories of potential benefits have not been monetized at all, and those that have been are given in ranges. Specifically, this RIA has adopted the approach of presenting a "plausible range" of monetized benefits to reflect these uncertainties by selecting alternative values for each of several key assumptions. Taken together, these alternative sets of assumptions define a "high end" and a "low end" estimate for the monetized benefits categories.

In choosing alternative assumptions, EPA has tried to be responsive to the many comment it received on the RIAs that accompanied the proposed rules. It should be emphasized, however, that the high and low ends of the plausible range are not the same as upper and lower bounds. For many of the quantitative assumptions involved in the analysis, arguments could be made for an even higher or lower choice, which could lead to an even greater spread between the high end and low end estimates. The analysis attempts to present a plausible range of monetized benefits for the categories that have been analyzed. Again, it must be stressed that many benefits categories have not been monetized at all, because of both conceptual and technical difficulties in doing so. These benefits are in addition to the plausible range of monetized benefits considered here.

SUMMARY OF RESULTS

Direct Cost and Economic Impact Analyses

Potential annual control costs (in 1990 dollars) are estimated for attainment of each alternative standard. Potential administrative costs of revising the PM_{10} monitoring network and the costs of a new $PM_{2.5}$ monitoring network as well as the administrative costs of implementing the new rules are also reported.

Possible economic impacts based on these control costs are estimated for the same alternative standards. This impacts analysis also include a screening analysis providing estimated annual average cost-to-sales ratios for all potentially affected industries.

Key Results and Conclusions

<u>OZONE</u>

- Estimated annual identifiable control costs corresponding to the partial attainment of the promulgated ozone standard is $1.1 billion per year incremental to the current standard. This estimate is based on the adoption, where needed, of all currently identifiable reasonably available control technologies for which EPA has cost data, and which cost less than $10,000/ton.

- Under the partial attainment scenario, there are estimated to be 17 potential residual nonattainment areas, 7 of which are also in residual nonattainment for the current ozone standard.

- The implication of residual nonattainment is that areas with a VOC or NOx deficit will likely need more time beyond 2010; new control strategies (e.g., regional controls or economic incentive programs); and/or new technologies in order to attain the standard.

- Under the illustrative scenario selected, at least one or more establishments (e.g. industrial plant) in up to 227 of U.S. industries (as defined by 3-digit SIC codes) which are estimated to have cost-to-sales ratios of at least 0.01 percent by the chosen standard. Approximately 25 of these are industries which have some establishments which are estimated to have cost-to-sales ratios exceeding 3 percent, and therefore may experience potentially significant impacts. These results are highly sensitive to the choice of control strategy.

- A very small proportion of establishments are potentially affected for most of the SIC codes affected by the new ozone standard. The number of establishments potentially affected is 0.13 percent of all establishments in affected SIC codes for the selected standard.

- This RIA does not attempt to force its models to project full attainment of the new standard in areas not predicted to achieve attainment by 2010. However, full attainment costs of the selected standard are estimated at $9.6 billion per year incremental to the current standard. It is important to recognize that EPA has much less confidence in these cost estimates because of the inherent uncertainties in attributing costs to new technologies.

PM

- Estimated annual identifiable control costs corresponding to the partial attainment of the selected PM standard are $8.6 billion per year incremental to the current PM_{10} standard. This estimate is based on the adoption of the majority of currently identifiable control measures for which EPA had cost-effectiveness data. For the PM analysis, a $1 billion/μg/$m^3$ cut-off is used to limit the adoption of control measures. Control measures providing air quality improvements are less than $1 billion/μg/$m^3$ are adopted where the air quality model and cost analysis identify control measures as being necessary.

- Under the partial attainment scenario, an estimated 30 potential residual nonattainment counties, 11 of which are also in residual nonattainment for the current PM_{10} standard.

- The implication of residual nonattainment is that counties with $PM_{2.5}$ levels above the standard will likely need more time beyond 2010; new control strategies (e.g., regional controls or economic incentive programs); and/or new technologies in order to attain the standard.

- Under the illustrative scenario selected, at least one or more establishments (e.g. industrial plant) in up to 198 of U.S. industries (as defined by 3-digit SIC codes) which are estimated to have cost-to-sales ratios of at least 0.01 percent by the chosen standard. Approximately 86 of these are industries which have some establishments which are estimated to have cost-to-sales ratios exceeding 3 percent, and therefore may experience potentially significant impacts. These results are highly sensitive to the choice of control scenario.

- A small proportion of establishments are potentially affected for most of the SIC codes affected by the new PM standards. The average number of establishments potentially affected is about 2.7 percent in total affected SIC codes for the selected standard.

- The year 2010 is prior to the time that full attainment is required under the CAA. This RIA does not attempt to force its models to project full attainment of the new standard in areas not predicted to achieve attainment by 2010. However, full attainment costs of the selected $PM_{2.5}$ standard in 2010 are estimated at $37 billion per year incremental to the current standard. It is important to recognize that EPA has much less confidence in these cost estimates because of the inherent uncertainties in attributing costs to new technologies.

Regional Haze

- The expected annual control cost for the year 2010 associated with the proposed regional haze rule ranges from $0 to a maximum of $2.7 billion. The additional cost of implementation of the proposed regional haze rules will vary depending on the visibility targets selected by States. If targets are adjusted through that process to parallel the implementation programs for the new ozone and PM standards, the costs for meeting the adjusted targets in those areas will be borne by the ozone and PM programs. The proposed rule, however, includes a presumptive target of 1.0 Deciview improvement over either 10 or 15 years (on the 20 percent worst days); any adjustments to this target must be justified by States on a case-by-case basis. The high end costs in this analysis assume that 76 mandated Class I areas will need additional reductions to meet the 10 year presumptive target from 2000 to 2010. The additional control cost associated with meeting the presumptive 1.0 deciview target in 10 years in 48 of these areas, and partial achievement in 28 areas is estimated to be $2.7 billion. If the 1.0 deciview improvement in 15 years target is promulgated, this analysis projects that 58 Class I areas would not meet this target with NAAQS controls alone. To fully attain a 0.67 deciview improvement between 2000 and 2010 in 41 of these areas and partially attain the 0.67 target in 17 areas would cost an estimated $2.1 billion.

Benefit Analysis

Health and welfare benefits are estimated for attainment of the PM and ozone standards and visibility improvements resulting from the proposed regional haze program. The estimated change in incidence of health and welfare effects is estimated for each air quality change scenario as defined by the 2010 baseline and post-attainment air quality distributions. These estimated changes in incidence are then monetized by multiplying the estimated change in incidence of each endpoint by its associated dollar value of avoiding an occurrence of an adverse effect. These endpoint-specific benefits are then summed across all counties to derive an estimate of total benefit. Because there are potentially significant categories for which health and welfare benefits are not quantified or monetized due to a lack of scientific and economic data, the benefit estimates presented in this analysis are incomplete.

Tables ES-1 and ES-2 list the anticipated health and welfare benefit categories that are reasonably associated with reducing PM and ozone in the atmosphere, specifying those for which sufficient quantitative information exists to permit benefit calculations. Because of the inability to monetize some existing benefit categories, such as changes in pulmonary function and altered host defense mechanisms, some categories are not included in the calculation of the monetized benefits.

Table ES-1 PM and Regional Haze Benefits Categories

	PM Health and Welfare Benefit Categories	
	Unquantified Benefit Categories	**Quantified Benefit Categories (incidences reduced and/or dollars)**
Health Categories	Changes in pulmonary function Morphological changes Altered host defense mechanisms Cancer Other chronic respiratory disease Infant Mortality Mercury Emission Reductions	Mortality (acute and long-term) Hospital admissions for: all respiratory illnesses congestive heart failure ischemic heart disease Acute and chronic bronchitis Lower, upper, and acute respiratory symptoms Respiratory activity days Minor respiratory activity days Shortness of breath Moderate or worse asthma Work loss days
Welfare Categories	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water Brown Clouds	Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters

Table ES-2 Ozone Benefits Categories

	Ozone Health and Welfare Benefit Categories	
	Unquantified Health Benefit Categories	**Quantified Benefit Categories (in terms of incidences reduced or dollars)**
Health Categories	Airway responsiveness Pulmonary inflammation Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Chronic respiratory damage/ Premature aging of lungs	Coughs Pain upon deep inhalation Mortality Hospital admissions for: all respiratory illnesses pneumonia chronic obstructive pulmonary disease (COPD) Acute respiratory symptoms Restricted activity days Lower respiratory symptoms Self-reported asthma attacks Cancer from air toxics Change in lung function
Welfare Categories	Ecosystem and vegetation effects in Class I areas (e.g., national parks) Damage to urban ornamentals (e.g., grass, flowers, shrubs, and trees in urban areas) Reduced yields of tree seedlings and non-commercial forests Damage to ecosystems Materials damage (other than consumer cleaning cost savings) Nitrates in drinking water Brown Clouds	Commodity crops Fruit and vegetable crops Commercial forests Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters Worker productivity

Key Results and Conclusions

There are a number of uncertainties inherent in the underlying functions used to produce quantitative estimates. Some important factors influencing the uncertainty associated with the benefits estimates are: whether a threshold concentration exists below which associated health risks are not likely to occur, the valuation estimate applied to premature mortality and the estimation of post-control air quality. Additionally, there is greater uncertainty about the existence and the magnitude of estimated excess mortality and other effects associated with exposures as one considers increasingly lower concentrations approaching background levels. The high and low end benefits estimates, as discussed above, attempt to bracket a plausible range that accounts for some of these uncertainties.

OZONE

- Partial attainment of the selected ozone standard results in estimated monetized annual benefits in a range of $0.4 and $2.1 billion per year incremental to the current ozone standard. The estimate includes from 0 to 330 incidences of premature mortality avoided.

- The major benefit categories that contribute to the quantified benefits include mortality, hospital admissions, acute respiratory symptoms and welfare effects. Mortality benefits represent about 90% of the high end benefits estimates. However, this analysis excludes a number of other benefit categories.

- Full attainment of the preferred ozone standard results in estimated monetized benefits of in a range of $1.5 to $8.5 billion per year incremental to the current ozone standard. The estimate includes 0 to 1300 incidences of premature mortality avoided (corresponding to long-term mortality, respectively).

- There are benefits from ozone control that could not be monetized in the benefits analysis, which in turn, affect the benefit-cost comparison. Nonmonetized potential benefits categories include: effects in lung function; chronic respiratory damage and premature aging of the lungs; increased susceptibility to respiratory infection; protection of ornamental plants, mature trees, seedlings, Class I areas, and ecosystems; reduced nitrates in drinking water, and reduced brown cloud effects. The effect of our inability to monetize these benefits categories leads to an underestimation of the monetized benefits presented in this RIA.

PM

- Partial attainment of the selected $PM_{2.5}$ standard results in estimated monetized annual benefits in a range of $19 to $104 billion per year incremental to the current PM_{10} standard, including 3,300 to 15,600 incidences of premature mortality avoided.

- The major benefit categories that contribute to the quantified benefits include mortality, hospital admissions, acute respiratory symptoms and welfare effects. Mortality benefits represent about 12% to 70% of the benefits estimates. However, this analysis excludes a number of other benefit categories.

- Full attainment of the preferred $PM_{2.5}$ standard results in estimated monetized benefits of in a range of $20 and $110 billion per year incremental to the current PM_{10} standard, including 3,700 to 16,600 incidences of premature mortality avoided (corresponding to short-term and long-term mortality, respectively). These numbers are significant underestimates because EPA has no procedure to predict full attainment benefits outside nonattainment county boundaries for $PM_{2.5}$.

- There are benefits from PM control that could not be monetized in the benefits analysis, which in turn affect the benefit-cost comparison. Nonmonetized potential benefits categories include: effects in pulmonary function; increased susceptibility to respiratory infection; cancer; infant mortality; effects associated with exposure to mercury; protection of ecosystems; reduced acid sulfate deposition; reduced materials damage; reduced nitrates in drinking water; and reduced brown cloud effects. The effect of our inability to monetize these benefit categories leads to an underestimation of the monetized benefits presented in this RIA.

Regional Haze

- The expected visibility and associated health and welfare annual benefits for the year 2010 associated with the proposed regional haze rule ranges from $0 to a maximum of $5.7 billion. The amount of benefits from implementation of the proposed regional haze rules will vary depending on the visibility targets selected by States. If targets are adjusted through that process to parallel the implementation programs for the new ozone and PM standards, the benefits for meeting the adjusted targets in those areas will not exceed those calculated for ozone and PM programs. The proposed rule, however, includes a presumptive target of a 1.0 Deciview improvement over either 10 or 15 years (on the 20 percent worst days); any adjustments to this target must be justified by States on a case-by-case basis. The high end benefits in this analysis assume that 76 mandated Class I areas will need additional emissions reductions to meet the 10 year presumptive target from 2000 to 2010. The additional benefits, resulting from 48 of the 76 areas meeting the presumptive 1.0 deciview target, and 28 of the 76 areas having partial achievement, are estimated to range from $1.7 to $5.7 billion. The additional benefits resulting from 41 Class I areas meeting the presumptive 0.67 deciview improvement target between 2000 and 2010, and 17 areas partially meeting the 0.67 deciview target range from $1.3 to $3.2 billion.

Monetized Benefit-Cost Comparison

Comparing the benefits and the costs provides one framework for comparing alternatives in the RIA. As noted above, both the Agency and the courts have defined the NAAQS standard setting decisions, both the initial standard setting and each subsequent review, as *health-based* decisions that specifically are *not* to be based on cost or other economic considerations. This benefit-cost comparison is intended to generally inform the public about the potential costs and benefits that may result when revisions to the ozone and PM NAAQS are implemented by the States. Costs and benefits of the proposed regional haze rule are also presented. Monetized benefit-cost comparisons are presented for both the full and partial attainment scenarios nonmonetized effects by definition cannot be included. In considering these estimates, it should be stressed that these estimates contain significant uncertainties as discussed throughout this analysis.

Estimated quantifiable partial attainment (P/A) benefits of implementation of the particulate matter (PM) and ozone NAAQS exceed estimated P/A costs. Estimated quantifiable net P/A benefits (P/A benefits minus P/A costs) for the combined $PM_{2.5}$ 15/65 and ozone 0.08 ppm 4th max standards range from approximately $10 to $96 billion.

Considered separately, estimated quantifiable P/A benefits of $PM_{2.5}$ standard far outweigh estimated P/A costs. Estimated quantifiable net P/A benefits of the selected $PM_{2.5}$ 15/65 standard range from $10 to $95 billion. Estimated quantifiable full-attainment (F/A) benefits may or may not exceed estimated F/A costs for PM depending on whether the low end or high end estimates are used. Net benefits for the $PM_{2.5}$ F/A scenario range from negative $18 billion to positive $67 billion . Estimated quantifiable P/A benefits of the ozone standard also exceed estimated quantifiable P/A costs, though by a smaller margin. Estimated quantifiable net P/A benefits of the ozone 0.08 ppm 4th max standard range from negative $0.7 to positive $1.0 billion. The full range of F/A benefit estimates are smaller than the F/A costs for ozone with net benefits ranging from negative $1.1 billion to negative $8.1 billion. Estimated quantifiable net benefits from the proposed regional haze program range from $0 to $3.0 billion.

Table ES-3. Comparison of Annual Benefits and Costs of PM-Only Alternatives in 2010[a] (1990$)

$PM_{2.5}$ Alternative ($\mu g/m^3$)	Annual Benefits of Partial Attainment[b] (billion $) (A)	Annual Costs of Partial Attainment (billion $) (B)	Net Benefits of Partial Attainment (billion $) (A - B)	Number of RNA Counties
16/65 (high end estimate)[c]	**90**	**5.5**	**85**	**19**
15/65 low end estimate[d] high end estimate[c]	**19** **104**	**8.6**	**10** **95**	**30**
15/50 (high end estimate)[c]	**107**	**9.4**	**98**	**41**

a All estimates are measured incremental to the baseline of the current ozone standard (0.12ppm , 1 expected exceedance per year), and the current PM_{10} standard (PM_{10} $\mu g/m^3$ annual/150 $\mu g/m^3$ daily, 1 expected exceedance per year).

b Partial attainment benefits based upon post-control air quality as defined in the control cost analysis.

c The high end estimates are based on assumptions of effects down to 12 $\mu g/m^3$ for PM mortality, down to background for chronic bronchitis, and a valuation approach to mortality benefits based on averting premature statistical deaths valued at $4.8 million each.

d The low-end estimates are based on assumptions of a threshold at 15 $\mu g/m^3$ for PM mortality and chronic bronchitis, an assumption that two-thirds of short-term deaths are premature by only days or weeks, a valuation approach to mortality benefits based on life-years valued at $120,000 each, and an adjustment to visibility benefits derived from a contingent valuation survey.

Table ES-4. Comparison of Annual Benefits and Costs of Ozone-Only Alternatives in 2010[a] (1990$)

Ozone Alternative (ppm)	Annual Benefits of Partial Attainment (billion $)[b] (A)	Annual Costs of Partial Attainment (billion $) (B)	Net Benefits of Partial Attainment (billion $) (A - B)	Number of RNA Areas
0.08 5th Max (high end estimate)[c]	**1.6**	**0.9**	**0.7**	**12**
0.08 4th Max		**1.1**		**17**
low end estimate[d]	**0.4**		**-0.7**	
high end estimate[c]	**2.1**		**1.0**	
0.08 3rd Max (high end estimate)[c]	**2.9**	**1.4**	**1.5**	**27**

a All estimates are measured incremental to the baseline current ozone standard (0.12ppm , 1 expected exceedance per year).

b Partial attainment benefits based upon post-control air quality estimates as defined in the control cost analysis.

c The high-end estimates use a meta-analysis of epidemiological studies of associations between ozone and short-term mortality, and PM related benefits of ozone controls.

d The low-end estimates are based on assumptions of no ozone mortality, and no ancillary PM-related benefits from ozone controls.

1.0 INTRODUCTION AND OVERVIEW

The Clean Air Act (CAA) directs the Environmental Protection Agency (EPA) to identify and set national standards for pollutants which cause adverse effects to public health and the environment. The EPA is also required to review national health and welfare-based standards at least once every 5 years to determine whether, based on new research, revisions to the standards are necessary to continue to protect public health and the environment. A growing list of health effects studies on particulate matter (PM) and ozone report associations between ambient fine particles [which is PM smaller than 2.5 micrometers (μm) in diameter, termed $PM_{2.5}$] and/or ambient ozone and serious effects such as increased mortality. As a result of the most recent review process, EPA has proposed to revise the National Ambient Air Quality Standards (NAAQS) for PM and ozone. In addition, EPA is proposing a regional haze (RH) rulemaking to achieve progress toward visibility goals. Pursuant to Executive Order 12866, this Regulatory Impact Analysis (RIA) assesses the potential costs, economic impacts, and benefits associated with the *implementation* of these and alternative NAAQS for PM and ozone as well as for a proposed RH rule. Potential costs, economic impacts, and benefits are estimated incremental to attainment of existing standards.

In setting the primary air quality standards, EPA's first responsibility under the law is to select standards that protect public health. In the words of the CAA, for each criteria pollutant EPA is required to set a standard that protects public health with "an adequate margin of safety." As interpreted by the Agency and the courts, this decision is a *health-based* decision that specifically is *not* to be based on cost or other economic considerations. This reliance on science and prohibition against the consideration of cost does not mean that cost or other economic considerations are not important or should be ignored. However, under the health-based approach required by the CAA, the appropriate place for cost and efficiency considerations is during the development of implementation strategies, strategies that will allow communities to meet the health-based standards. Through the development of national emissions standards for cars, trucks, fuels, large industrial sources and power plants, for example, and through the development of appropriately tailored state and local implementation plans, the implementation process is where decisions are made -- both nationally and within each community -- affecting how much progress can be made, and what time lines, strategies and polices make the most sense. In summary, this RIA and associated analyses are intended to generally inform the public about the potential costs and benefits that may result when the new PM and ozone NAAQS are implemented by the States, but are not relevant to establishing the standards themselves. In contrast, results from this analysis may be used to support the RH rule development process.

1.1 THE NATIONAL AIR QUALITY CHALLENGE

1.1.1 Particulate Matter

PM represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. For regulatory purposes, fine particles can be generally defined as those particles with an aerodynamic diameter of 2.5 µm. or less, while coarse fraction particles are those particles with an aerodynamic diameter greater than 2.5 µm., but less than or equal a nominal 10 µm. The health and environmental effects of PM are strongly related to the size of the particles.

Emission sources, formation processes, chemical composition, atmospheric residence times, transport distances and other parameters of fine and coarse particles are distinct (U.S. EPA, 1996d). Fine particles are generally formed secondarily from gaseous precursors such as sulfur dioxide (SO_2) , nitrogen oxides, and/or organic compounds, and are composed of sulfate, nitrate, and/or ammonium compounds; elemental carbon; and metals. Fine particles can also be directly emitted. Combustion of coal, oil, diesel, gasoline, and wood, as well as high temperature process sources such as smelters and steel mills, produce emissions that contribute to fine particle formation. In contrast, coarse particles are typically mechanically generated by crushing or grinding and are often dominated by resuspended dusts and crustal material from paved or unpaved roads or from construction, farming, and mining activities. Fine particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers, while coarse particles deposit to the earth within minutes to hours and within tens of kilometers from the emission source.

Geographic differences (e.g., rural vs. urban locations, East vs. West) also exist between ambient levels of fine and coarse particles and their related characteristics (U.S. EPA, 1996d). For instance, total concentrations of coarse fraction particles are generally higher and the crustal material contribution relatively larger in arid areas of the Western and Southwestern U.S. In the Eastern U.S., fine particle sulfate is a significant component of ambient $PM_{2.5}$ concentrations. The differences in fine and coarse particle characteristics and their geographic variability are significant considerations in the design of control strategies to reduce levels of ambient PM.

Since the last review of the PM air standards, there has been significant new evidence from community epidemiological studies that serious health effects are associated with exposures to ambient concentrations of fine particle PM found in the urban U.S. even at levels below current PM standards. The U.S. EPA PM Criteria Document (U.S. EPA, 1996b) and U.S. EPA PM Staff Paper (U.S. EPA, 1996d) discuss and evaluate scientific information identifying the key health effects associated with fine particle PM, including: premature mortality (particularly among the elderly and people with respiratory or cardiovascular disease), increased hospital admissions and emergency room visits (primarily for the elderly and individuals with cardiopulmonary disease); increased respiratory symptoms and disease (e.g., for children and individuals with cardiopulmonary disease); decreased lung function (particularly in children and individuals with asthma); and alterations in lung tissue and structure and in respiratory tract defense mechanisms. Elevated concentrations of fine particles also contribute to visibility impairment, and materials damage and soiling effects.

1.1.2 Ozone

Ozone is created when its two primary components, volatile organic compounds (VOC) and oxides of nitrogen (NOx), combine in the presence of sunlight under specific meteorological conditions. VOC and NOx, are often referred to as ozone *precursors*, which are, for the most part, emitted directly into the atmosphere from a combination of natural and anthropogenic sources. Attempts to decrease ozone pollution in the United States have been confounded by a number of factors, including the inherent non-linearity of the photochemical mechanism, the contribution of natural precursor emissions, long range transport of ozone and its precursors (primarily NOx), meteorological variability, the general lack of essential data (primarily inventory related), and the limitations of current modeling tools.

Recent scientific evidence indicates that ground-level ozone not only affects people with impaired respiratory systems (such as asthmatics), but healthy adults and children as well. The new studies taken into account during this latest review show health effects at levels below that of the current standard (0.12 ppm, 1-hour form) (U.S. EPA, 1996a,c). In particular, active children and outdoor workers exposed for 6-8 hours of ozone levels as low as 0.08 ppm may experience several acute effects such as decreased lung function, acute lung inflammation, and premature aging of the lung. Recent epidemiological studies also provide evidence of an association between elevated ozone levels and increases in hospital admissions and mortality; and animal studies indicate repeated exposure to high levels of ozone for several months can produce permanent structural damage in the lungs.

1.1.3 Regional Haze

Under Section 16A and 169B of the CAA, 156 Class I Federal areas are identified for visability protection. The CAA require that “reasonable progress” be made toward achieving a visibility goal of essentially no manmade visibility impairment in areas of concern. The EPA is proposing that reasonable progress be defined as equivalent to a 1 deciview improvement (a perceptible change) in the most impaired days over a 10-year period, with no degradation occurring in the cleanest days. Impairment is primarily due to transport since there are few emission sources within the areas of concern. Thus to achieve reasonable progress, emission controls must be employed in surrounding areas.

1.1.4 The Integrated Air Quality Management Challenge

The EPA is promulgating the PM and ozone NAAQS and proposing the RH rule concurrently. While not all attributes of ozone and PM are linked, important commonalities exist among the PM, ozone, and RH problems, which provide the technical and scientific rationale for integrated analysis. Similarities in pollutant sources, formation, and control exist between PM, ozone, and RH, in particular with respect to the fine fraction of particles addressed by the current PM NAAQS. These similarities include:

(1) atmospheric residence times of several days, leading to regional-scale transport of the pollutants,

(2) similar gaseous precursors, including NOx and VOC, which may contribute to the formation of PM, ozone, and RH in the atmosphere,

(3) similar combustion-related source categories, such as utilities, industrial boilers, and mobile sources, which emit particles directly as well as gaseous precursors of particles (e.g., SO_2, NOx, VOC) and ozone (e.g., NOx, VOC), and

(4) similar atmospheric chemistry driven by the same chemical reactions and intermediate chemical species which often favor high fine particle levels, ozone, and RH.

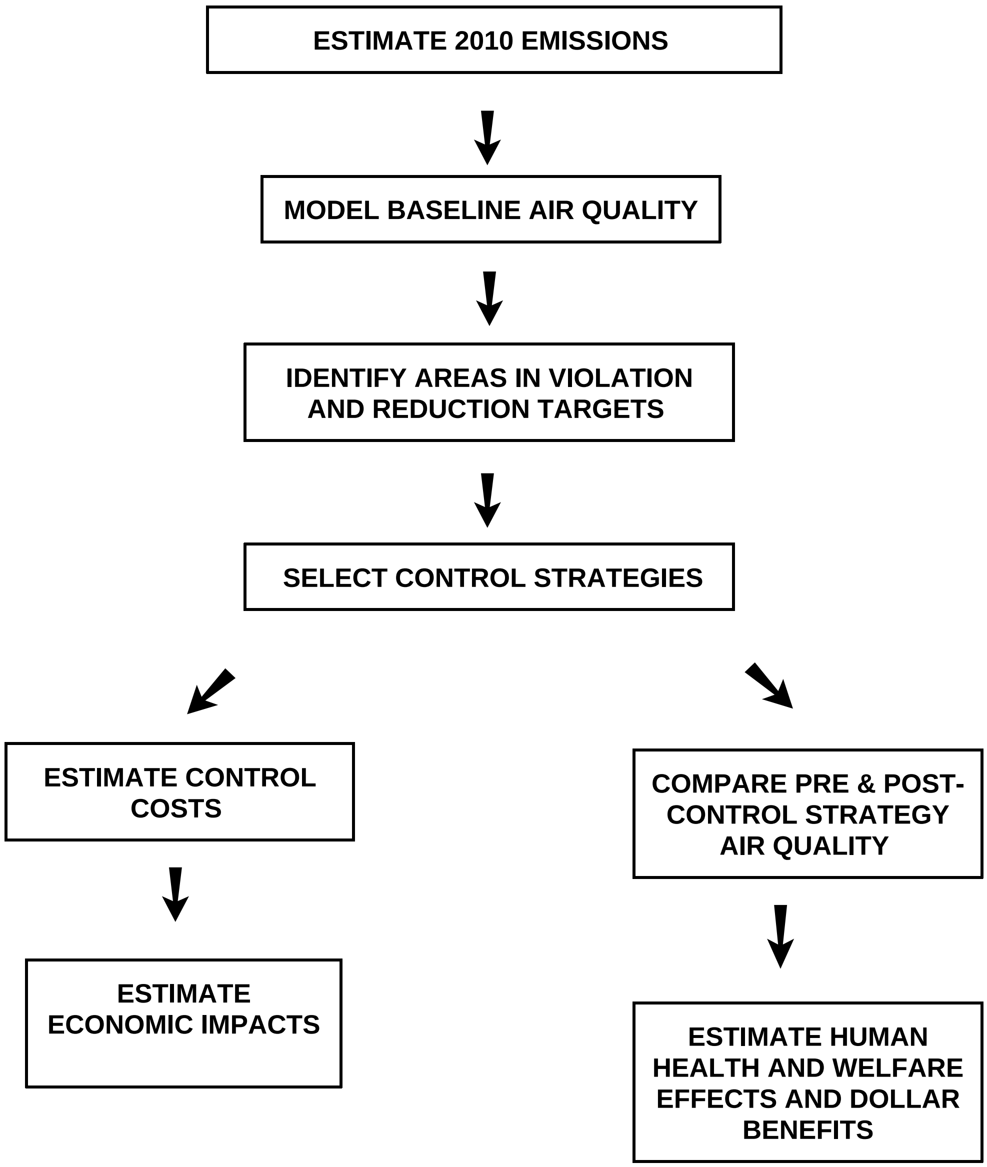
These similarities provide opportunities for optimizing technical analysis tools (i.e., monitoring networks, emission inventories, air quality models) and integrated emission reduction strategies to yield important co-benefits across various air quality management programs. Integration of implementation is likely to result in a net reduction of the regulatory burden on some source category sectors that would otherwise be impacted separately by PM, ozone, and visibility protection control strategies.

1.2 OVERVIEW OF THE RIA METHODOLOGY

1.2.1 Basic Analytical Approach

Figure 1.1 displays the basic analytical structure of this RIA. An emissions inventory is developed and projected to the year 2010 (see Chapter 4). The year 2010 was selected as the base year for the analysis primarily because by this year the vast majority of CAA Amendment requirements will have fully taken effect. Baseline air quality is then estimated using air quality models, areas in violation with alternative NAAQS and with regional haze targets are identified, and air quality or emission reduction targets are computed (see Chapter 4). Control strategies to achieve air quality goals are then selected and potential costs are computed based on the control measures chosen (see Chapters 5-8). Based on these potential costs as well as potential administrative costs to governments (see Chapter 10), potential economic impacts to large and small businesses and governments are assessed (see Chapter 11). Since the controls employed and costed in chapters 5-7 do not achieve full attainment of the NAAQS, a rough full attainment cost assessment also is provided (see Chapter 9). Based on estimated air quality changes resulting from the control measures employed, the resulting change in human health and welfare effects is predicted and the monetized value of these effects is estimated (see Chapter 12). Finally, benefit and cost estimates are compared (see Chapter 13).

FIGURE 1.1: Flowchart of Analytical Steps



1.2.2 Limited PM/Ozone/RH Integration

Ideally, analyses of the concurrent implementation of the PM and ozone NAAQS and a proposed RH rule should be fully integrated. However, since each NAAQS review is a separate regulatory decision, the health effects and scientific information for each pollutant need to be judged separately and on their own merits. For purposes of consistency, this RIA presents cost, benefit, and other economic impact results of a separate PM and a separate ozone NAAQS.

It is not possible at this time to perform a fully integrated benefit-cost analysis of these rules. Air quality models are not currently available to sufficiently assess the atmospheric interactions of PM, ozone, and precursor pollutants at the national level. Moreover, efforts to develop integrated implementation strategies have not been completed. The joint impacts of a PM and ozone NAAQS are assessed as a sensitivity study in this RIA by a layering strategy. For example, attainment of one NAAQS is attempted, baseline emissions and air quality are changed, then attainment of the other NAAQS is attempted. This approach eliminates double-counting of controls and allows for the computation of the ancillary benefits associated with attaining one NAAQS toward attaining the other NAAQS. Full integration is not achieved, however, since air chemistry interactions associated with joint implementation are not modeled and because the control selection approach to attain one standard does not consider the potential beneficial impact toward achievement of the other standard. For this latter reason, a least cost estimate associated with joint implementation of a PM and ozone NAAQS is not presented in this analysis.

Concurrent with the review of the PM and ozone NAAQS and development of the RH proposed rule, EPA has requested the assistance of stakeholder groups to help design a new implementation approach to controlling PM, ozone, and RH and is setting forth critical implementation principles accompanying the new standards. This stakeholder group has been charged to evaluate new approaches to controlling these pollutants, focusing on the interaction of these pollutants in the atmosphere. As part of this process, EPA will strive to perform more fully integrated analyses to support subsequent stages of the implementation process.

1.2.3 Control Strategies Modeled

To perform an RIA for NAAQS and for a proposed RH rule, it is necessary for EPA to make certain broad assumptions concerning control strategies on a national level. The fact the EPA has selected control strategies as part of this assessment should not be taken to mean that EPA recommends these control strategies or anticipates that these control strategies and measures will be imposed in all nonattainment areas. The CAA requires EPA to set NAAQS and develop a RH rule, and it requires the states, with assistance from EPA, to develop implementation plans and submit them to EPA for review. This places primary responsibility for implementing the air quality management process on the states and allows for Federal oversight of states' efforts to achieve and maintain the required level of air quality. Because states have considerable flexibility in developing control strategies for attaining the PM and ozone NAAQS as well as the RH rule, it is unlikely that the control strategy assumptions in this RIA will exactly correspond to the attainment strategy ultimately developed for any particular area. Moreover, this analysis forecasts control strategies for year 2010. Substantial uncertainty is inherent in any projections so far into the future. Finally, there may be some cases where the strategies that are assumed to be applied nationwide are not appropriate for application in a particular area.

The CAA allows for substantial flexibility in the development of implementation strategies, both for control strategies and schedules, for attaining the new NAAQS and RH reduction goals. Specific to the new standards, EPA has established a formal advisory committee under the Federal Advisory Committee Act (FACA). The specific purpose of the broad-based stakeholder group is to advise EPA on ways to develop innovative, flexible, practical and cost-effective implementation strategies, and to advise us directly on transitional strategies as well.

Control strategies employed in this RIA are limited in part because of our inability to predict the breadth and depth of the creative approaches to implementation that may be forthcoming via the FACA process, and in part by technical limitations in modeling capabilities. For example, lower-cost "market-based" strategies are modeled in this analysis only to a limited extent. This limitation, in effect, may force cost estimates to be developed based on compliance strategies that reflect suboptimal implementation approaches. Thus, cost estimates presented in this analysis may overstate actual implementation costs.

1.3 KEY IMPROVEMENTS FROM THE PROPOSAL RIAs

In December, 1996, EPA published separate RIAs that assessed the benefits, costs, and other economic impacts associated with the proposed PM and ozone NAAQS. Since December, EPA has made various revisions, updates, and other improvements to the these proposal RIAs. This document incorporates these improvements, merges and to some extent integrates the PM and ozone analyses, and includes an assessment of the proposed RH rule.

Many of the improvements made to the proposal RIAs and incorporated in this document are made as the direct result of helpful comments received by the EPA from RIA Interagency Committee members and the public. Among the most important of these improvements are:

- A more integrated analysis that avoids double-counting of costs is performed based on a common emission inventory;

- Air quality modeling is improved (e.g., an updated source receptor matrix is used for PM, ozone attainment targets are revised in accordance with new modeling information, etc.);

- The baseline year for the analyses is changed from 2007 to 2010, primarily to better reflect the actual implementation of the new standards;

- Administrative costs are estimated;

- Costs in marginal ozone nonattainment areas are estimated;

- Additional control measures are included and control cost and emission reduction estimates are updated;

- The residual nonattainment problem is assessed and characterized more fully and explicitly;

- The potential impact of technological progress in pollution control is more fully assessed;

- Rough estimates of full-attainment costs are calculated;

- Additional benefit categories are monetized and qualitatively discussed;

- The analysis of valuation of mortality risk reduction from reduced ozone is updated and strengthened substantially;

- Long-term mortality risk from PM is reassessed to correct for a previous statisticalerror;

- The valuation estimate for cases of chronic bronchitis has been adjusted downward to reflect new information;

- The economic impact assessment is revised (e.g., the cost to sales ratio approach is improved, impacts on the utility and pollution control industries are assessed, etc.);

- A plausible range of monetized benefits is presented that reflects some of the key uncertainties in the analysis.

- Various additional sensitivity analyses are performed.

While these changes have significantly improved the quality of this analysis, this RIA is still limited in various ways and substantial uncertainties regarding the results from this analysis remain. Data, modeling, time, and resource constraints inevitably limit the rigor of any RIA. Qualitative, and when possible, quantitative discussions of uncertainties, limitations, and potential biases are included in this RIA. Additional refinements to this analysis are planned to support later stages of the implementation process.

1.4 KEY LIMITATIONS

1.4.1 General Limitations of Benefit-Cost Analysis

The consideration of cost and the use of benefit-cost analyses, provides a structured means of evaluating and comparing various implementation policies, as well as a means of comparing the variety of tools and technologies available for air pollution control efforts. The EPA has found the use of such analyses to be of significant value in developing regulatory options over the years.

General limitations, however, continue to affect the accuracy and usefulness of benefit-cost analyses. Wide ranges of uncertainties and omissions often exist within an analysis, especially within complex studies of national scope involving forecasts over extended periods of time. Benefit-cost analyses and results, continue to be limited by inabilities to monetize certain benefit categories. Comparisons of such incomplete benefits to the more quantifiable and usually more complete cost estimates can be misleading. Benefit-cost analyses also can not provide a basis for resolving distributional issues, i.e., to assess the equity of policies that provide benefits to some and costs to others. At best, the distribution of benefits and costs can be described.

These limitations notwithstanding, the process of developing such analyses can provide useful insights for environmental managers and policy makers. These insights can be especially useful to those working to develop implementation strategies because the analytical framework provides a mechanism for measuring, however roughly, alternative strategies or tools against a common framework.

1.4.2 Specific Limitations with this RIA

In addition to the general limitations associated with benefit-cost analysis described above, the reader should be fully aware of the numerous limitations associated with this particular analysis. Significant uncertainties and limitations exist associated with each analytical block within Figure 1.1. Existing emissions inventories are limited, projections to the year 2010 may involve significant error, available air quality models are limited, control cost estimates are inexact, health and welfare effect predictions are not precise, valuation approaches are controversial and potentially significant benefit categories are not monetized, and so on. The accumulation of these uncertainties is substantial.

To the degree feasible, the analysis that follows attempts to identify and characterize in some detail the various uncertainties and limitations related to the specific components of this analysis. In many cases, however, the lack of data prevent a rigorous quantitative treatment of uncertainties. Whether quantified or not, the reader should keep in mind all of the above uncertainties and limitations when reviewing and interpreting the results presented in the chapters that follow.

1.5 REFERENCES

U.S. Environmental Protection Agency (1996a), Air Quality Criteria for Ozone and Related Photochemical Oxidants. Office of Research and Development; Office of Health and Environmental Assessment; Research Triangle Park, N.C.; EPA report nos. EPA/600/P-93/004aF-cF.

U.S. Environmental Protection Agency (1996b), Air Quality Criteria for Particulate Matter. Office of Research and Development, Office of Health and Environmental Assessment; Research Triangle Park, N.C.; EPA report no. EPA/600/P-95/001aF; April.

U.S. Environmental Protection Agency (1996c), Review of the National Ambient Air Quality Standards for Ozone: Assessment of Scientific and Technical Information. Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; EPA report no. EPA/4521R-96-007.

U.S. Environmental Protection Agency (1996d), Review of the National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information. Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; EPA report no. EPA/4521R-96-013.

2.0 STATEMENT OF NEED FOR THE PROPOSED REGULATIONS

2.1 INTRODUCTION

Congress passed the Clean Air Act (CAA) to protect public health and the environment from the adverse effects of air pollution. This section summarizes the statutory requirements affecting the development and revision of the National Ambient Air Quality Standard (NAAQS) and briefly describes the health and welfare effects of particulate matter (PM), ozone, and regional haze (RH) and the need for regulatory action at this time.

2.2 STATUTORY AUTHORITY AND LEGISLATIVE REQUIREMENTS FOR PM AND OZONE NAAQS, AND RH RULE

2.2.1 PM and Ozone

Two sections of the CAA govern the establishment and revision of NAAQS. Section 108 (42 U.S.C. 7408) directs the Administrator to identify pollutants which "may reasonably be anticipated to endanger public health or welfare" and to issue air quality criteria for them. These air quality criteria are intended to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air . . . ."

Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants identified under section 108. Section 109(b)(1) defines a primary standard as one "the attainment and maintenance of which in the judgment of the Administrator, based on [the] criteria and allowing an adequate margin of safety, [are] requisite to protect the public health."[2] A secondary standard, as defined in section

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2 The legislative history of section 109 indicates that a primary standard is to be set at “the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population,” and that for this purpose “reference should be made to a representative

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 revise NAAQS. After promulgation or revision of the NAAQS, the standards are implemented by the States.

As discussed in the preambles to the PM and ozone rules (U.S. EPA, 1997 b and c), the costs and technological feasibility of attainment are not to be considered in setting NAAQS. These factors, however, can be considered in the development of State plans to implement such standards. Under section 110 of the Act, the States are to submit to EPA for approval State Implementation Plans (SIP) that provide for the attainment and maintenance of NAAQS by certain deadlines.

The current reviews of the NAAQS for PM and ozone have two separate and distinct components: the development of any new or revised standards which are codified in 40 CFR Part 50; and the development of cost-effective implementation strategies to achieve such standards, codified in 40 CFR Part 51.

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sample of persons comprising the group rather than to a single person in such a group." (S. Rep. No. 91-1196, 91st Cong., 2d Sess. 10 (1970)).

2.2.2 RH

In addition to the NAAQS for PM and ozone, EPA is proposing a RH rulemaking to achieve reasonable progress towards the national visibility protection goal. The EPA recognized that visibility impairment is an important effect of PM on public welfare and concluded that the most appropriate approach for addressing it is to establish secondary standards for PM identical to the suite of primary standards, along with a revised visibility protection program to address RH in Class I Federal areas. The sources, precursor pollutants, and geographical areas of concern that ozone, PM and RH have in common provide the opportunity to minimize the regulatory burden on sources that would otherwise be required to comply with separate controls for each of these pollutants. These pollutants will most likely be considered jointly by the various authorities responsible for the implementation of the new standards.

In 1970, section 169A of the CAA set forth a national visibility goal that calls for “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution.”

The EPA’s 1980 visibility regulations address visibility impairment that is “reasonably attributable” to a single source or small group of sources. These rules were designed to be the first phase in EPA’s overall program to protect visibility. The EPA explicitly deferred action addressing RH impairment until some future date “when improvement in monitoring techniques provides more data on source-specific levels of visibility impairment, regional scale models become refined, and our scientific knowledge about the relationships between emitted air pollutants and visibility impairment improves.” (U.S. EPA, 1997a).

Congress added section 169B as part of the 1990 Amendments to focus attention on RH issues. Section 169B(f) called for EPA to establish the Grand Canyon Visibility Transport Commission (GCVTC) to assess scientific and technical information pertaining to RH in the Grand Canyon National Park. The final report from the Commission, “Recommendations for Improving Western Vistas,” was completed in June 1996. Section 169B(e) calls for the

Administrator, within 18 months of receipt of the Commission's report, to carry out her "regulatory responsibilities under section [169A], including criteria for measuring 'reasonable progress' toward the national goal." (U.S. EPA, 1997a)

2.3 AUTHORITY FOR THIS RIA

Pursuant to Executive Order (E.O.) 12866, this Regulatory Impact Analysis (RIA) assesses the costs, economic impacts, and benefits associated with the implementation of these and alternative NAAQS for PM and ozone, as well as for the proposed RH rule. E.O. 12866 states that "Federal agencies should promulgate only such regulations as are required by law, are necessary to interpret the law, or are made necessary or compelling by public need . . . . In deciding whether and how to regulate, agencies should assess all costs and benefits of available regulatory alternatives, including the alternative of not regulating. Costs and benefits shall be understood to include both quantifiable measures . . . and qualitative measures of costs and benefits that are difficult to quantify, but nevertheless essential to consider. Further, in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits . . ., unless a statute requires another regulatory approach." Since the CAA precludes consideration of costs or technological feasibility in determining the ambient standards, the results of this RIA were not taken into account by the Administrator in her decision on whether to change the current NAAQS. Further discussion of other alternatives pursuant to E.O. 12866 is contained in Chapter 3 of this document.

The Unfunded Mandates Reform Act of 1995 (UMRA), in title II, section 201, directs agencies "unless otherwise prohibited by law [to] assess the effects of Federal regulatory actions on State, local, and tribal governments, and the private sector . . . ." Section 202 of title II directs agencies to provide a qualitative and quantitative assessment of the anticipated costs and benefits of a Federal mandate resulting in annual expenditures of $100 million or more, including the costs and benefits to State, local, and tribal governments, or the private sector. This section does not apply to the NAAQS because EPA cannot consider economic or technological feasibility in setting the PM and ozone NAAQS, and the NAAQS will not in themselves establish any new regulatory requirements. Section 205 requires that the least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule be selected or an explanation of why such alternative was not selected. This section applies only when a written statement is required under section 202. Section 204 requires each Agency to develop a process to permit State, local and tribal officials to provide meaningful and timely input in the development of regulatory proposals containing significant Federal intergovernmental mandates. The EPA had a series of preproposal outreach meetings that solicited input on issues related to the NAAQS (U.S. EPA, 1997 b and c)

The proposed RH rule establishes presumptive targets for visibility improvements in mandatory Class I Federal areas, but also provides discretion to the States to establish alternative targets where warranted. This RIA fulfills the UMRA section 202 requirement to analyze the costs and benefits of implementing a RH program. In view of the discretion the proposed rule would provide the States, the RIA analyzes two different presumptive targets for visibility improvement; one target equal to a rate over 10 years, the other over 15 years. The RIA analysis estimates that the RH rule would likely result in the expenditure by State, local, and tribal governments in the aggregate, or by the private sector of over $100 million per year for either presumptive option.

The UMRA section 204 consultation requirement was met by providing numerous opportunities for State, local and tribal governments to provide input during development of the proposed RH rule as described in the preamble to the final rule.

The Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA) provides that, whenever an agency is required to publish a general notice of rulemaking for a proposed rule, the Agency must prepare regulatory flexibility analyses for the proposed and final rule unless the head of the Agency certifies that it will not have a significant economic impact on a substantial number of small entities. Since the NAAQS themselves do not establish any requirements applicable to small entities, the Agency may certify that the rules will not have a significant economic impact on a substantial number of small entities. The EPA has explained in some detail in the preambles to the NAAQS rules and the proposed RH rules why these rules do not have a significant adverse impact on a substantial number of small entities. While speculative, the Agency has conducted general analyses of the potential cost impacts on small entities of control measures the States might adopt to attain the proposed NAAQS and proposed RH rule, and has included these analyses in this RIA.

Executive Order 12898, “Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations,” requires that each Federal agency make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minorities and low-income populations. The implementation plans determining which control measures will be used to attain the PM and ozone NAAQS and RH rule are developed by the States, therefore it is not possible to rigorously assess environmental justice concerns in this analysis.

Detailed discussions of the applicability of the above mentioned Executive Order and Acts to the PM and ozone NAAQS and the RH rule can be found in the preambles to these rules.

2.4 KEY HEALTH AND WELFARE EFFECTS

2.4.1 PM

As identified and discussed in the PM Criteria Document (CD) and PM Staff Paper (SP) (U.S. EPA, 1996c and d), key health effects categories associated with PM include: 1) premature mortality; 2) aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days); 3) changes in lung function and increased respiratory symptoms; 4) changes to lung tissues and structure; and 5) altered respiratory defense mechanisms.

Based on a qualitative assessment of the epidemiological evidence of effects associated with PM, the populations that appear to be at greatest risk from exposure to PM are: 1) individuals with respiratory disease and cardiovascular disease; 2) individuals with infectious respiratory disease; 3) elderly individuals; 4) asthmatic individuals; and 5) children.

In formulating alternative approaches to establishing adequately protective, effective, and efficient PM standards, it is necessary to specify the fraction of particles found in the ambient air that should be used as the indicator(s) for the standards. The scientific evidence indicates that continued use of PM_{10} as the *sole* indicator for the PM standards would not provide the most effective and efficient protection from the health effects of PM. The recent health effects evidence and the fundamental physical and chemical differences between fine and coarse fraction particles have prompted consideration of separate standards for the fine and coarse fractions of PM_{10}. In this regard, the CD (U.S. EPA, 1996d) concludes that fine and coarse fractions of PM_{10} should be considered separately. Taking into account such information, the Clean Air Scientific Advisory Committee (CASAC) found sufficient scientific and technical bases to support establishment of separate standards relating to these two fractions of PM_{10}. Specifically, CASAC advised the Administrator that “there is a consensus that retaining an annual PM_{10} NAAQS . . . is reasonable at this time” and that there is “also a consensus that a new $PM_{2.5}$ NAAQS be established.”

There are significant physical and chemical differences between the two subclasses of PM_{10} and it is reasonable to expect that differences may exist between fine and coarse fraction particles in both the nature of potential effects and the relative concentrations required to produce such effects. The specific components of PM that could be of concern to health include components typically within the fine fraction (e.g., acid aerosols, sulfates, nitrates, transition metals, diesel particles, and ultra fine particles), and other components typically within the coarse fraction (e.g., silica and resuspended dust). While components of both fractions can produce health effects, in general, the fine fraction appears to contain more of the reactive substances potentially linked to the kinds of effects observed in the epidemiological studies. The fine fraction also contains the largest number of particles and a much larger aggregate surface area than the coarse fraction which enables the fine fraction to have a substantially greater potential for absorption and deposition in the thoracic region, as well as for dissolution or absorption of pollutant gases.

With respect to welfare or secondary effects, fine particles have been clearly associated with the impairment of visibility over urban areas and large multi-state regions. Fine particles and their major constituents are also implicated in materials damage, soiling, and acid deposition. Coarse fraction particles also contribute to soiling and materials damage.

Particulate pollution is a problem affecting localities, both urban and non-urban, in all regions of the United States. Manmade emissions that contribute to airborne PM result principally from stationary point sources (fuel combustion and industrial processes), industrial process fugitive particulate emission sources, non-industrial fugitive sources (roadway dust from paved and unpaved roads, wind erosion from cropland, etc.) and transportation sources. In addition to manmade emissions, consideration must also be given to natural emissions including dust, sea spray, volcanic emissions, biogenic emissions (e.g., from plants and animals), and emissions from wild fires when assessing particulate pollution and devising control strategies (U.S. EPA, 1996c and d).

2.4.2 Ozone

As identified and discussed in the ozone CD and SP (U.S. EPA, 1996a and b), key health effects categories associated with ozone exposure include: 1) change in pulmonary function responses; 2) increased respiratory symptoms and effects on exercise performance; 3) increased airway responsiveness; 4) acute inflammation and respiratory cell damage; and based on animal studies 5) chronic respiratory damage.

In addition to the various health effects associated with exposure to ozone identified in the ozone CD and Staff Paper (U.S. EPA, 1996 a and b), recent peer reviewed scientific publications indicate that exposure to ambient ozone increases the risk of mortality. While this evidence was not used in the NAAQS standard setting process, this new evidence suggests that substantial additional health benefits associated with reducing ozone concentrations may exist.

The populations identified as having demonstrated particular susceptibility to ozone include "exercising" or active healthy and asthmatic individuals, including children, adolescents, and adults working outdoors. There are limited data on the ozone susceptibility of individuals with preexisting respiratory disease or other limitations on their pulmonary function and exercise capacity (e.g., those with chronic obstructive pulmonary disease, ischemic heart disease). However, these individuals may be of concern based on the likelihood that decrements in lung function or exercise capacity due to ozone exposure may have greater clinical importance to them than similar changes in healthy persons.

Welfare effects of ozone include, but are not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation. Of these welfare effect categories, the effects of ozone on crops, vegetation, and ecosystems are of significant concern at concentrations typically occurring in the U.S. As stated in a previous ozone CD and SP (U.S. EPA, 1989), "of the phytotoxic compounds commonly found in the ambient air, ozone is the most prevalent, impairing crop production and injuring native vegetation and ecosystems more than any other air pollutant." By affecting crops and native vegetation, ozone also directly affects natural ecosystem components such as soils, water, animals, and wildlife, and ultimately the ecosystem itself. Some of these impacts have direct, quantifiable economic value, while others are currently not quantifiable.

Finally, additional health and welfare effects and benefits accrue directly from control of ozone precursors (NOx and VOC). For example, reduced NOx results in substantial benefits from reduced nitrogen deposition into water bodies such as the Chesapeake Bay and from reduced PM. Reduced VOC results in air toxics reductions and reduced cancer risk.

2.4.3 RH

Regional haze is produced from a multitude of sources and impairs visibility in every direction over a large area, possibly over several states. Regional haze masks objects on the horizon and reduces the contrast of nearby objects. The formation, extent, and intensity of RH is a function of meteorological and chemical processes, which sometimes cause fine particle loadings to remain suspended in the atmosphere for several days and to be transported hundreds of kilometers from their sources. It is this type of visibility degradation that is principally responsible for impairment in national parks and wilderness areas across the country. Visibility in urban areas may be dominated by local sources, but may be significantly affected by long-range transport of haze as well. Fine particles transported from urban areas in turn may be significant contributors to regional-scale visibility impairment.

Visibility has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, both in the places where they live and work, and in the places where they enjoy recreational opportunities. Visibility is also highly valued because of the importance people place on protecting nationally-significant natural areas.

2.5 NEED FOR REGULATORY ACTION

2.5.1 Market Failure (Externality)

In the absence of government regulation, market systems have failed to deal effectively with air pollution because air sheds have been treated as public goods and because most air polluters do not internalize the full damage caused by their emissions. For an individual firm, pollution is usually an unusable by-product which can be disposed of at no cost by venting it to the atmosphere. However, in the atmosphere, pollution causes real costs to be incurred by others. This is generally referred to in economic theory as a negative externality.

The fact that the producer, or consumer, whose activity results in air pollution, does not bear the full costs of his/her action leads to a divergence between private costs and social costs.

This negative externality causes a "market failure" because it causes a misallocation of society's resources, with more resources being devoted to the polluting activity than would be if the polluter had to bear the full social cost of his/her actions..

There are a variety of market and nonmarket mechanisms available to correct this situation. Examples of market mechanisms include emission fees and trading systems. Other than regulation, nonmarket approaches would include negotiations or litigation under tort law and general common law. In theory, these latter approaches might result in payments to individuals to compensate them for the damages they incur.

Such resolutions may not occur, however, in the absence of government intervention. Two major impediments often block the correction of pollution inefficiencies and inequities by the private market. The first is high transaction costs when millions of individuals are affected by thousands of polluters, such as is the case with PM, ozone, and RH pollution problems. The transaction costs of compensating individuals adversely impacted by air pollution include contacting the individuals affected, apportioning injury to each from each pollution source, and executing the appropriate damage suits or negotiations. If left to the private market, each polluter and each affected individual must litigate or negotiate on their own or organize into groups for these purposes. The transaction costs involved could be so high as to exceed the benefits of the pollution reduction.

The second factor discouraging private sector resolution of the PM, ozone, and RH pollution problem is that pollution abatement tends to be a public good. That is, after pollution has been abated, benefits of the abatement can be enjoyed by additional people at no additional cost. This constitutes the classic "free rider" problem. Any particular individual is reluctant to contribute time or money to reduce PM, ozone, and RH expecting that they may be able to "free ride" on others' efforts to mitigate the problem.

In view of the clear legal requirements placed on the EPA by the CAA, the Agency is proposing to revise the NAAQS for PM and ozone and propose a RH rule to provide adequate protection of public health and welfare. As this RIA shows, there are resource costs associated with the implementation of these standards by the States. However, governmental action is required by the CAA. Moreover, these standards, when implemented by the States, will mitigate the negative externalities which would otherwise occur due to the failure of the marketplace.

2.6 REFERENCES

U.S. Environmental Protection Agency (1989), Review of the National Ambient Air Quality Standards for Ozone: Assessment of Scientific and Technical Information. Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; EPA report no. EPA-450/2-92/001.

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U.S. Environmental Protection Agency (1997a), Draft Notice of Proposed Rulemaking for Revisions to Existing Visibility Protection Regulations (40 CFR 51.300-307) to Address Regional Haze (Regional Haze Preamble). Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; June.

U.S. Environmental Protection Agency (1997b), Draft National Ambient Air Quality Standards for Ozone--Final Decision (Ozone Preamble). Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; May.

U.S. Environmental Protection Agency (1997c). Draft National Ambient Air Quality Standards for Particulate Matter--Final Decision (PM Preamble). Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; May.

3.0 NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS) AND REGIONAL HAZE (RH) ALTERNATIVES ASSESSED

3.1 INTRODUCTION

The assessment of the available quantitative and qualitative health effects data presented in the criteria documents and the Office of Air Quality Planning and Standards (OAQPS) Staff Papers, together with recommendations from the Clean Air Scientific Advisory Committee (CASAC) and other public commenters, suggest a range of alternatives for short-term (24-hour) and long-term (annual) particulate matter (PM) standards and for an 8-hour ozone standard. Based on the available scientific data, the Environmental Protection Agency (EPA) proposed new and revised PM and ozone standards on November 27, 1996. The EPA is also proposing a rulemaking on RH.

For a comprehensive discussion of the scientific data that serve as a basis for these alternatives as well as the rationale for the Administrator's approach to this decision, the reader is referred to the OAQPS Staff Papers and Criteria Documents, as well as the Federal Register notices announcing the Administrator’s proposed and final decisions.

Although EPA received numerous comments and suggestions concerning the alternatives that should be evaluated in this regulatory impact analysis (RIA), there is a limit to the number of different analyses that could be performed, due to time, resource, and other constraints. The alternatives described below are chosen because EPA believes they provide a sufficient variation within the range indicated by the data and because these alternatives could be assessed given available data and models. This RIA includes an evaluation of the incremental benefits and costs associated with these alternatives in relation to the current PM and ozone NAAQS baseline. The current standards are the appropriate baseline to use because they represent the point of comparison for the future if no new standards are implemented. The analysis assists in informing the public regarding which alternatives may return the greatest benefits in relation to the costs incurred when implemented by the States.

3.2 DESCRIPTIONS AND RATIONALES FOR STANDARDS EVALUATED

3.2.1 Current PM_{10} Standards

The current particulate matter annual and 24-hour standards 50 μg/m^3, annual arithmetic mean and 150 μg/m^3 24-hour, one expected exceedance. These standards are abbreviated as PM_{10} 50/150. The EPA is retaining the PM_{10} standards at their current level, but is changing the form of the 24-hour PM_{10} standard to the 99th percentile concentration over a 3-year period. This form of the standard is not analyzed in this RIA because it is considered a relaxation from the current standard and would, therefore, result in a cost savings when compared to the current standard. The annual standard will be retained in its current form.

3.2.2 Alternative New PM Standards

On November 27, 1996, EPA proposed to revise the current primary PM_{10} standards by adding two new primary $PM_{2.5}$ standards set at 15 μg/m^3, annual mean, and 50 μg/m^3, 24-hour average, to provide increased protection against a wide range of fine particle PM-related health effects as described in Chapter 2. The proposed annual $PM_{2.5}$ standard was based on the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations, spatially averaged across an area. The proposed 24-hour $PM_{2.5}$ standard was based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations at each monitor within an area. After reviewing comments on these proposed standards, EPA has selected final standards of 15 μg/m^3, annual mean, and 65 μg/m^3, 24-hour average. The proposed 24-hour $PM_{2.5}$ standard is based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations at each monitor within an area.

The EPA proposed to revise the current secondary PM standards by making them identical to the suite of proposed primary standards. These standards, in conjunction with the establishment of a regional haze program under section 169A of the Act, would provide appropriate protection against PM-related public welfare effects including soiling, material damage, and visibility impairment.

This RIA evaluates three sets of alternative $PM_{2.5}$ standards as shown in Table 3.1. Figure 3.1 is a schematic of the process for evaluating these standards. The term "2010 Baseline" in Figure 3.1 and the other figures that follow refers to estimated air quality in the year 2010 if current Clean Air Act (CAA) requirements are implemented. This is used as a starting point for all of the analyses in this RIA. This is discussed in more detail in Chapter 4. The first of these are standards of 15 μg/m^3 spatially-averaged annual arithmetic mean and 50 μg/m^3 24-hr, average of the 98th percentile concentration over a 3-year period ($PM_{2.5}$ 15/50). These standards were chosen because they are the levels of the proposed new standards as discussed above. The second set of standards are 15 μg/m^3 spatially-averaged annual arithmetic mean and 65 μg/m^3 24-hr ($PM_{2.5}$ 15/65). These were chosen because they are the selected standards. The third set of standards are 16 μg/m^3 spatially-averaged annual arithmetic mean and 65 μg/m^3 24-hr ($PM_{2.5}$ 16/65). These standards were chosen because they bound the selected standards. All of these standards are within the range recommended by CASAC. A sensitivity analysis also was performed to compare the 98th and 99th percentile forms for the $PM_{2.5}$ 15/50 standards.

Figure 3.1 Schematic of PM Alternatives

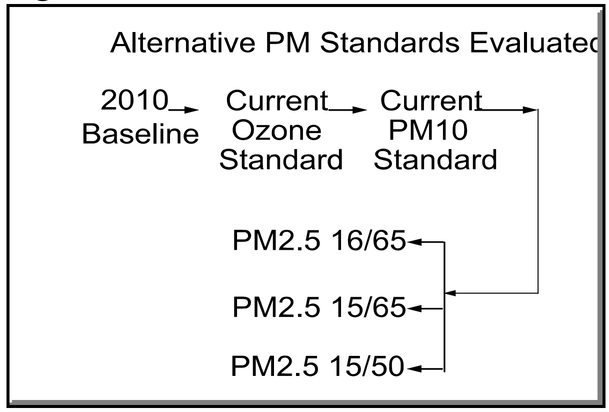

Table 3.1 PM Alternatives Assessed

PM Alternatives	Cost	Benefit	Economic Impact
$PM_{2.5}$ Standard 15μg/m^3, 24-hour/50μg/m^3, annual ($PM_{2.5}$ 15/50)	✔	✔	
$PM_{2.5}$ Standard 15μg/m^3, 24-hour/65μg/m^3, annual ($PM_{2.5}$ 15/65)	✔	✔	✔
$PM_{2.5}$ Standard 16μg/m^3, 24-hour/65μg/m^3, annual ($PM_{2.5}$ 16/65)	✔	✔	

3.2.3 Regional Haze Rulemaking Scenarios

The proposed presumptive standard for visibility improvement is a 1 deciview improvement every 10 years. As shown in table 3.2, costs, benefits and economic impacts are evaluated after application of the selected $PM_{2.5}$ standards of 15/65. In addition, a standard of 1 deciview improvement over every 15 years (or .67 deciview over 10 years) is evaluated. Figure 3.2 is a schematic of the process for evaluating these scenarios. The regional haze scenarios are evaluated after application of the PM standards because implementation of the PM standards should provide significant progress toward meeting regional haze requirements.

Figure 3.2 Schematic of Regional Haze Scenarios

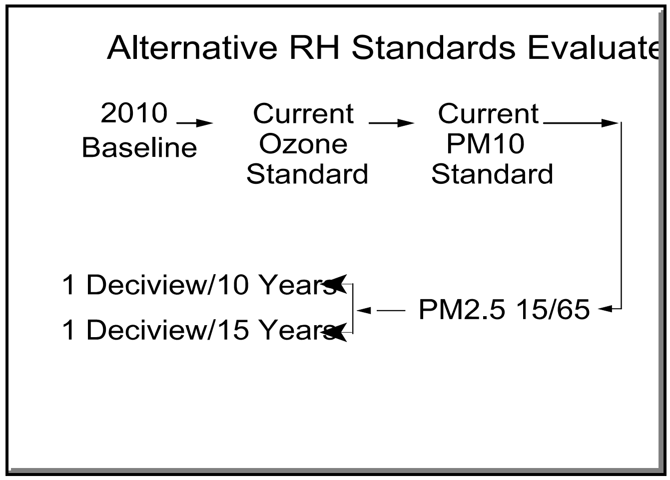

Table 3.2 Regional Haze Alternatives Assessed

Regional Haze Alternatives	Cost	Benefit	Economic Impact
1 deciview improvement per 10 years (after $PM_{2.5}$ 15/65)	✔	✔	
1 deciview improvement per 15 years (after $PM_{2.5}$ 15/65)	✔	✔	

3.2.4 Current Ozone Standard

The current ozone standard is 0.12 parts per million (ppm), 1-hour, 1 expected exceedance averaged over 3 years. This standard is abbreviated as 0.12, 1Ex.

3.2.5 Alternative New Ozone Standards

On November 27, 1996, EPA proposed to change the current primary ozone standard in the following respects: 1) attainment of the standard would no longer be based upon 1-hour averages, but instead on 8-hour averages; 2) the level of the standard would be lowered from the present 0.12 parts per million (ppm) to 0.08 ppm; and 3) the proposed NAAQS would be met in an area if the 3rd maximum daily maximum ozone concentration, averaged over 3 years, is less than or equal to .08 ppm. After reviewing comments, EPA selected a standard of 0.08 ppm, 4th maximum 8-hour daily maximum.

The EPA also proposed to replace the current secondary standard with one of two alternative standards: one set identical to the proposed new primary standard or, alternatively, a new seasonal standard expressed as a sum of hourly ozone concentrations greater than or equal to 0.06 ppm, cumulated over 12 hours per day during the consecutive 3-month period of maximum concentrations during the ozone monitoring season, set at a level of 25 ppm/hour. Either of the proposed alternative secondary standards would provide increased protection against ozone-induced effects, such as agricultural crop loss, damage to forests and ecosystems, and visible foliar injury to sensitive species. The EPA has chosen to set the secondary standard identical to the primary standard. Therefore, no separate analysis of the secondary standard is included in this RIA.

This RIA evaluates three alternative primary ozone standards as shown in Table 3.3. The selected standard of 0.08 ppm, 4th maximum 8-hour daily maximum (0.08 4th max) is assessed. In addition, a standard of 0.08 ppm, 3rd maximum 8-hour daily maximum (0.08 3rd max) and a standard of 0.08 ppm, 5th maximum 8-hour daily maximum (0.08 5th max) are analyzed. These latter two standards are chosen for analysis and presentation to bound the selected standard.   Figure 3.3 is a schematic of the process of evaluating these standards.

Figure 3.3 Schematic of Ozone Alternatives

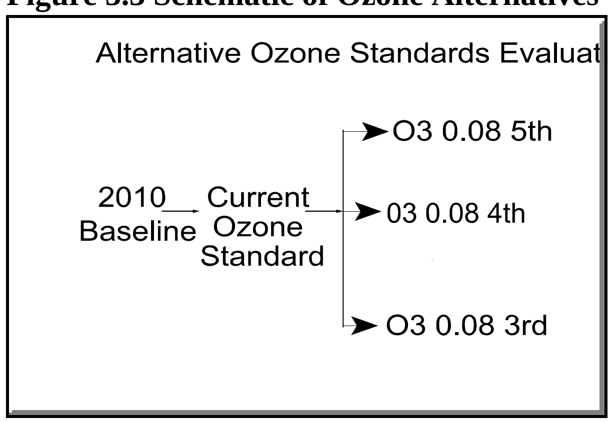

Table 3.3 Ozone Alternatives Evaluated

Ozone Alternatives	Cost	Benefit	Economic Impact
Alternative 0.08 ppm, 3rd Maximum 8-hour Daily Maximum (0.08 3rd max)	✔	✔	✔
Alternative 0.08 ppm, 4th Maximum 8-hour Daily Maximum (0.08 4th max)	✔	✔	✔
Alternative 0.08 ppm, 5th Maximum 8-hour Daily Maximum (0.08 5th max)	✔	✔	

Although Executive Order 12866 requires that all alternatives be examined, only the most likely ones need to be analyzed in detail. Because the CAA requires EPA to promulgate national standards, there are few likely alternatives to be considered. One alternative to changing the PM and ozone standards is to maintain the *status quo*. This is the “no regulation” alternative. For both PM and ozone, recent new scientific evidence examined in the Criteria Documents and Staff Papers indicates that the current standards do not provide an adequate level of protection as required by the CAA. Therefore, given the requirements of the CAA for the Agency to provide an adequate level of public health protection, a “no regulation” alternative is not considered a reasonable option.

Given the statutory requirements, other alternatives are not specifically evaluated. However, to the extent possible, these alternatives are factored into the analysis and may provide important tools for flexible implementation of the standards. For example, other regulatory approaches such as performance- and technology-based standards and regional controls are considered. Performance- and technology-based standards serve as useful adjuncts to ambient standards. However, they cannot serve as substitutes for ambient standards since even perfect compliance with them may not produce acceptable air quality levels. Performance- and technology-based standards are required by the present law in a variety of forms (e.g., new source performance standards for new and modified sources, lowest achievable emission rate, and reasonably available control technology in non-attainment areas, etc.). They are not based solely on health and welfare criteria but are designed, in part, to augment control strategies for attainment of the NAAQS. These standards generally specify allowable emission rates for specific source categories. Emission reductions from such standards were considered in the baseline for this analysis as appropriate. In addition, the analysis incorporates in the baseline certain regional control strategies that serve to reduce the amount of transported pollutants. This, in turn, reduces the burden on downwind areas and may result in a more cost-effective approach to attaining standards.

This analysis also considers market based approaches to the extent they are currently in place (e.g., acid rain) as well as through modeling of an emissions cap and trade program for utilities. Additional opportunities for PM and ozone management through the application of market based mechanisms for further nitrogen oxides and sulfur dioxide reductions may be identified and evaluated during the development of implementation plans for the new and revised standards.

3.3 REFERENCES

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4.0 BASELINE EMISSIONS AND AIR QUALITY

4.1 RESULTS IN BRIEF

Baseline 2010 emissions are projected from 1990 by application of sector-specific growth factors and Clean Air Act (CAA)-mandated controls to 1990 base year emissions. Total 2010 emissions of VOC, NOx, SO_2 and secondary organic aerosols are estimated to decrease from 1990 levels; however, emissions of primary PM_{10} and $PM_{2.5}$ are estimated to increase.

Baseline particulate matter (PM) air quality concentrations in 2010 are estimated using the Phase II Climatological Regional Dispersion Model (CRDM). Initial nonattainment counties (i.e., prior to application of controls) for each PM_{10} and $PM_{2.5}$ standard alternative are estimated based on these modeled air quality predictions for counties with PM monitors during 1993 - 1995. At the national level, 45 counties are estimated to be in initial nonattainment of the current PM_{10} standard (50/150- 1 expected exceedance). Before applying the National PM Strategy, 102 counties are estimated to initially violate the selected $PM_{2.5}$ standard (15/65- 98th percentile) incremental to the current PM_{10} standard. These projections are for purposes of estimating costs and benefits; specific nonattainment designations will be based on monitoring data collected in the future for each area. As discussed in Chapter 6, the National PM Strategy brings 35 counties into attainment of the selected $PM_{2.5}$ standard, leaving 67 counties requiring additional control for attainment. At the national level, 11 counties are estimated to be in initial nonattainment of the selected PM_{10} standard (50/150- 99th percentile).

Baseline ozone air quality concentrations in 2010 are estimated using a Regional Oxidant Model (ROM) extrapolation methodology. Initial nonattainment areas for alternative ozone standards are identified based on these modeled values for counties with ozone monitors in 1990. At the national level, nine areas are predicted to be in initial nonattainment of the current one-hour ozone standard; an additional 10 areas (19 total areas) are predicted to violate the 0.08 ppm/8-hr/4th max ozone alternative. These projections are for purposes of estimating costs and benefits; specific nonattainment designations will be based on monitoring data collected in the future for each area.

4.2 INTRODUCTION

This chapter describes the methods used to estimate baseline emissions and air quality in 2010 in order to assess the costs, benefits and economic impacts of alternative ozone and PM standards and regional haze goals. The assessments are conducted from a consistent analytical baseline. A single emissions inventory employing consistent methods is used as the basis for the ozone, PM and RH analyses. The year 2010 is selected as the year of analysis to provide an appropriate period in which 1) major programs of the CAA of 1990 will be reaching full implementation; 2) current standards are to be achieved; and 3) new standards are being implemented.

The PM and ozone analyses have been constructed such that benefits and costs are estimated incremental to those derived from the combined effects of implementing both the CAA of 1990 and the current ozone and PM standards as of the year 2010. These analyses provide a "snapshot" of air quality impacts, costs, and benefits associated with implementation of the new ozone and PM standards from a baseline of future CAA implementation and attainment of current standards. RH visibility goals are evaluated incremental to implementation of the new ozone and PM standards.

For the purpose of identifying the nonattainment areas associated with alternative NAAQS, this RIA excludes areas that did not have monitors during 1990 - 1995. Once nonattainment areas have been identified within the set of monitored areas, the analysis assumes control strategies on a local, regional, and national basis for the purpose of bringing identified nonattainment areas into attainment. Therefore, while the nonattainment areas are identified from within monitored areas only, control requirements, costs, benefits, and other economic impacts are estimated for both monitored and unmonitored areas.

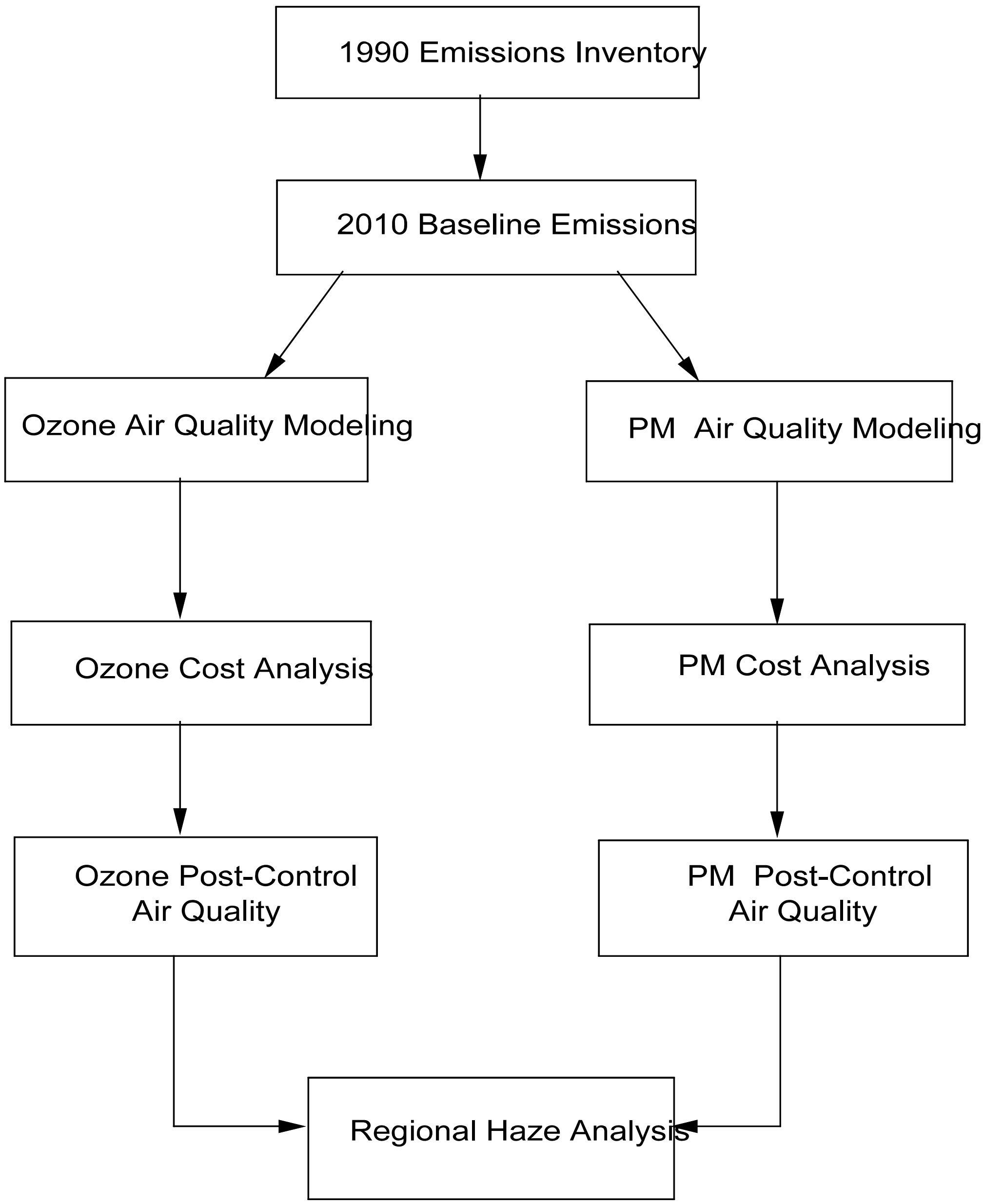
EPA believes that the monitored counties analytic approach for identifying nonattainment areas is most appropriate because 1) the likelihood of significant nonattainment in unmonitored areas after RIA controls are imposed is small; 2) serious modeling difficulties exist that prevent reliable prediction of nonattainment in unmonitored areas; and 3) any such nonattainment in unmonitored areas may not be detected (U.S. EPA, 1997c). It is possible, however, that even after all controls are imposed, nonattainment areas may exist that are not identified in the RIA, but may be identified in the future by the placement of new monitors.

Figure 4.1 illustrates the analytical approach employed for this assessment. Base year emissions for 1990 are projected to 2010 by applying sector-specific growth factors. CAA-mandated controls (i.e., control efficiencies or control-specific emission factors) then are applied to these future emissions to capture implementation of the CAA. The 2010 post-CAA control emissions are input to air quality models to predict baseline PM and ozone air quality from which PM and ozone nonattainment areas subsequently are identified. Control measures to bring these areas into attainment of alternative PM and ozone standards are evaluated and applied in the cost analyses. Emission reductions achieved by these control measures determine the "post-control" PM and ozone air quality in these areas. Given that regional haze goals are to be evaluated by areas after implementation of proposed PM and ozone standards, the post-control PM and ozone air quality serve as the baseline from which regional haze goals are analyzed. The methodologies used to estimate visibility for assessing the RH targets are discussed in Chapter 8.

4.3 ESTIMATION OF 1990 EMISSIONS AND 2010 EMISSIONS PROJECTIONS

The initial step in the assessment of alternative ozone and PM standards and RH goals is the development of the 2010 CAA emission estimates. These emissions serve as the baseline for

Figure 4.1 Overview of Emissions and Air Quality Analytical Approach



evaluation of alternative control measures for reducing ozone and PM precursor emissions for attainment of ozone and PM standards. The emissions estimation and projection methodologies build upon work conducted for the December 1996 ozone and PM Regulatory Impact Analyses (RIAs) (U.S. EPA, 1996f, 1996g). Major updates and refinements to the December 1996 emissions estimation methodologies are listed below.

- Version 3 of the 1990 National Particulates Inventory (NPI v.3)(Pechan, 1996c) is used as the base year emissions inventory (Version 2 was used in the December 1996 assessments (Pechan, 1995));

- Bureau of Economic Analysis (BEA) projections of Gross State Product (GSP) (BEA, 1995) are used to estimate 2010 emissions (BEA earnings data were employed in the December 1996 assessments (BEA, 1990));

- Utility sector CAA-control emission projections incorporate future utility deregulation and a 0.15 lb/MMBtu nitrogen oxides (NO_x) cap with trading and banking;

- The following CAA-mandated control assumptions are updated in the 2010 baseline emissions:

    - Control measure effectiveness for volatile organic compounds (VOC) and NO_x control measures is increased from 80% to 95%;

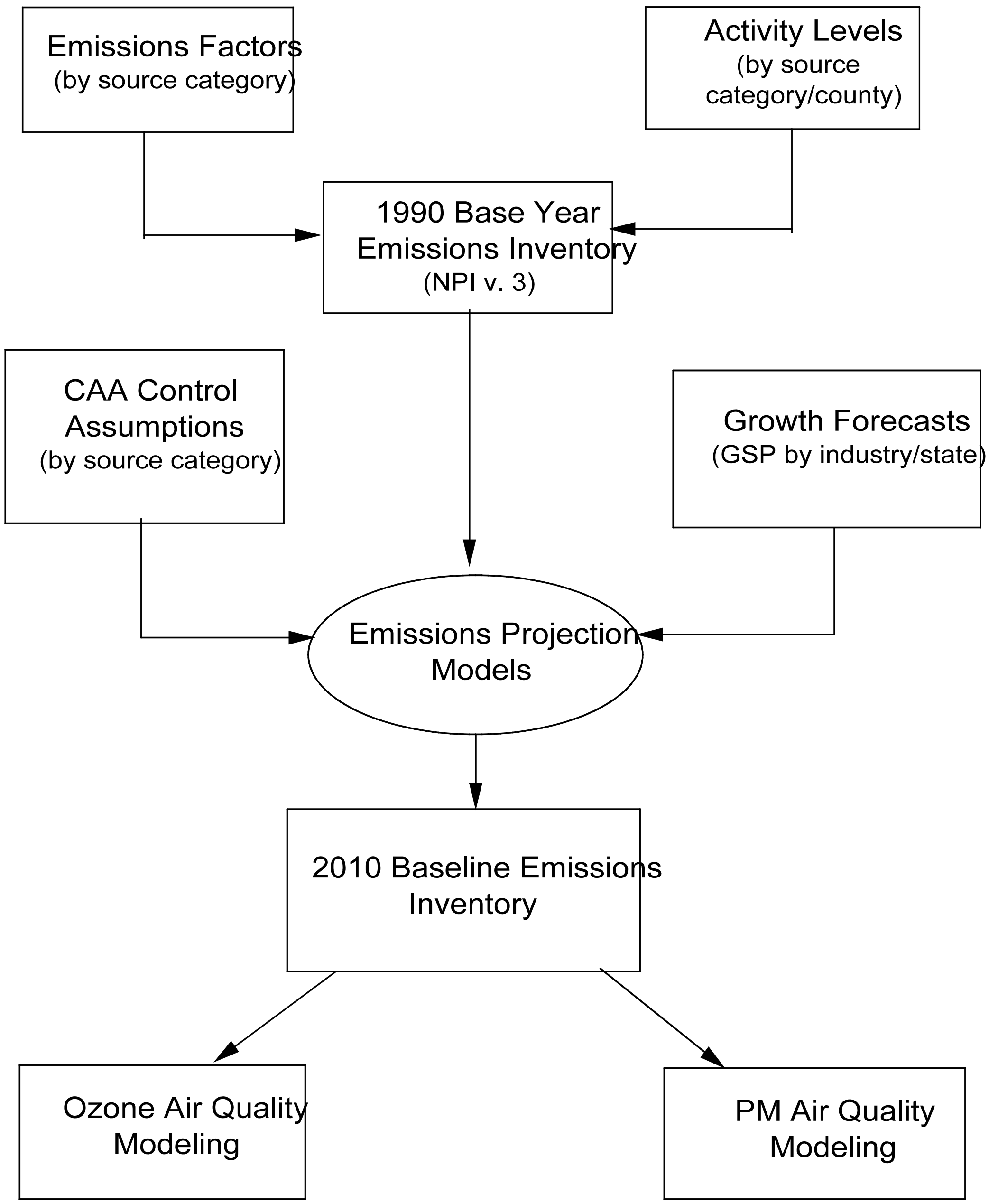
    - OTAG Level 2 NO_x controls on industrial point sources in 37 OTAG states are applied;

    - Estimated emission reductions from 7/10 year Maximum Achievable Control Technology (MACT) standards are included;

    - Proposed control requirements for Architectural and Industrial Maintenance (AIM) coatings and consumer and commercial products rules are incorporated.

Figure 4.2 illustrates the steps followed in the development of 2010 baseline emissions. First, source category-specific activity levels and emissions factors are used to estimate emissions for the base year 1990. Any pollution controls in place prior to 1990 are reflected in these base

Figure 4.2 Development of 2010 Baseline Emissions



year values. Emissions are estimated for VOC, NOx, sulfur dioxide (SO_2), primary PM_{10} and $PM_{2.5}$, secondary organic aerosols (SOA) and ammonia. As described in the introduction, certain VOC species, based on the reactivity of these organic compounds with atmospheric oxidants, form SOA (Grosjean and Seinfeld, 1989). To estimate SOA emissions, fractional aerosol coefficients (FACs) based on VOC species profiles for each Source Classification Code (SCC) are applied to 1990 VOC emissions (Pechan, 1997a).

Biogenic VOC emissions are involved in ozone and SOA formation and are estimated for the base year inventory.

Additionally, ammonia plays a role in the formation of particulate ammonium sulfate and ammonium nitrate. However, anthropogenic emissions of ammonia are a small component of total ammonia emissions. The majority of the ammonia that enters the atmosphere is produced by the biological decomposition of organic material in soils, plant residues, and wastes from animals and humans (NAPAP, 1991). Given that ammonia is not a limiting factor in the formation of secondary particles, ammonia emissions are not considered in the PM NAAQS control strategy analysis.

Because air quality modeling is conducted on the county level, emissions are estimated for all counties in the contiguous 48 states. The 1990 emissions are then input to an emissions projection model (e.g., Emission Reduction and Cost Analysis Model (ERCAM) for VOC and NOx) that predicts emissions in 2010 based on state-level growth forecasts and control assumptions reflective of implementation of CAA-mandated programs. The resultant 2010 emissions then serve as inputs to the ozone and PM air quality modeling.

4.3.1 Development of 1990 Base Year Emissions Inventory

The 1990 base year emissions inventory is based on Version 3 of the NPI (Pechan, 1996c; Pechan, 1997a). This is a more recent version of the NPI than was used in the December 1996 RIAs (i.e., NPI version 2 (Pechan, 1995)). The major difference in the inventories is in the fugitive dust PM emissions estimates: version 3 fugitive dust emissions estimates are lower than version 2.

The NPI is developed using a "top-down" approach to estimate national emissions at the county level. Top-down methods rely on existing data sources and use estimation techniques that are comprehensive but with less area-specific detail. In general, emissions factors for individual source types are applied to activity levels for source categories within the major emitting sectors (i.e., utility, industrial point, area, nonroad engines/vehicles, mobile sources and biogenics/natural sources). Emissions factors are expressed in terms of amount of a pollutant emitted for a given activity level (e.g., per ton of fuel consumed, per vehicle mile travelled). EPA emission factors are available for VOC, NOx, SO_2, and PM_{10}. Because there are no emission factors for $PM_{2.5}$, a PM calculator program containing particle size distribution data for various source categories is used to develop these estimates (Pechan, 1994). The program estimates the fraction of PM emissions from both controlled and uncontrolled sources that are within the fine particle fraction (i.e., < 2.5 microns in diameter) and coarse particle fraction (i.e., between 2.5 and 10 microns in diameter). Finally, anthropogenic ammonia emission factors are a compilation of estimates based primarily on recent European studies (Asman, 1992; Battye et al., 1994).

For the states of California and Oregon and for prescribed burning and wildfire emissions in the 11 western states, emissions estimates based on a bottom-up assessment conducted by the Grand Canyon Visibility Transport Commission (GCVTC) are used (Radian, 1995). These emission estimates are derived from more recent and detailed surveys of emissions from various source categories.

Biogenic VOC emissions are developed based on EPA's Biogenic Emissions Inventory System (BEIS) (Pierce et al., 1990). Biogenic SOA is estimated from application of VOC species-specific FACs to biogenic VOC emissions (Pechan, 1997a). Natural sources of PM emissions (i.e., wind erosion) are taken from the National Emission Trends Inventory (U.S. EPA, 1996h).

Table 4.1 summarizes the approaches used in development of the base year inventory. Appendix A.1 describes in more detail the emissions estimation methodologies used for each major emitting sector.

4.3.2 1990 Emissions Inventory Results and Discussion

Table 4.2 presents a summary of 1990 emissions by pollutant and major sector. Appendix A.2 presents 1990 emissions by source category and major sector. Area sources are the largest contributor to anthropogenic VOC emissions in 1990 (45% of total national anthropogenic VOC emissions). Biogenic and natural sources of VOC emissions are estimated to be roughly equivalent in magnitude to the anthropogenic total. Motor vehicles account for 33% of total national NO_x emissions with 46% of the motor vehicle emissions contributed by cars (i.e., light-duty gasoline vehicles). With regard to national SO_2 emissions, the utility sector is the largest emitter (71%). Area sources account for the bulk of PM_{10} and $PM_{2.5}$ emissions. Anthropogenic fugitive dust sources contribute the majority of primary PM_{10} and $PM_{2.5}$ emissions. More recent emission inventory efforts indicate that these estimates are overestimated. Refer to Section 4.3.3 for a discussion of the potential biases in these estimates.

Although biogenic and anthropogenic VOC are approximately equivalent, biogenic SOA is almost 17 times greater than anthropogenic SOA. This difference is due to the FACs used to estimate SOA. The FAC for terpenes, which account for 15 - 60% of biogenic VOCs, is 30%, while the average FAC for anthropogenic VOC sources is less than 1%.

Anthropogenic ammonia emissions are estimated to be approximately 4 million tons per year in 1990, but are believed to be a small component relative to natural sources of ammonia. Given that ammonia is not a limiting factor in the formation of secondary particles, ammonia

Table 4.1 Base Year Emission Inventory - Summary of Approach

Major Source Type	Modeling Approach/Data Sources
Industrial Point Sources	1985 National Acid Precipitation Assessment Program (U.S. EPA, 1989) emissions inventory grown to 1990 based on historical BEA earnings data (BEA, 1990). PM_{10} and $PM_{2.5}$ emissions based on total suspended particulate (TSP) emissions and particle-size multipliers (U.S. EPA, 1994b). California and Oregon State data substituted (Radian, 1995).
Electric Utilities	Based on EIA-767 fuel use for 1990 and unit-specific emission limits (DOE, 1991b) and AP-42 emission rates (U.S. EPA, 1995a)
Nonroad	Internal Combustion Engines/Vehicles (VOC, NO_x, $PM_{2.5}$, PM_{10}): 1991 Office of Mobile Sources (OMS) Nonroad Inventory (U.S. EPA, 1991b) Internal Combustion Engines/Vehicles (SO_2) and Aircraft, Commercial Marine Vessels, Railroads: 1985 NAPAP (U.S. EPA, 1989) grown to 1990 based on historical BEA earnings data (BEA, 1990).
Motor Vehicles	Federal Highway Administration travel data (FHWA, 1992), MOBILE5a/PART5 emission factors (U.S. EPA, 1993a).
Area Sources	1985 NAPAP inventory grown to 1990 based on historical BEA earnings data (BEA, 1990) and State Energy Data System (SEDS) fuel use data (DOE, 1991a); emission factor changes for selected categories (U.S. EPA, 1995a). California and Oregon State data substituted (Radian, 1995).
Solvents	National solvent usage estimates by end-use category from U.S. Paint Industry Data Base and industrial solvent marketing reports (Connolly et al., 1990). Allocated to county level based on industry employment and population (BOC, 1987, 1988a, 1988b).
Fugitive Dust (PM_{10}, $PM_{2.5}$)	
Agricultural Tilling	U.S. Department of Agriculture data (USDA,1991), U.S.EPA PM_{10} emission factors (U.S. EPA ,1995a).
Construction	Census Bureau Construction Expenditures (BOC, 1992), EPA PM_{10} emission factors (U.S. EPA, 1995a).
Unpaved and Paved Roads	EPA PART5 emission factors (U.S. EPA, 1994c), FHWA travel data (FWHA, 1992).
Livestock	USDA farming activity levels (USDA, 1991), EPA PM_{10} emission factors (U.S. EPA, 1995a). Particle size multipliers are applied to PM_{10} emissions to estimate $PM_{2.5}$ emissions (U.S. EPA, 1994b).
Biogenic VOC	Emissions for eight landcover types based on a forest canopy model which was used to account for the effects of solar radiation, temperature, humidity, and wind speed on predicted VOC emission rates (Lamb et al., 1993).
Wind Erosion	PM wind erosion emissions from agricultural lands based on acres of spring- or fall-planted crops in each State from the USDA and the expected dust flux (emission rate) based on a simplified version of the NAPAP method (Gillette, 1991). Emissions were distributed to the county level based on rural land area.
Agricultural Ammonia (NH_3)	NH_3 emissions for livestock feedlots and fertilizers based on Census of Agriculture data (BOC, 1992)and EPA-recommended emission factors (Battye et al., 1994).

emissions are not considered for control in the PM control strategy-cost analysis.

It should be noted that the ambient air quality impacts of emissions from any individual sector may not be proportional to their contribution to national emissions. The reader is referred to the PM and ozone air quality modeling sections (Chapter 4) and the PM and ozone cost chapters (Chapters 5 and 6) to understand how emissions from various source categories impact PM and ozone air quality.

4.3.3 Key Uncertainties Associated with 1990 Base Year Emissions

Given the on-going nature of emissions research, improvements to emissions estimation methodologies will continue to be made. However, there will be uncertainties associated with top-down approaches that rely on existing data sources and less source-specific data.

Because development of 1990 emissions employs emissions factors as primary inputs, more uncertain emission estimates result than if source-specific stack tests, load-curve based factors or continuous emissions monitoring (CEM) data are used. The differences in utility SO_2 and NOx emissions between alternative estimation methodologies, however, are not that large. Recent comparisons of SO_2 CEM data with estimates based on SO_2 emission factors and fuel consumption for a sample of plants showed that the two techniques produced emission estimates within an average of 8 percent at the State level (Schott, 1996). A comparison of NOx emissions based on CEM data and NOx emissions based on EPA emission factors for a sample of utilities in Louisiana resulted in a difference of 22 percent between the two methods (Schott, 1996). However, for area, non-road and motor vehicle sources where source-specific data is mostly unavailable, emission factors are applied to activity levels for each county. Thus, the potential uncertainties are greater for these sources than the better inventoried utility and industrial point sources (Pechan, 1996a). Finally, any possible biases in national emissions estimates from using emissions factors is unclear.

Table 4.2 Summary of National 1990 Base Year Emissions Estimates by Major Sector

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
Utility	37	7,426	15,865	283	109	1
Industrial Point	3,467	2,850	4,644	926	589	35
Area	10,098	2,100	1042	35,290	7,639	92
Nonroad	2,054	2,836	242	336	293	23
Motor Vehicle	6,811	7,446	568	355	291	48
Anthropogenic Subtotal	**22,466**	**22,656**	**22,359**	**37,190**	**8,921**	**198**
Biogenics	25,988					3,325
Natural Sources	248	89	1	5,429	995	
TOTAL	**48,702**	**22,745**	**22,360**	**42,619**	**9,916**	**3,525**

Note: Emissions estimates may not sum due to rounding.

1990 fugitive dust emissions have not been adjusted here as described in Section 4.4.2.3.

Air quality impacts from major emitting sectors are not necessarily proportional to their contribution to national emissions estimates. See PM and Ozone Air Quality Modeling Sections 4.4 and 4.5 and Chapters 6 and 7.

Use of particle size multipliers to estimate PM_{10} and $PM_{2.5}$ emissions from TSP data yields uncertain results relative to application of PM_{10} or $PM_{2.5}$ emission factors. The degree of uncertainty may vary by source category; however, there is no known bias in these factors.

The more recent biogenic emissions estimates from BEIS2 (Geron et al., 1994) are not incorporated in version 3 of the NPI. VOC emissions estimated using BEIS2 are 28 percent higher than biogenics included in the base year emissions. These higher VOC estimates also lead to higher biogenic SOA. However, given that BEIS2 emission estimates have better spatial resolution, higher or lower biogenic VOC emissions for specific counties may result relative to the NPI estimates. Thus at the national level, biogenic VOC and SOA may be underestimated, but in any individual county the bias is unclear (Pechan, 1997a).

The most recent fugitive dust emissions estimates developed for the National Emissions Trends Inventory (U.S. EPA, 1997h) indicate that NPI version 3 PM_{10} fugitive dust emissions may be overestimated by 40% and $PM_{2.5}$ fugitive dust emissions may be overestimated by 72% relative to the Trends estimates. The Trends fugitive dust information was available after PM air quality modeling had been completed and therefore could not be incorporated into this analysis. See Section 4.4.2.3 for a discussion of the implications of this overestimate of fugitive dust emissions on modeled PM air quality. Of particular interest is that the $PM_{2.5}$ emission estimate for agricultural operations (tilling and windblown dust) was decreased by about 50%, or 1 million tons per year. The emissions decrease from farming operations is clearly concentrated in the farm belt of the central US. Thus, the PM air quality analysis is likely biased toward overestimating fugitive dust impacts in farming areas, relative to other areas. While some other categories of fugitive dust emissions were also decreased, the net effect of those changes on the PM air quality analysis is unclear.

Fractional aerosol coefficients are used to estimate the percentage of VOCs that may react in the atmosphere and form secondary organic aerosols. There is considerable uncertainty associated with this estimation approach. This assessment assumes that 100% of all photochemically-reactive VOC species released eventually react to form SOA. This assumption may lead to overstated modeled SOA concentrations in areas close to the emission sources of organic species having long reaction times (Pechan, 1997a).

For the nonroad emissions category, the extrapolation of the nonroad inventory for 27 nonattainment areas to the rest of the country introduces uncertainty to the nonroad emissions estimates, however, with no known bias.

Because the 1985 NAPAP inventory serves as the basis for the 1990 base year inventory for some source categories, a number of factors are not accounted for. New plant construction, control equipment installation and retirement of emissions sources between 1985 and 1990 are not incorporated in the 1990 inventory. The magnitude of the uncertainty and direction of potential bias in national 1990 emission estimates as a result of these factors is unclear. Additionally, state-level industry earnings data is used to grow emissions from 1985 to 1990 rather than applying the more recent BEA GSP estimates. This may result in a small underestimate of 1990 emissions (Pechan, 1997a).

Considering relative uncertainty across emissions of individual pollutants, SO_2 emission estimates are the most certain. SO_2 is generated during combustion of any sulfur-containing fuel and is emitted by industrial processes that consume sulfur-containing raw materials. Apart from control efforts, sulfur emissions are directly related to the fuel sulfur content. As long as fuel usage and fuel sulfur content are measured, SO_2 emissions can be estimated within a relatively narrow range. For example, as part of the GCVTC emission inventory, uncertainty estimates were developed for various major SO_2 sources (Balentine and Dickson, 1995). The uncertainty estimate calculated for SO_2 emissions from copper smelting is $\pm$ 50 percent. However, associated uncertainty for emissions estimates from diesel and gasoline vehicles are assessed at $\pm$ 150 percent. Most of this uncertainty is due to the variability in the sulfur content of the fuels.

The NOx estimates are the next most certain category of emissions. Like SO_2, NOx is a product of fuel combustion. Since NOx formation is somewhat more complicated than SO_2, emission estimates are more variable, and uncertain, as well.

The level of uncertainty in PM_{10} emission estimates varies widely by source category. The largest component of the 1990 PM_{10} emission estimates is fugitive dust including fugitive emissions from paved and unpaved roads, construction activities, agricultural tilling, and windblown dust. The GCVTC study estimated the uncertainty for unpaved road emissions to be $\pm$ 400 percent. The estimated uncertainty for $PM_{2.5}$ emissions from paved road dust is $\pm$ 180 percent (Ballentine and Dickson, 1995). PM_{10} emission estimates for large point sources such as utility boilers are likely more certain than the fugitive dust source estimates, because these stacks are typically controlled using baghouses or electrostatic precipitators, the outlets of which are frequently tested to ensure compliance with regulations.

VOC emissions are uncertain because organics are emitted both as a product of fuel combustion and through evaporation. Evaporative emissions are difficult to quantify due to measurement problems. The GCVTC study estimated VOC emissions uncertainty for motor vehicles to be $\pm$ 150 percent (Ballentine and Dickson, 1995).

Table 4.3 summarizes the key uncertainties associated with estimation of 1990 emissions (Pechan, 1997a). For each potential source of uncertainty in the base year emissions, the direction of bias is provided. “Positive bias” indicates that 1990 emissions may be overestimated; “negative bias” indicates that they may be underestimated; and “bias unclear” indicates that the direction of potential bias in the emission estimates is unknown.

Table 4.3 Uncertainties and Possible Biases in Estimating 1990 Emissions

Potential Source of Uncertainty	Positive Bias? (Overestimate)	Negative Bias? (Underestimate)	Bias Unclear
Use of emission factors rather than stack test, load-curve, or CEM data			✓
Use of particle-size multipliers to estimate PM_{10} and $PM_{2.5}$ emissions from TSP emissions			✓
Extrapolation of nonroad inventory from 27 nonattainment areas to nation			✓
Use BEIS rather than more recent BEIS2 for biogenic VOC		✓ (total biogenic VOC and SOA)	✓ (county-level biogenic VOC and SOA)
Use NPI version 3 for fugitive dust emissions rather than more recent data from National Emissions Trends	✓		
Use FACs to estimate SOA from VOC emissions	✓		
Use of 1985 NAPAP inventory for some source categories: - lack data to incorporate for 1985- 1990 new plant construction, control equipment installation, retirement of sources. - used state-level earnings data rather than recent BEA GSP to grow emissions from 1985 to 1990.		✓ (small)	✓

4.3.4 Development of 2010 Emission Projections

The base year emissions are projected to 2010 to develop the emissions baseline from which to evaluate additional control measures needed to meet alternative ozone and PM standards and RH goals. In general, emissions are projected by applying expected increases in 1990 emissions or activity levels and incorporating the effects of 2010 CAA-mandated controls through application of control efficiencies or emission factors, respectively.

4.3.5 Growth Assumptions by Major Sector

This section describes the sector-specific growth assumptions used to project emissions to 2010. Table 4.4 summarizes the emissions projection modeling approach by major sector. Version 3 of the NPI employs 1995 BEA Gross State Product (GSP) 2010 projections by State/Industry for industrial point sources and, in combination with BEA population projections, for nonroad and area source categories. In the absence of product output projections, value added projections such as GSP are superior than earnings or employment projections for estimating future emissions (U.S. EPA, 1991a). Value added is the difference between the value of industry outputs and inputs. BEA GSP projections are a fuller measure of growth given that future changes in production processes, efficiency, and technological changes are captured.

For the utility sector, the Integrated Planning Model (IPM) is used to predict how the electric power industry will operate in the future given deregulation (i.e., movement from cost-of-service pricing to competitive pricing) and consequent industry restructuring (U.S. EPA, 1996j). Utility deregulation was not accounted for in the December 1996 RIAs. National Electric Reliability Council (NERC) forecasts of regional electricity demand are used to reflect the assumption that utility deregulation will likely lead to lower electricity prices for many users and therefore increased electricity demand. Additional major assumptions included in the utility modeling are the following: 1) technology will continue to improve for coal and natural gas

Table 4.4   2010 Growth Assumptions by Major Sector

Sector	Growth Forecast	Modeling Approach
Industrial Point	BEA Gross State Product (GSP) Projections by State/Industry (BEA, 1995)	VOC, NO_x – Emission Reduction and Cost Analysis Model (ERCAM): applies BEA growth projections to base year emissions and applies future year controls as selected by the user (Pechan, 1994, 1996b). PM_{10}, $PM_{2.5}$, SO_2, NH_3 – While no formal model exists, the same basic approach applied in ERCAM was used for these pollutants (Pechan, 1997a).
Utility	Projections of heat input by unit based on National Electric Reliability Council (NERC) data, price and demand forecasts, and technology assumptions.	SO_2, NO_x - Integrated Planning Model (IPM) (U.S. EPA, 1996i). VOC, PM_{10}, $PM_{2.5}$ – base year emission rates or AP-42 emission factors applied to IPM projected heat input by unit (Pechan, 1997a). NH_3 – NH_3 slippage for units controlling with selective catalytic reduction (SCR) (Pechan, 1997a).
Nonroad	BEA GSP and Population Projections by State/Industry (BEA, 1995)	VOC, NO_x – ERCAM (Pechan, 1994, 1996b). PM_{10}, $PM_{2.5}$, SO_2, NH_3 – ERCAM approach (no formal model)(Pechan, 1997a).
Motor Vehicle	National Vehicle Miles Traveled (VMT) Projections from the EPA OMS MOBILE Fuel Consumption Model (FCM) Scaled to Metropolitan/Rest-of-State Areas by Population (U.S. EPA, 1993)	NO_x, VOC – ERCAM: applies MOBILE5a emission factors to projected VMT by month and county/vehicle type/roadway classification (U.S. EPA, 1991c, 1993a). PM_{10}, $PM_{2.5}$, SO_2 – PART5 emission factors(U.S. EPA, 1994c) applied to projected VMT (U.S. EPA, 1991c). NH_3 – special study emission factors applied to projected VMT (Pechan, 1997a).
Area	BEA GSP and Population Projections by State/Industry (BEA, 1995)	VOC, NO_x – ERCAM (Pechan, 1994, 1996b). PM_{10}, $PM_{2.5}$, SO_2, NH_3 – ERCAM approach (no formal model)(Pechan, 1997a).
Biogenic VOC and PM Wind Erosion	Emissions held at 1990 levels	--

production so that energy prices for these fuels will not substantially increase between 1990 and 2010; 2) the large steam electric generation stock fueled by coal, oil, and gas will be the source of a large amount of power in the future; 3) improvement of the performance and reduction of the costs of electric generation technologies will continue; and 4) movement of power will be primarily constrained at the 16 NERC regions modeled in the analysis (U.S. EPA, 1997a).

Mobile source 1990 emissions are projected to 2010 based on growth in VMT. EPA's MOBILE4.1 Fuel Consumption Model (FCM) is used as the basis for the VMT projections (U.S. EPA, 1991c).

There is no growth assumed in biogenic emissions of VOC or SOA. Similarly, 2010 PM emissions from natural sources are assumed equal to 1990 levels.

4.3.6 2010 CAA Control Emissions by Major Sector

In order to capture the effects in 2010 of implementation of the CAA, future year control efficiencies or emission factors are applied to projected 2010 emissions or activity levels respectively. Table 4.5 summarizes the major CAA requirements that are modeled for the 2010 baseline. These control requirements are discussed in Appendix A.3 for each major sector.

For the 2010 CAA-control emissions, refined control measure effectiveness (CME) estimates are employed in combination with control efficiencies. CME reflects the degree to which individual control measures achieve their intended effect. An 80% CME was applied in the December 1996 RIAs for a subset of primarily VOC source category-control measure combinations. For this assessment, CME is assumed to be 95% for this subset. The refined CME estimate is based upon a recent study of historical EPA monitoring and enforcement data that indicate that, on average, control measures achieve 95 - 100 percent of the intended impact (PQA, 1997). The new CME is applied to the appropriate control measure efficiencies in place prior to

Table 4.5 CAA 2010 Projection Scenario Summary by Major Sector

Major Sector	Major CAA Scenario Requirements
Industrial Point	VOC and NO_x RACT for all NAAs (except NO_x waivers). New control technique guidelines (CTGs). 0.15 pounds per million British thermal unit (lb/MMBtu) Ozone Transport Assessment Group (OTAG)-wide NO_x cap on fuel combustors $\geq$ 250 MW. OTAG Level 2 NO_x controls across OTAG States. MACT standards (primarily VOC).
Utility	Title IV Phase I and Phase II limits for all boiler types. 250 ton Prevention of Significant Deterioration (PSD) and New Source Performance Standards (NSPS). RACT and New Source Review (NSR) for all non-waived (NO_x waiver) NAAs. Phase II of the Ozone Transport Commission (OTC) NO_x memorandum of understanding (MOU). 0.15 lb/MMBtu OTAG-wide seasonal NO_x cap utility boilers with banking/trading.
Nonroad	Federal Phase I and II compression ignition (CI) engine standards. Federal Phase I and II spark ignition (SI) engine standards. Federal locomotive standards. Federal commercial marine vessel standards. Federal recreational marine vessel standards.
Motor Vehicles	Tier 1 tailpipe standards. 49-State LEV program. Phase 2 Reid vapor pressure (RVP) limits. I/M programs for O_3 and carbon monoxide (CO) NAAs. Federal reformulated gasoline for O_3 NAAs. California LEV (California only). California reformulated gasoline (California only). Diesel fuel sulfur content limits. Oxygenated fuel in CO NAAs.
Area	VOC and NO_x RACT requirements. New CTGs (VOC). MACT Standards (VOC). PM NAA controls. Onboard vapor recovery (vehicle refueling). Stage II vapor recovery systems. Federal rules (consumer/commercial product limits, architectural and industrial maintenance (AIM) coating limits).

1990 and those controls assumed in the 2010 CAA-control emissions projections.

Rate of Progress (ROP) and Reasonable Further Progress (RFP) requirements are not modeled for the 2010 emissions baseline; instead, the emission reductions and costs are assessed for future attainment of the current ozone standard. Appendix C discusses the methodology and results of this analysis.

Additionally, updated information regarding proposed Title I AIM Coatings and Consumer and Commercial Products rules and Title III 7 and 10 year MACT rules are incorporated in the 2010 CAA-control emissions.

Ozone air quality modeling analyses show that NOx emissions must be substantially reduced in broad areas of the country in order for areas that are not meeting the current ozone standard to meet that standard (U.S. EPA, 1996b). Efforts to address long-range ozone transport issues have been undertaken by the Northeast Ozone Transport Commission (OTC, 1994) and the Ozone Transport Assessment Group (OTAG). These efforts will likely result in implementation of regional NOx control measures far in advance of the 2010 air quality assessment undertaken for this RIA. Because these control measures will be applied for the purpose of attaining the current standard, they are included in the analytical baseline of this RIA.

The 2010 baseline reflects the application of regional NOx reductions that are intended to approximate the reductions EPA would propose based upon OTAG recommendations. The regional NOx controls applied for this analysis include: 1) OTAG-wide 0.15 lb/MMBtu NOx emission limit on utilities and on non-utility boilers $\geq$ 250 MW; 2) OTAG Level 2 NOx controls on non-utility point sources across OTAG states; National Low Emission Vehicle (LEV) emissions standards on light duty vehicles in 49 states, beginning with the 1999 model year. The OTAG recommendation covers a broader universe of sources and provides for an emissions trading program. In addition, OTAG's recommendation does not include uniform control measures across the entire 37-State region. Of the States for which OTAG did not currently recommend controls, only Louisiana, Oklahoma and Texas have areas that are projected to be nonattainment for one or more of the standards evaluated. Because regional controls were not recommended for these States, the RIA may underpredict costs and benefits for these areas.

The LEV program is included in the baseline based on negotiations with the automobile industry that were initiated several years ago in order to help meet the current standard. Although no agreement has yet been reached, additional reductions from mobile sources likely will be required, either nationally or on a State-by-State basis, in order to meet the current standard. Therefore, inclusion of these reductions in the baseline is appropriate. This analysis, however, does not prejudge the outcome of negotiations with the automobile industry.

4.3.7 2010 Baseline Emissions Results and Discussion

Table 4.6 summarizes national 2010 CAA emissions by major sector. Appendix A.4 presents 2010 emissions by source category and major sector. Total emissions of VOC, NOx, SO_2, and SOA are estimated to decrease from 1990 levels; however, emissions of PM_{10} and $PM_{2.5}$ are estimated to increase between 1990 and 2010. The increases in PM emissions are due primarily to growth in anthropogenic sources of fugitive dust (i.e., paved roads and construction activity).

Emission reductions in 2010 attributable to individual CAA programs are also estimated (U.S. EPA. 1997j). These emission reductions reflect the change in emissions between projected 2010 emissions (i.e., incorporating growth between 1990 and 2010) with and without the application of CAA-mandated controls. National VOC emission reductions estimated to be achieved in 2010 due to Titles I and III point source controls are 1.0 million tons of VOC per year. 2010 Title I and III area source controls are projected to achieve 5.7 million tons of VOC emission reductions per year.

National NOx emission reductions for Title I industrial point source controls are estimated to total 1.6 million tons per year: CAA-mandated controls and the NOx cap account for approximately 500,00 tons and 100,000 tons of NOx reductions respectively and OTAG-wide

Level 2 NOx controls contribute an additional 1 million tons per year of NOx reductions (U.S. EPA, 1997j). Title I area source NOx controls account for reductions of 1.4 million tons of NOx per year. Title I mandated controls, Title IV Acid Rain NOx requirements, and the OTAG-wide NOx cap result in an estimated 3 million tons of summertime NOx reductions from the utility sector (U.S. EPA, 1997a).

Title II mobile source VOC and NOx controls including a national LEV program are estimated to result in annual reductions of 2.8 million tons of VOC and 3.5 million tons of NOx nationally in 2010 (U.S. EPA, 1997j).

The Title IV Acid Rain Program accounts for an 8 million ton reduction in utility SO_2 emissions from 2010 no-control levels (U.S. EPA, 1997a).

4.3.8 Key Uncertainties Associated with 2010 Baseline Emissions

Table 4.8 summarizes the key uncertainties associated with the 2010 baseline emissions. Because 1990 emissions and activity levels are the basis from which 2010 emissions are projected, the uncertainties associated with 1990 emissions estimates are carried through to the 2010 baseline. These uncertainties are discussed in Section 4.3.4.

There are uncertainties associated with the activity surrogates and projections data used to make 2010 growth forecasts for each source sector. However, there are no known biases in either of these data inputs.

Table 4.6 Summary of National 2010 CAA Emissions Estimates by Major Sector

Major Sector	**VOC (1000 tpy)**	**NOx (1000 tpy)**	**SO_2 (1000 tpy)**	**PM_{10} (1000 tpy)**	**$PM_{2.5}$ (1000 tpy)**	**SOA** (1000 tpy)
Utility	**50**	**3,755**	**9,746**	**277**	**111**	0
Industrial Point	2,164	1,958	5,990	1,170	745	25
Area	7,533	2,932	1,518	41,051	8,931	73
Nonroad	1,888	2,063	236	336	292	24
Motor Vehicle	3,946	5,574	409	204	141	27
Anthropogenic Subtotal	**15,581**	**16,282**	**17,899**	**43,038**	**10,220**	**150**
Biogenics	25,988					3,325
Natural Sources	248	89	1	5,429	995	
TOTAL	**41,817**	**16,371**	**17,900**	**48,467**	**11,215**	**3,475**

Note: Emissions estimates may not sum due to rounding.
1990 fugitive dust emissions have not been adjusted.
Air quality impacts from major emitting sectors are not necessarily proportional to their contribution to national emissions estimates. See PM and Ozone Air Quality Modeling Sections 4.4 and 4.5 and Chapters 6 and 7.

The 2010 control assumptions used to incorporate the effects of CAA-mandated controls also have related uncertainties. Potential revisions to existing rules or rules that are currently in draft form but would be implemented in 2010 are not incorporated in the 2010 emissions baseline. It is unclear the net effect of these omissions on baseline emissions. Because RFP and ROP are not incorporated in the baseline, 2010 emissions could be underestimated. There may be an overestimate in baseline emissions given that the co-control emission reductions (e.g., PM, NOx) from MACT standards and off-set requirements in the OTR and ozone nonattainment areas have not been estimated. Finally, because the NPI is a top-down inventory, area-specific control measures as outlined in nonattainment State Implementation Plans (SIPs) have not been incorporated in the baseline emissions. The potential bias is unclear for this potential source of uncertainty.

Table 4.8 Uncertainties and Possible Biases in Estimating 2010 Emissions

Potential Source of Uncertainty	Positive Bias? (Overestimate)	Negative Bias? (Underestimate)	Bias Unclear
1990 Emissions	✓ (fugitive dust)	✓ (total biogenic VOC and SOA)	✓
<u>Growth Forecasts</u>:			
- activity surrogates			✓
- projections data			✓
<u>2010 Control Assumptions</u>:			
- Potential revisions to existing rules or rules in draft form not incorporated;			✓
- RFP/ROP for individual ozone nonattainment areas not estimated;		✓	
- Co-control from MACT standards not estimated;	✓		
- Off-set requirements in OTR and ozone nonattainment areas not estimated;	✓		
- Area-specific reductions as reflected in SIPs not incorporated.			✓

4.4 ESTIMATION OF BASELINE PM AIR QUALITY CONCENTRATIONS IN 2010

The methodology for estimation of baseline PM air quality concentrations for this assessment builds upon the previous method used in the December 1996 PM NAAQS RIA. The CRDM is used to estimate ambient PM concentrations in 2010. This model predicts quantitative relationships (i.e., source-receptor relationships) between county-level emissions of primary particles and secondary particle precursors and annual concentrations of PM_{10} and $PM_{2.5}$ at county-level receptors. The following updates to data inputs, methodological refinements, and sensitivity analyses are implemented for this assessment:

- Updated Phase II CRDM air quality modeling results are employed;
- The source-receptor matrix is calibrated using 1993 -1995 Aerometric Information Retrieval System (AIRS) monitoring data for all 711 counties monitored for PM_{10} in the 48 contiguous states during this 3-year period;
- The number of monitored counties covered in the nonattainment county analysis is increased (i.e., 504 counties vs. 470 in the December 1996 analysis);
- Sensitivity analyses of the following are conducted:
  - number of counties covered in the baseline PM nonattainment county analysis
  - fugitive dust adjustment factor;
- Analysis of PM air quality as it relates to regional haze visibility improvement goals is included.

4.4.1 Overview of Phase II PM Air Quality Modeling

This section provides a general overview of the Phase II PM air quality modeling analysis. More detailed information follows in subsequent sections. The December 1996 PM RIA assessment employed the Phase I source-receptor (S-R) matrix as produced by the CRDM. The Phase I modeling results are thought to be deficient in that they likely underestimated the impacts of secondary particle precursor emissions. For Phase II, the Lagrangian Regional Model is used to guide the refinement of the CRDM to correct for this misestimation (Latimer, 1996). Using 1990 meteorology, the refined CRDM is applied to 1990 emissions to calculate a transfer matrix of S-R relationships for all relevant primary and precursor emissions to estimate cumulative regional ambient concentrations of $PM_{2.5}$ and PM_{10}, as well as the important chemical constituents of secondary particulates: sulfate, nitrate, secondary organics and ammonium. As described in section 4.4.2, the refined CRDM, when used with adjusted primary PM fugitive dust emissions, provides representative estimates of the spatial distribution of annual PM concentrations in the United States (Pechan, 1997b).

The S-R matrix next is calibrated using 1993 - 1995 PM_{10} and $PM_{2.5}$ annual monitoring data to benchmark the modeling to ambient air quality values. Additionally, this calibration provides a way to capture the 3-year and spatial averaging aspects of the $PM_{2.5}$ annual standard alternatives.

In order to predict ambient PM concentrations in 2010, emissions projections as described in Section 4.3 are input to the calibrated S-R matrix to produce annual PM_{10} and $PM_{2.5}$ concentration values at county-level receptors. Finally, 1993 - 1995 peak-to-mean ratios (i.e., ratio of 24-hour value to annual average value) for each monitored county in the analysis are used to estimate the 24-hour PM concentration (i.e., 4th highest daily maximum for the current PM_{10} daily form and 98th percentile value for the $PM_{2.5}$ daily form alternatives) from the model-predicted annual PM concentration. Nonmonitored counties are calibrated using regional average normalization factors. Additionally, regional peak-to-mean ratios are used to derive the 24-hour PM concentration in the nonmonitored counties.

Once 2010 baseline air quality is developed, monitored counties are evaluated for violation of alternative standards. Figure 4.3 illustrates the development of 2010 baseline PM air quality concentrations.

4.4.2 Elements of PM Air Quality Modeling

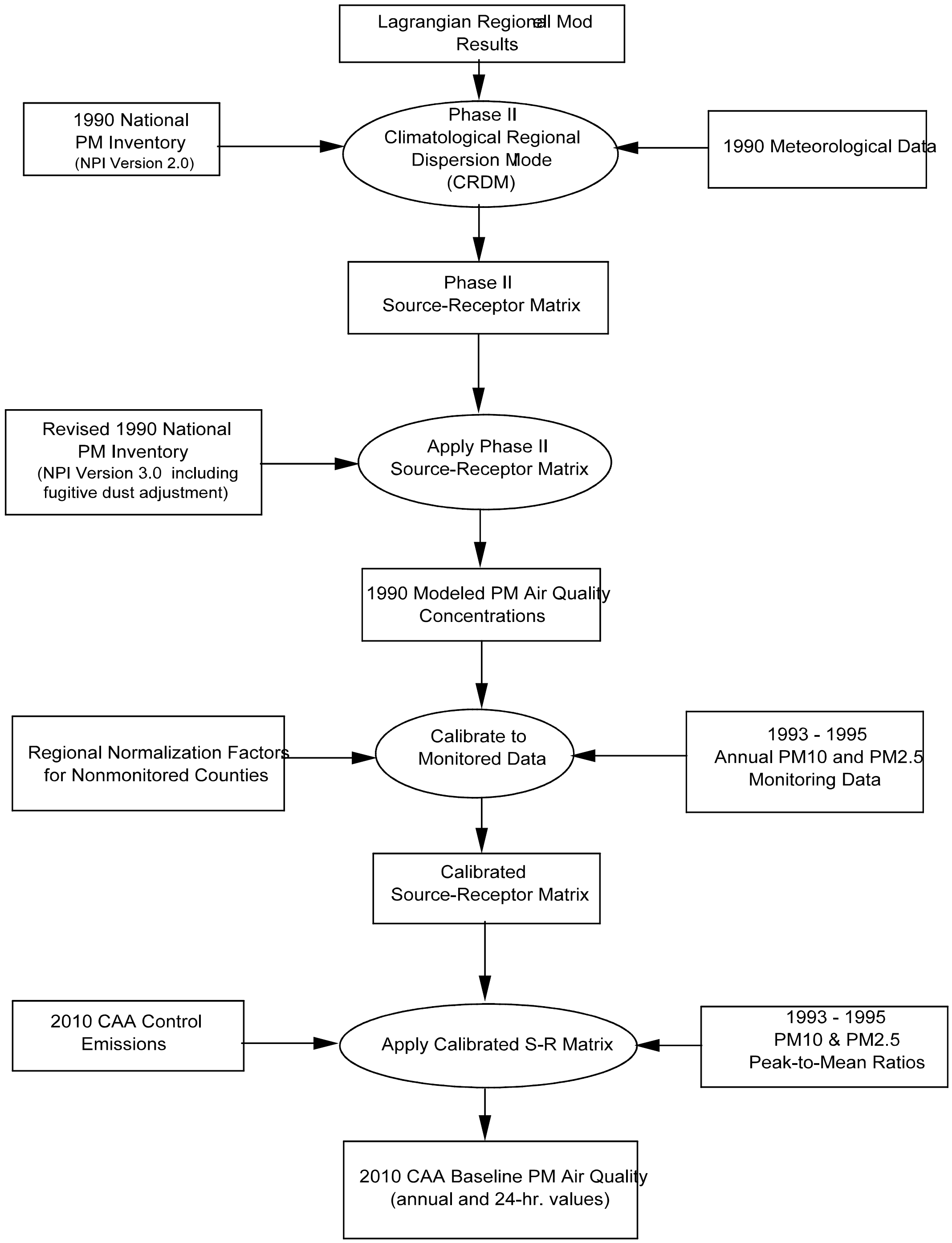
4.4.2.1 Lagrangian Regional Model

The Lagrangian Regional Model (LRM) is used to guide the refinement of the CRDM through the estimation of the transport, diffusion, deposition, and chemical conversion of emissions using a spatially and temporally varying wind field. Because the computer memory and run times are excessive to run the LRM for the entire country with 6,000 sources and 3,000 receptors, the LRM was tested for a single point source for a few days of 1990 meteorological data from the MM-4 mesoscale model. The LRM simulates the hourly release of puffs which are transported by the averaged winds appropriate for the time and location of the puff. In general, puff-type air quality models are better than Gaussian dispersion models at handling transport and diffusion of pollutants at low wind speeds and therefore show a greater air quality impact from emissions in the local area. A single uniform concentration of each particulate chemical constituent for each hourly puff is calculated based on standard vertical diffusion coefficients, limited by the mixed layer height, and mesoscale diffusion coefficients. Results from the LRM are subsequently used to refine CRDM assumptions to take account of long-range transport of secondary particles and impacts of a county's primary emissions on its air quality (Latimer, 1996).

4.4.2.2 Climatological Regional Dispersion Model

The CRDM is used to generate a matrix of S-R relationships that relate emissions of direct PM_{10} and $PM_{2.5}$ and particle precursors to annual average PM_{10} and $PM_{2.5}$ concentrations (Pechan, 1997b). The S-R matrix reflects the relationship between PM concentration values at a single receptor in each county (a hypothetical design value monitor sited at the county population centroid) and the contribution by PM species to this concentration from each emission source. The CRDM uses assumptions similar to the Industrial Source Complex Short Term (ISCST3), an EPA-recommended short range Gaussian dispersion model (U.S. EPA, 1995b). CRDM

Figure 4.3
Development of 2010 Baseline PM Air Quality



incorporates terms for wet and dry deposition and chemical conversion of SO_2 and NOx, and uses climatological summaries (annual average mixing heights and joint frequency distributions of wind speed and direction) from 100 upper air meteorological sites throughout North America. For this analysis, meteorological data for 1990 is used.

The CRDM uses Turner's sector-average approach, a probabilistic method in which the frequencies of occurrence of various wind and stability conditions are used to calculate the frequencies of transport of pollutants in various sectors. This method is recommended for estimation of long-term average pollutant concentrations and is discussed more fully in a contractor report (Pechan, 1997b). The assumptions related to chemical conversion of secondary particle precursors, long-range transport of secondary particles and the impact of a county's primary emissions on itself are refined based upon the LRM results. For the Phase II modeling, chemical conversion, transport and deposition equations are updated. Additionally, it was assumed that all primary emissions from the county are evenly distributed over a square with the same area as the county. It is also assumed that primary emissions from the county are always impacting the county. A simple box model is used for each wind speed and stability category. The vertical diffusion coefficient is calculated at a downwind distance corresponding to the length of the side of the square. These assumptions are necessary since spatial variation of emissions within a county cannot be provided for a national scale model.

Emissions data from version 2.0 of the 1990 NPI are input to the CRDM. Stationary and mobile source emissions, as well as ground-level area source emissions, for 3,081 counties in the contiguous United States are contained in the 1990 NPI. The high number of point sources in the inventory (61,619 point sources) made it impractical to model each point source individually. As a result, elevated point source emissions are aggregated at the county level by plume height. The effective stack height of each of these sources was calculated for an average wind speed (5 meters/second) using the plume rise algorithm for ISCST3. Two aggregated elevated point source groupings are made: one for sources with effective stack heights less than 250 m, and one for sources with effective stack heights between 250 and 500 m. Sources with effective stack heights greater than 500 m are modeled as separate sources. In addition to point sources, the modeled emission sources also include total area/mobile sources for each county and emissions for 10 Canadian provinces and 29 Mexican cities/states. Receptors modeled include all county centroids plus receptors in Canada and Mexico.

A total of 5,944 sources (i.e., industrial point, utility, area, nonroad, and motor vehicle) of primary and precursor emissions are modeled. In addition, secondary organic aerosols formed from anthropogenic and biogenic VOC emissions are modeled. Natural sources of PM_{10} and $PM_{2.5}$ (i.e., wind erosion and wild fires) are also included. Emissions of SO_2, NOx, and ammonia are modeled in order to calculate ammonium sulfate and ammonium nitrate concentrations, the primary particulate forms of sulfate and nitrate. The CRDM produces an S-R matrix of transfer coefficients for each of these primary and particulate precursor pollutants. These coefficients can be applied to the emissions of any unit (area source or individual point source) to calculate a particular source's contribution to a county receptor's total annual PM_{10} or $PM_{2.5}$ concentration. Each individual unit in the inventory is associated with one of the source types (i.e., area, point sources with effective stack height of 0 to 250 m, 250 m to 500 m, and individual point sources with effective stack height above 500 m) for each county.

Once the S-R matrix is developed, the transfer coefficients must be adjusted to reflect concentrations of secondarily-formed particulates (Latimer, 1996). First, the transfer coefficients for SO_2, NOx, and ammonia are multiplied by the ratios of the molecular weights of sulfate/SO_2, nitrate/nitrogen dioxide and ammonium/ammonia to obtain concentrations of sulfate, nitrate and ammonium.[a] The relative concentrations in the atmosphere of ammonium sulfate and ammonium nitrate depend on complex chemical reactions. In the presence of sulfate and nitric acid (the gas phase oxidation product of NOx), ammonia reacts preferentially with sulfate to form particulate ammonium sulfate rather than react with nitric acid to form particulate ammonium nitrate. Under conditions of excess ammonium and low temperatures, ammonium nitrate forms. For each county receptor, the sulfate-nitrate-ammonium equilibrium is estimated

a Ratio of molecular weights: Sulfate/SO_2= 1.5; nitrate/nitrogen dioxide = 1.35; ammonium/ammonia = 1.06.

based on the following simplifing assumptions:

- All sulfate is neutralized by ammonium;
- Ammonium nitrate forms only when there is excess ammonium;
- Because ammonium nitrate forms only under low temperatures, annual average particle nitrate concentrations are divided by four assuming that sufficiently low temperatures are present only one-quarter of the year.

Finally, the total particle mass of ammonium sulfate and ammonium nitrate is calculated.[a]

4.4.2.3 <u>Comparison of Modeled and Measured PM Concentrations</u>

In order to evaluate the performance of the Phase II CRDM, model-predicted PM concentrations and measured ambient PM concentrations are compared. Measured annual average PM concentrations by chemical species from the Interagency Monitoring for Protection of Visual Environments (IMPROVE) network are examined for the three-year period March 1988 - February 1991. This period is chosen because it relates closely to 1990 emissions and meteorological data used in the CRDM. Given that IMPROVE network monitors visibility impairment in predominantly rural Class I areas, these comparisons are incomplete due to the lack of coverage in urban areas. With the exception of the fugitive dust component of $PM_{2.5}$ and PM_{10}, modeled and measured concentrations of sulfate, nitrate and organics are comparable (Latimer, 1996).

Additionally, some preliminary air quality modeling has been conducted using the Regional Acid Deposition Model-Regional Particulate Model (RADM-RPM) for the Eastern U.S. using 1990 emissions and meteorology (U.S. EPA, 1997b). This is a Eulerian gridded model incorporating more comprehensive physics and chemistry to enable better characterization

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a To calculate total particle mass of ammonium sulfate and ammonium nitrate, the anion concentrations of sulfate and nitrate are multiplied by 1.375 and 1.29 respectively.

of secondarily-formed pollutants than Lagrangian-based methods. In general, the CRDM results show a similar East-West trend in sulfate and nitrate concentrations within the same modeling region. Also, the CRDM-predicted annual average concentrations of sulfate are within the range of RADM-RPM base-case predictions. Relative to RADM-RPM base case results, CRDM appears to overpredict nitrate concentrations in the Mid-west and underpredict nitrate concentrations in the Mid-Atlantic states.

This PM air quality modeling effort attempts to model the "background" contribution to ambient PM concentrations. Background PM is defined as the distribution of PM concentrations that would be observed in the U.S. in the absence of anthropogenic emissions of PM and precursor emissions of VOC, NOx and SOx in North America (U.S. EPA, 1996l). Estimating background PM concentrations is important for the cost analysis as it represents that portion of PM mass that is uncontrollable. Background PM levels vary by geographic location and season. The natural component of background arises from physical processes of the atmosphere that entrain small particles of crustal material (i.e., soil from wind erosion) as well as emissions of organic particles and nitrate precursors resulting from natural combustion sources such as wildfire. In addition, certain vegetation can emit SOA. Biogenic sources and volcanos also emit sulfate precursors. The exact magnitude of this natural portion of PM for a given geographic location can not be precisely determined because it is difficult to distinguish from the long-range transport of anthropogenic particles and precursors. The PM Criteria Document (U.S. EPA, 1996a) reports that annual average $PM_{2.5}$ concentrations range from 1 - 4 ug/m^3 in the West and from 2 - 5 ug/m^3 in the East.

Given the uncertainties in estimating biogenic VOC and SOA emissions and primary PM emissions from natural sources as well as the uncertainties in the PM air quality model, there is considerable uncertainty in the modeled predictions of the background contribution to PM mass. For some nonattainment counties, apparent overpredictions in the background contribution to PM mass reduces the relative contribution of anthropogenic sources to PM mass. This in turn can significantly diminish the modeled effectiveness of control measures on anthropogenic sources in reducing estimated PM concentration levels. This issue is discussed in Chapter 6 for

PM residual nonattainment areas.

Although the bulk of primary PM emissions are from anthropogenic and natural fugitive dust sources[a], available speciated monitoring data indicate that fugitive dust contributes substantially less to total $PM_{2.5}$ levels relative to other particle species such as sulfates and nitrates. The CRDM-predicted average fugitive dust contribution to $PM_{2.5}$ mass is 31% in the East and 32% in the West (Pechan, 1997b). Speciated monitoring data show that minerals (i.e., crustal material) comprise approximately 5 percent of $PM_{2.5}$ mass in the East and approximately 15 percent of $PM_{2.5}$ mass in the West (U.S. EPA, 1996a). The 1990 model predictions therefore are not consistent with ambient data. These disparate results may suggest a systematic overbias in the fugitive dust emission estimates. Subsequent PM emission inventory efforts indicate that fugitive dust emissions are overestimated in the baseline emissions inventory. The NPI version 3 fugitive dust PM_{10} and $PM_{2.5}$ emissions used in this analysis are 40% and 73% greater, respectively, than the most recent National Emissions Trends Inventory estimates[b] (U.S. EPA, 1997h). Furthermore, this overestimate in the contribution of fugitive dust to modeled ambient fine particle concentrations relative to speciated monitoring data is likely to be compounded by uncertainties in the air quality modeling (U.S. EPA, 1996c).

To address this bias, a multiplicative factor is applied nationally to fugitive dust emissions as a reasonable first-order attempt to reconcile differences between modeled predictions of $PM_{2.5}$ and actual ambient data. Two multiplicative factors are examined: 0.25 and 0.10. The 0.25 multiplicative adjustment results in a fugitive dust contribution to modeled ambient $PM_{2.5}$ concentrations of 10 - 17%, while the 0.10 multiplicative factor results in a 4 - 8% contribution.[c]

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a Natural and anthropogenic fugitive dust emissions account for 93% of PM_{10} emissions and 76% of $PM_{2.5}$ emissions in the 1990 base year inventory (NPI version 3).

b Natural and anthropogenic fugitive dust emissions account for 86% of PM_{10} emissions and 59% of $PM_{2.5}$ emissions in the most recent 1990 National Emission Trends Inventory.

c See map on p. 6-5 for delineation of cost modeling regions. Using 0.25 multiplicative factor, fugitive dust as percentage of $PM_{2.5}$ mass for: Central U.S. = 17.2%; Eastern U.S.= 10.4%; Western U.S.= 10.6%. Using 0.10 multiplicative factor, fugitive dust as

Given that the 0.25 multiplicative factor appears to bring the modeled fugitive dust contribution to $PM_{2.5}$ mass more within the range of values reported from speciated monitoring data, the main PM analysis of costs and benefits uses the 0.25 multiplicative factor to adjust fugitive emissions. However, a sensitivity analysis is conducted using the 0.10 multiplicative factor. The impact of the fugitive dust adjustment factor on PM nonattainment county counts is discussed in section 4.4.3. Appendix D provides more detailed information on this sensitivity analysis.

4.4.2.4 Application of Phase II S-R Matrix to Updated 1990 National Particulate Emissions Inventory

As described in section 4.3, version 3 of the NPI is used as the base year 1990 inventory. This recent emissions inventory update concluded after completion of Phase II CRDM modeling. In order to account for this emission inventory refinement as well as the fugitive dust adjustment as discussed above, the Phase II S-R matrix next is applied to the revised PM emissions inventory to predict 1990 PM air quality concentrations.

4.4.2.5 Normalization of S-R Matrix for Annual Estimates of PM_{10} and $PM_{2.5}$

The resulting 1990 annual PM_{10} and $PM_{2.5}$ values are compared and calibrated to monitored annual PM_{10} and $PM_{2.5}$ concentrations. All predictions are normalized regardless of overprediction or underprediction relative to monitored values. This is done by application of a "normalization factor", calculated as the monitored value divided by the modeled value. This factor was applied consistently across particle species contributing to the air quality value at a county-level receptor. Calibration is conducted for county-level modeled PM_{10} and $PM_{2.5}$ estimates falling into one of four air quality data tiers. The tiering scheme reflects increasing

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percentage of $PM_{2.5}$ mass for: Central U.S. = 7.8%; Eastern U.S.= 4.5%; Western U.S.= 4.6%. By comparison, without using a multiplicative factor, fugitive dust as a percentage of $PM_{2.5}$ mass for: Central U.S. = 44.6%; Eastern U.S. = 30.9%; Western U.S. = 31.5%. As discussed previously, the overestimation of fugitive dust emissions from farming operations could easily account for the increased fugitive dust contribution in the Central U.S., where farming operations are concentrated.

relaxation of data completeness criteria and therefore increasing uncertainty for the annual design value (U.S. EPA, 1997k). Tier 1 monitored counties cover the 504 counties with at least 50% data completeness and therefore have the highest level of certainty associated with the annual design value. Tier 2 monitored counties cover 100 additional counties with at least one data point (i.e., one 24-hour value) for each of the three years during the period 1993 -1995. Tier 3 monitored counties cover 107 additional counties with missing monitoring data for one or two of the three years 1993 - 1995. In total, Tiers 1, 2 and 3 cover 711 counties currently monitored for PM_{10} in the 48 contiguous states.[a] Tier 4 covers the remaining 2369 nonmonitored counties. Normalization factors are calculated and applied to the respective counties for Tiers 1 through 3. Tier 4 nonmonitored counties are calibrated using the appropriate regional normalization factor calculated as the average of Tier 1 normalization factors across a given modeling region[b].

The calibration procedure is conducted employing 1993 - 1995 PM_{10} ambient monitoring data from the AIRS database following the air quality tier data completeness parameters discussed above. The PM_{10} data represent the annual average of design value monitors averaged over three years (U.S. EPA, 1996i). The standardization for temperature and pressure was eliminated from this concentration data based upon proposed revisions to the reference method for PM_{10}.[c]

Because there is little $PM_{2.5}$ monitoring data available, a general linear model is developed to predict $PM_{2.5}$ concentrations directly from the 1993 - 1995 PM_{10} values (U.S. EPA, 1996e). A SAS™ general linear model (i.e., GLM) procedure is used to predict $PM_{2.5}$ values (dependent variable) as a function of independent variables for season, region, and measured PM_{10} value.

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a The current PM_{10} monitoring network consists of approximately 1600 individual monitors with a coverage of approximately 711 counties in the 48 contiguous states.

b As presented in Chapter 6, the contiguous 48 states are divided into six modeling regions for the control strategy-cost analysis. See p. 6-5.

c See Proposed Revisions to Appendix J - Reference Method for PM_{10} , Proposed Rule for National Ambient Air Quality Standards for Particulate Matter (Federal Register, Vol. 61, No. 241, p. 65666, December 13, 1996).

These derived $PM_{2.5}$ data are used to calibrate model predictions of annual average $PM_{2.5}$. Given the $PM_{2.5}$ annual standard alternatives allow for spatial averaging, model-predicted annual average $PM_{2.5}$ air quality data are calibrated to the spatially-averaged annual $PM_{2.5}$ value[a] from the derived $PM_{2.5}$ dataset. Additionally, the proposed form of the standard allows for averaging over three years of air quality data. These derived, annual $PM_{2.5}$ data represent the annual average value over a three-year period. These $PM_{2.5}$ concentrations also reflect the elimination of the temperature and pressure standardization, given that they are developed from the previously discussed PM_{10} dataset.

4.4.2.6 Application of Calibrated Phase II S-R Matrix to 2010 CAA Control Emissions

The calibrated Phase II S-R matrix is next applied to the 2010 CAA control emissions to predict baseline PM annual air quality at the county level. This baseline air quality reflects the fugitive dust emissions adjustment of 0.25.

4.4.2.7 Peak-to-mean Ratios for Calculating 24-hour Average Concentration Value

Since the CRDM predicts only annual average PM_{10} and $PM_{2.5}$ concentrations, peak-to-mean ratios are employed to derive these values. For each annual PM concentration for the Tier 1 through 3 monitored counties, three sets of peak-to-mean ratios are used to predict 24-hour peak PM_{10} and $PM_{2.5}$ concentrations reflective of the forms of the alternatives being analyzed.[b] The first peak-to-mean ratio is the three-year average 4th highest 24-hour maximum PM_{10} value to the annual arithmetic mean PM_{10} value. This ratio is applied to the modeled annual average PM_{10} value to predict the 4th highest daily maximum PM_{10} value, the form of the current PM_{10} daily standard. The ratio of annual mean PM_{10} to 99th percentile 24-hour PM_{10} is used to predict

a County-level spatial averaging is used for this analysis.

b Used 1993 - 1995 AIRS monitoring data following air quality data tiering scheme discussed in section 4.3.2.4.

the three-year average 99th percentile PM_{10} value (i.e., form of the selected PM_{10} standard) from the annual mean PM_{10}. The $PM_{2.5}$ peak-to-mean ratio is calculated as the three-year average 98th percentile 24-hour peak $PM_{2.5}$ value to the spatially averaged annual arithmetic mean $PM_{2.5}$ value. This ratio is applied to the annual mean $PM_{2.5}$ value to predict the three-year average 98th percentile 24-hour peak $PM_{2.5}$ value (U.S. EPA, 1996e).

4.4.3 PM Nonattainment Counties by Alternative

The model-predicted PM_{10} and $PM_{2.5}$ air quality data for the 2010 CAA-control baseline is used to determine county air quality status. The rounding convention proposed for the PM NAAQS is used in the identification of counties predicted to have PM levels in 2010 greater than the standards examined.[a] Table 4.9 presents estimates of PM nonattainment counties by region. These results also reflect application of the 0.25 fugitive dust adjustment factor as discussed in Section 4.4.2.3. For the main analysis, nonattainment counties are identified from the Tier 1 set of 504 counties monitored during 1993 - 1995 for reasons discussed in Section 4.2 and because there is relatively more certainty associated with predicted air quality in these counties. Predicted PM concentrations are the most certain for the Tier 1 counties since the estimates are calibrated using 50% complete AIRS data as described in Section 4.4.2.5. This set represents approximately 70% of the counties within the 48 contiguous states monitored for PM_{10} during 1993 -1995, covering approximately 150 million people.

A sensitivity analysis is conducted for the 15/50 alternative to examine the extent of PM nonattainment when the Tier 1 county scope assumption is relaxed. In this sensitivity assessment, the set of counties from which nonattainment counties is identified is extended to include Tiers 2 and 3. This assumption increases monitored county coverage to all 711 counties monitored for PM_{10} in the contiguous 48 states during 1993 - 1995. It should be noted that the

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a Rounding convention: $PM_{2.5}$ annual standard - rounded to the nearest 0.1; $PM_{2.5}$ daily standard - rounded to the nearest 1; PM_{10} annual - rounded to the nearest 1; PM_{10} daily - rounded to the nearest 10.

Tier 2 and 3 air quality estimates are less certain relative to Tier 1 estimates. The number of estimated nonattainment counties increases by 10 counties for the current PM_{10} standard (total of 53) and by 23 for the proposed $PM_{2.5}$ standard (15/50) (total of 108). Appendix D presents the detailed results of this sensitivity analysis.

A sensitivity analysis also is conducted for the 15/50 alternative to examine the extent of PM nonattainment when the 0.10 fugitive dust adjustment factor is employed. By reducing fugitive dust emissions by 90%, the number of initial nonattainment counties decreases by 11 counties for the proposed $PM_{2.5}$ standard (15/50) and stays the same for the current PM_{10} standard. The 0.10 adjustment factor has implications for cost and residual nonattainment as discussed in Appendix D.

4.4.4 Uncertainties in PM Air Quality Modeling

The methodology used to project PM concentrations in 2010 from 1990 emissions and ambient concentration data introduces several sources of uncertainty to the control strategy-cost and benefits analyses. Table 4.6 presents potential sources of uncertainty and associated biases in estimating 2010 initial PM nonattainment counties. "Positive bias" indicates that estimated 2010 nonattainment counties may be overestimated; "negative bias" indicates that estimated 2010 nonattainment counties may be underestimated; "bias unclear" indicates that the direction of impact from a given potential source of uncertainty on 2010 nonattainment counties is unknown. The level of uncertainty associated with a particular input variable to the air quality projection procedure has been quantified to the extent possible based on information from published literature or internal EPA studies.

Because 1990 emissions are an input to the CRDM model, the uncertainties associated with the emissions inventory are carried through to the PM air quality modeling. As discussed in section 4.3.3, apart from the fugitive dust and biogenic VOC and SOA categories, emissions of primary PM and PM precursors are uncertain although with no known bias. Fugitive dust PM emissions appear to be overestimated by 40% for PM_{10} and 73% for $PM_{2.5}$ relative to the more recent National Emissions Trends Inventory. The biogenic VOC emissions are underestimated relative to the more recent BEIS2 estimates. Finally, the methodology used to estimate SOA formation from reactive VOCs may overestimate SOA emissions and therefore ambient concentrations of SOA.

There is uncertainty associated with the 1993 - 1995 monitored annual average and 24-hour PM_{10} concentration values that are used to calibrate the ambient concentrations generated by the CRDM at the county-level receptors. These monitoring values are taken from the AIRS data base, which has a performance requirement of 5 $\mu g/m^3$ for concentrations less than 80 $\mu g/m^3$ and $\pm$ 7 percent for concentrations greater than 80 $\mu g/m^3$. However, a comparison of AIRS data obtained from side-by-side samplers of the same and different types indicated measurement differences ranging from 10 to 14 percent for like samplers to 16 to 26 percent for dissimilar samplers (U.S. EPA, 1996k). However, there is no known bias associated with these values.

Since the $PM_{2.5}$ data are derived from monitored PM_{10} concentrations, they too have associated uncertainty due to instrument measurement error, as described above. Additionally, and more importantly, the $PM_{2.5}$ values are predicted from a regression model (U.S. EPA, 1996e), and therefore are subject to uncertainty associated with this model. Subsequent reanalysis of the model has shown that there is no systematic bias to the $PM_{2.5}$ estimates (U.S. EPA, 1997i).

Table 4.9 Predicted Counties in Initial Nonattainment of PM Standards in 2010 Using 0.25 Fugitive Dust Adjustment Factor (Tier 1 counties only)

Region[a]	Total Tier 1 Counties in Region[b]	Number of Counties Predicted in Initial Nonattainment of PM Alternative				
		PM_{10} 50/150 - 1Ex) (current)	PM_{10}[c] 50/150-99th (selected)	$PM_{2.5}$[d] 16/65-98th	$PM_{2.5}$[4] 15/65-98th (selected)	$PM_{2.5}$[4] 15/50-98th (proposal)
Midwest/Northeast	218	6	2	38	56	58
Southeast	86	1	0	8	16	16
South Central	59	4	1	5	7	8
Rocky Mountain	64	12	1	8	11	18
West	49	15	6	11	12	16
Northwest	28	7	1	0	0	6
Total Counties in Nonattainment		45	11	70	102	122

a See map on p. 6-5 for delineation of control strategy modeling regions.

b Total number of monitored counties modeled in analysis = 504

c This alternative is analyzed incremental to 2010 baseline (i.e., prioit to application of the National PM Strategy).

d These alternatives are analyzed incremental to the current PM_{10} standard and are assessed prior to application of the National PM Strategy.

The CRDM used to generate a matrix of S-R transfer coefficients employs a large number of input variables in its calculations, including meteorological data (i.e., wind speed, wind velocity, and stability conditions). While there have been no studies of uncertainty associated with CRDM output, Freeman *et al.* (1986) used error propagation and Monte Carlo simulation to study the uncertainty of short range concentration estimates calculated by a similar model, EPA's ISCST Gaussian dispersion model for a single point source. Freeman *et al.* found that for relatively low values of uncertainty assigned to input values (1 to 10 percent), the uncertainty of the concentration at distances from 3 to 15 kilometers downwind of a source averaged 16 percent. When input data uncertainties were increased by a factor of 4, however, the output uncertainty ranged from about 75 - 160 percent.

Despite application of the fugitive dust adjustment factor, comparisons of modeled PM predictions to ambient data indicate that the CRDM overpredicts the contribution of fugitive dust to total $PM_{2.5}$ mass. CRDM may overestimate or underestimate other fine particle species when evaluating county-level model predictions relative to $PM_{2.5}$ ambient data. For example, in some PM residual nonattainment counties, the predicted biogenic organic contribution to $PM_{2.5}$ mass appears to be overestimated relative to speciated monitoring data. However, at the national level, there appears to be no systematic bias to the modeled air quality predictions for the non-fugitive dust particle species.

The uncertainties and biases in the 1990 modeled predictions combined with uncertainites in 2010 emission projections bring about similar uncertainties and biases in the 2010 PM air quality predictions.

Although the CRDM S-R matrix serves as a useful tool in the design of cost-effective PM control strategies, the modeling approach does not reflect application of state-of-the-art techniques. Many of the physical and chemical formulations in the CRDM are crude representations of actual mixing and reaction phenomena required to address aerosol formation, transport and removal phenomena. Where available, more scientifically credible Regional Acid Deposition Model (RADM) results are used to complement the CRDM results. However, even with the anticipated delivery of more comprehensive modeling techniques, the scarcity of speciated ambient data in both urban and rural environments to evaluate model behavior will continue to compromise the certainty of model-derived conclusions.

As indicated in the sensitivity analysis in Section 4.4.3, the Tier 1 geographic scope assumption underestimates to a small degree the number of predicted PM nonattainment areas relative to identifying potential nonattainment areas from across Tiers 1, 2 and 3 counties.

Table 4.6 Uncertainties and Possible Biases in Estimating 2010 Nonattainment Counties

Potential Source of Uncertainty	Positive Bias? (Overestimate)	Negative Bias? (Underestimate)	Bias Unclear
Base Year 1990			
- 1990 emissions	✓ (fugitive dust, SOA)	✓(total biogenic VOC and SOA)	✓ (other emissions)
- 1993 - 1995 PM10 ambient data			✓
- 1993 - 1995 PM2.5 derived data			✓
- CRDM 1990 adjusted S-R matrix	✓ (fugitive dust)		✓ (other emissions)
Projection Year 2010			
- Uncertainties from 1990 adjusted S-R matrix	✓ (fugitive dust)		✓
- 2010 emissions projections	✓ (fugitive dust, SOA)	✓ (total biogenic VOC and SOA)	✓ (other emissions)
- 2010 air quality predictions	✓ (fugitive dust)		✓ (other particle species)
2010 Nonattainment Counties			
- Tier 1 geogphraphic scope assumption		✓ (small)	

4.5 ESTIMATION OF BASELINE OZONE AIR QUALITY CONCENTRATIONS IN 2010

The methodology for estimating baseline ozone air quality concentrations for this assessment builds upon previous work conducted for the December 1996 Ozone NAAQS RIA (U.S. EPA, 1996g). Monitoring data for 1990 and ROM 2007 air quality estimates are used to develop 2010 baseline air quality and identify potential nonattainment areas of alternative ozone standards. Updates to data inputs and methodological refinements have been incorporated where feasible. Major updates and refinements to the December 1996 ozone air quality analysis are listed below.

- A more informed picture of the future ozone nonattainment situation is provided based on comparison of model-predicted nonattainment with:
  - 1993 - 1995 monitored air quality data;
  - Air quality modeling from comparable emission reduction scenarios using ROM and Urban Airshed Model-Variable scale (UAM-V);
  - State Implementation Plan air quality modeling information;
- Model-predicted nonattainment counties are based on counties having ozone monitors in 1990;
- The concept of marginal nonattainment areas is eliminated;
- The concept of downwind transport areas is incorporated into the baseline ozone nonattainment area analysis.

4.5.1 Overview of Development of 2010 Baseline Ozone Air Quality

To assess national annual costs and benefits of alternative ozone standards in the absence of temporally and spatially comprehensive air quality modeling tools is a challenging task. Most ozone air quality models are run to examine peak ozone concentrations for specific ozone episodes. Rarely are models run for an entire ozone season. Additionally, available ozone air quality modeling is limited in its geographic scope. The Eastern U.S. is covered by regional-scale models such as the ROM or the UAM-V; however, geographic coverage of available models outside of the Eastern U.S. is limited. Therefore, the development of baseline ozone air quality data relies upon a full year of ozone monitoring data and available seasonal air quality modeling results to create a national picture of ozone air quality concentrations across a full year.

Figure 4.4 illustrates the steps followed to develop 2010 baseline air quality. ROM air quality modeling information for 2007 is used in combination with 1990 historical ozone air quality monitoring data to develop 2007 ozone air quality for the 48 contiguous states. The 2007 predicted air quality is then adjusted to account for 2010 emissions inventory differences and additional ozone modeling and monitoring information (i.e., 1993 - 1995 AIRS monitoring data, ROM and UAM-V air quality modeling data) to yield 2010 baseline ozone air quality data. Because this future air quality is based on counties with monitoring data in 1990, the centroid model is used to develop air quality for nonmonitored counties through geographic interpolatation. This data is input to the benefits analysis. The 2010 baseline ozone air quality data for monitored counties is used to identify ozone nonattainment areas. This information is input to the control strategy and cost analysis. The following sections describe in more detail the various components of the analysis as illustrated in Figure 4.4.

4.5.2 Elements of Ozone Air Quality Modeling

4.5.2.1 <u>2007 ROM Air Quality Modeling</u>

A series of ROM analyses are conducted for the ozone NAAQS proposal to serve as rough planning tools for the development of policies to implement a new ozone NAAQS as well as for estimation of costs and benefits. Covering the eastern 37 states, ROM air quality modeling results are available for the following scenarios: (1) 1990 basecase; (2) 2007 CAA-mandated control; (3) NOx and VOC across-the-board reductions (i.e., matrix runs) from this 2007 CAA scenario; and (4) 2007 regional control strategy (U.S. EPA, 1996b). Because of the limited geographic scope of the ROM modeling domain and the need for ozone air quality predictions for the entire continental U.S. in order to assess national costs and benefits of alternative ozone standards, a methodology is developed to extrapolate ROM predictions to all counties in the U.S.

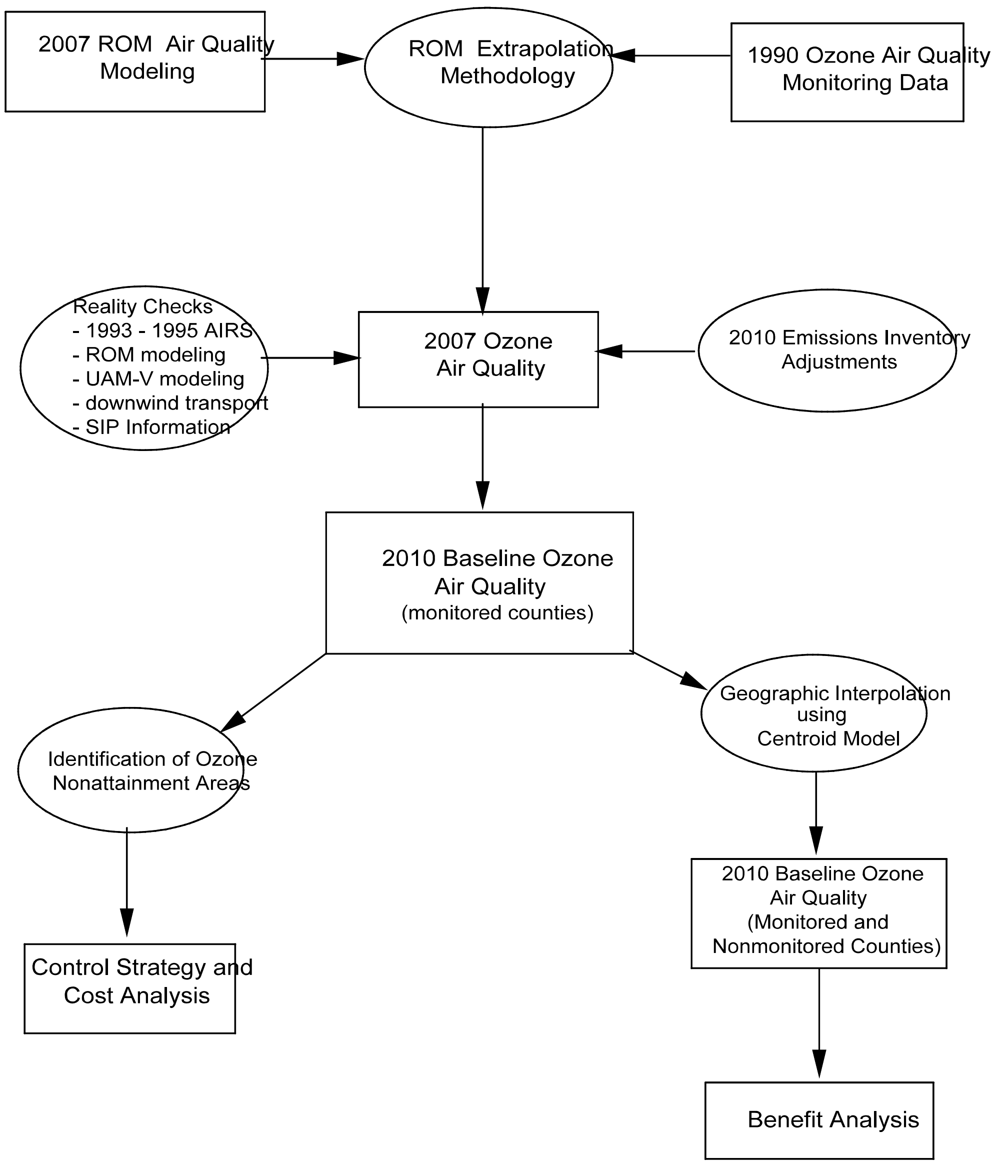
Given the limited availability of meteorological data for input to the air quality model, the ROM simulations selected 1987 meteorological conditions to predict hourly ozone concentrations for the June through August period. It is desirable to employ for air quality modeling purposes meteorological data that are representative of typical ozone-forming conditions. According to a method discussed by Cox and Chu (1996), 1987 is not a particularly severe year in the Northeast nor in the Gulf regions. In the South and the Midwest, 1987 does stand out as a rather conducive year for high ozone, though not as severe as 1988. When viewed in the context of the 10 year period 1986 - 1995, overall the year 1987 is not an unusually conducive year for high ozone across the Eastern U.S. Thus, 1987 is considered a representative meteorological year for ROM modeling purposes.

4.5.2.2 <u>Development of 1990 Ozone Air Quality Data</u>

A dataset of empirical ozone concentration data was developed from AIRS. Hourly ozone concentration values meeting data inclusion criteria are obtained for the year 1990 for the contiguous 48 states. Given that the baseline emissions inventory from which 2007 emissions projections were made and the basecase ROM modeling both used 1990 emissions, the year 1990 was selected as a representative baseline year for ambient air quality. This 1990 air quality data set was corrected for duplicate monitor site records, obsolescence of monitor data and missing values (MathTech, 1997).

Although the form of the proposed standard is expressed as the average 3rd max concentration over a three year period and this analysis uses only one year of ozone monitoring data, an examination of the data shows that at the national level, 1990 compares well with the 1993 - 1995 period. An evaluation of 1990 annual 3rd max 8-hour design values relative to 1993 - 1995 average 3rd max design values was conducted. This assessment indicates that across the U.S. the difference between the 1990 annual 3rd maximum concentrations and the 1993-1995 average annual 3rd maximum concentrations is less than or equal to 0.015 ppm 90 percent of the time (U.S. EPA, 1997e). In spite of area-specific differences in 8-hour 3rd maximum values between 1990 and 1993-1995, ozone air quality data for the year 1990 is considered to be comparable at the national level to 8-hour average 3rd max design values for 1993-1995.

Figure 4.4. Development of 2010 Baseline Ozone Air Quality



4.5.2.3 <u>Temporal Extrapolation of 1990 Monitored Air Quality to 2007/2010 based on Regional Oxidant Model Results</u>

This analysis next develops equations to predict expected ozone concentration values for the year 2007 for monitored counties based on available air quality modeling conducted under alternative future year emissions assumptions. The temporal extrapolations lead to future year baseline ozone concentrations that incorporate anticipated air quality improvements due to implementation of current CAA requirements. The 2007 air quality predictions for monitored counties are used to identify and define nonattainment areas for the control strategy and cost analysis. The year 2007 was used as the year of analysis for the December 1996 assessment (U.S. EPA, 1996g). The current analysis examines the ozone nonattainment situation in the year 2010. Adjustments are made to the 2007 nonattainment area air quality to account for the different analytical year. The adjustment methodology is discussed at the end of this section.

ROM ozone air quality predictions for the 1990 basecase, 2007 CAA-mandated control, and 2007 regional control strategy scenarios are used in two regression equations to determine the statistical relationships between 1990 and 2007 ozone air quality concentrations under two alternative emission scenarios. The first emissions scenario, the 2007 CAA control scenario, simulates the net effects of growth and application of control measures currently required by the CAA on ozone concentrations in 2007 throughout the modeling domain. The second scenario, the 2007 regional control strategy, augments the CAA control scenario with application of a NOx cap limiting emissions from utility boilers and other boilers $\geq$ 250 MW to 0.15 lb/MMBtu and initiation of a national low emission vehicle (NLEV) requirement beginning with the 1999 model year to the entire modeling domain. It should be noted that biogenic VOC emissions are modeled for all scenarios as an uncontrollable component of VOC emissions. Thus, biogenic VOCs are factored into the responsiveness of simulated ozone concentrations to changes in anthropogenic ozone precursors.

The equations used to predict average expected changes in ozone concentrations between 1990 and 2007 are generated through Ordinary Least Squares (OLS) regression of 1990 ROM basecase ozone concentration predictions and a number of explanatory variables against 2007 ROM predictions for the two emissions scenarios (MathTech, 1997). As noted earlier, ROM air quality results are available for the Eastern U.S. However, air quality concentrations are needed for the entire country to assess national benefits and costs. Through the inclusion of other explanatory variables, the regression equations control for factors that may differ between the east and west and could therefore explain variations in concentration values between 1990 and 2007. The specifics of these regression equations are outlined in Appendix A.5.

The results for the CAA-control scenario indicate that, all else equal, 2007 hourly ozone concentrations can be expected to decrease relative to 1990 hourly ozone concentrations. The results for the regional control strategy scenario suggest that, all else equal, 2007 hourly ozone concentrations also can be expected to decrease relative to 1990 hourly ozone concentrations. Evaluating the mean 1-hour ozone concentration in the regression function indicates that the regional control strategy results in a 7% decrease in mean hourly ozone concentrations relative to 1990 mean air quality concentrations. In comparison, the CAA-control scenario results in a 3% decrease in mean hourly ozone concentrations relative to the 1990 modeled predictions (MathTech, 1997).

The regression analyses show that the projected concentration values for 2007 are primarily affected by 1990 concentration values. Given that the goal of this method is to create a dataset of predicted hourly ozone data for each monitor in 2007, the results of the regression analysis are next applied to each monitor by multiplying each hourly 1990 monitored value by the appropriate coefficient. Adjustments are made at the county level by computing the quantitative impacts of the remaining terms in the regression equation. For the East, the results under the 2007 regional control strategy are applied given that the NOx cap and NLEV are assumed to be in place by 2010 in the emissions baseline for the current analysis. For the Western U.S., the results of the regression analysis for the 2007 CAA-control scenario are applied since a comparable NOx cap is not assumed in the 2010 emissions baseline for these areas. The NOx cap constitutes the bulk of the NOx emissions under the regional control scenario as the NLEV program in the Eastern 37 states is assumed to be fully implemented sometime beyond 2010. Thus application of the 2007 CAA-control case for the West is more appropriate.

4.5.2.4 Identification of Ozone Nonattainment Areas

The predicted 2007 air quality for counties with ozone monitoring data in 1990 is next used to determine nonattainment status of individual counties. The air quality distribution for each monitored county is reviewed to identify the concentration value that triggers nonattainment for a specific form of the ozone standard. For example, the 3rd highest daily maximum 8-hour value is identified to determine whether that value exceeds an alternative standard level. This value for each monitor is defined as the “standard measure” for that monitor and standard. The highest standard measure for each standard alternative among the monitors in a given county is used as the county “design value”. The design value location (i.e., monitor) may vary from one standard alternative to another in a given county. The design value for each county is evaluated against the concentration level triggering nonattainment to identify counties that do not meet each standard alternative. The rounding convention associated with the proposed ozone standard is factored into the concentration level triggering noncompliance for each standard alternative.[a]

A series of steps are then followed to define nonattainment areas for each standard alternative based on the county design value. Nonattainment areas may be a single county or a group of counties in a Consolidated Metropolitan Statistical Area or Metropolitan Statistical Area (C/MSA). The general principle used here in identification of nonattainment areas is that if the air quality of an area violates the ozone standard or if sources in that area contribute to violations in a nearby area, the area is considered nonattainment. This is not to prejudge how States may make future decisions in implementing the new standards. Ozone monitors generally are placed in areas with a high probability of recording standard violations, typically in counties

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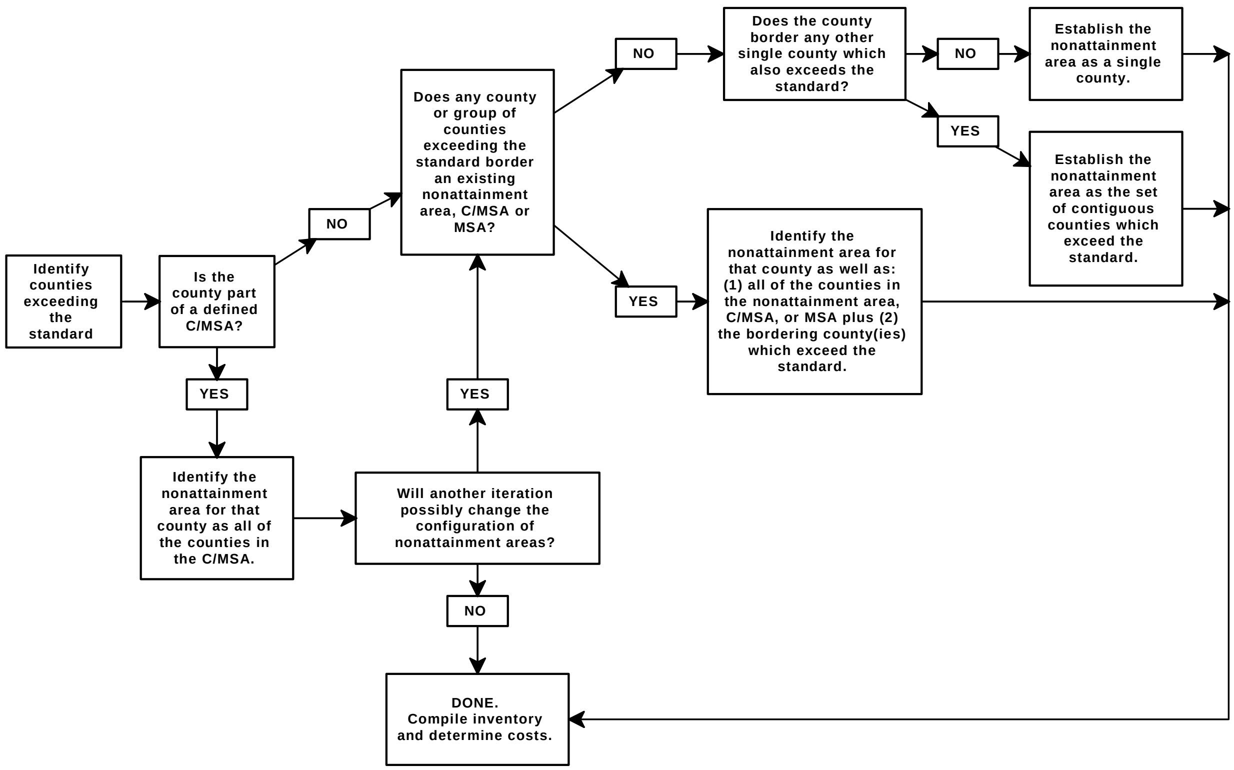
a The Federal Register Notice for the proposed ozone NAAQS (FR Vol. 61, No. 241, December 13, 1996) states that the rounding convention associated with the proposed standard is to round to the nearest 0.001 ppm. The current rounding convention is to round up digits equal to or greater than 5.

downwind of urban areas. Therefore, when these counties record violations of the standard, the upwind area(s) contributing the emissions should be included in the nonattainment area definition. The following schematic in Figure 4.5 describes the decision rules used to identify and define nonattainment areas (U.S. EPA, 1997d).

Figure 4.5 Process for Identification and Definition of Ozone Nonattainment Areas



4.5.2.5 Adjustments to 2007 Ozone Air Quality to Develop 2010 Air Quality

2010 Emissions Inventory Adjustments

As noted previously, the current analysis examines ozone air quality concentrations in the year 2010 assuming implementation of CAA-mandated controls and a regional control strategy in the East and CAA-mandated controls in the West. Because new air quality modeling is not conducted for this alternative analytical year, a method is developed to adjust 2007 baseline air quality in Eastern nonattainment areas to reflect changes in emissions between 2007 and 2010.

This adjustment is performed by comparing the 2010 NOx and VOC emissions for each nonattainment area to the 2007 ROM-predicted NOx and VOC emission reduction targets (U.S. EPA, 1997f) needed for attainment of the most stringent ozone alternative considered in the analysis, the .08 ppm/8 hour/3rd max concentration. The change in VOC and/NOx emissions between 2007 and 2010 are counted towards achievement of the VOC and NOx emission reduction targets for the .08 ppm/8 hour/3rd max estimated for a given area as described below (U.S. EPA, 1997g):

$$\text{Air Quality Adjustment} = \frac{(NOx_{2007} - NOx_{2010}) + (VOC_{2007} - VOC_{2010})}{\text{NOx emission reduction target}_{2007} + \text{VOC emission reduction target}_{2007}}$$

where:

NOx_{2007} = NOx emissions in 2007 (tpd)

NOx_{2010} = NOx emissions in 2010 (tpd)

VOC_{2007} = VOC emissions in 2007 (tpd)

VOC_{2010} = VOC emissions in 2010 (tpd)

NOx/VOC emission reduction target = amount of NOx or VOC that needs to be reduced to achieve attainment in 2007 (tpd)

The air quality adjustment is then applied to the nonattainment area design value monitor for the 0.08 ppm/8 hour/3rd max alternative to determine the percent rollback to be applied at all monitors in the nonattainment area. This alternative is used because it is the most stringent of the ozone alternatives analyzed and adjustment to air quality for this alternative only preserves a consistent air quality distribution across all alternatives.

Once the necessary baseline air quality adjustments have been made to capture nonattainment area emission inventory differences between 2007 and 2010, the development of air quality values in monitored counties for 2010 is complete. Thus, for the remaining discussion, the baseline air quality is referred to as 2010 baseline ozone air quality. This adjusted air quality is used to evaluate for a second time nonattainment status of monitored counties.

Additional Information Applied to 2010 Baseline Ozone Air Quality

Given uncertainties in the method for predicting future year ozone concentrations, additional ozone air quality monitoring and modeling information is utilized to better characterize the 2010 ozone nonattainment picture.

1993 - 1995 Ambient Ozone Air Quality Monitoring Data

Ozone design values based on 1993 - 1995 AIRS data corresponding to the appropriate standard form are compared to the model-predicted design values. Those areas for which the 1993 - 1995 ozone design value is less than or equal to the level specified in the standard alternative are considered attainment for that alternative (U.S. EPA, 1997g). It is assumed for these areas that CAA-mandated controls will be sufficient to attain the specific standard alternative. There are three areas excluded from the current standard analyses based on this comparison. There are no areas excluded for the selected standard (0.08/4th max) analysis based on this comparison.

ROM and UAM-V Air Quality Modeling Results

Air quality modeling results for comparable emission reduction scenarios from ROM and UAM-V modeling for the Ozone Transport Assessment Group (OTAG) are also examined (U.S. EPA, 1997g). Those areas for which air quality modeling predicts will be in attainment of alternative standards in 2007 are considered attainment for this analysis based on this comparison. There are three areas excluded from the current standard analysis and 4 areas excluded from the selected standard (0.08/4th max) analysis based on this comparison.

Downwind Nonattainment Areas Identified through Air Quality Modeling

A number of small, individual counties are predicted to violate alternative standards in 2010. Upon closer inspection and examination of available ROM air quality results, these counties are determined to be downwind transport areas. Many of these counties are rural counties that have low NOx and VOC emissions. The predicted violations are a result of upwind contributions of ozone precursor emissions. Thus for control strategy and cost analysis purposes, control measures are not applied in these counties as it is assumed that upwind NOx and VOC reductions will mitigate the ozone problem in these downwind areas. For the benefit analysis, these downwind transport areas are assumed to be "attached" to the associated upwind nonattainment area. Thus, when calculating partial attainment air quality, air quality rollbacks for the upwind nonattainment area are applied to the downwind transport area in order to capture the air quality impacts of the upwind controls (U.S. EPA, 1997f).

4.5.3 Ozone Nonattainment Areas by Alternative

The model-predicted ozone air quality data for the 2010 CAA-control baseline is used to determine county air quality status. Nonattainment areas are identified from the set of counties monitored for ozone in 1990 as described in Section 4.5.2.4. Areas predicted to be in initial nonattainment of alternative ozone standards in 2010 for the East (i.e., 37 eastern States) versus the West are listed in Table 4.11. These are projections based on estimates and assumptions. Ultimate nonattainment area designations will be based on actual ambient monitoring data.

Table 4.11 Predicted Nonattainment Areas for Alternative Ozone Standards in 2010

Region	Number of Areas Predicted in Nonattainment of Ozone Alternatives			
	0.12ppm/1xx (current)	0.08ppm/3rd max (proposed)	0.08/4th max (selected)	0.08/5th max
East	5	20	12	8
West	4	8	7	7
TOTAL	**9**	**28**	**19**	**15**

4.5.4 Geographic Interpolation of Baseline Ozone Air Quality Using the Centroid Model for Ozone Standard Benefit Analysis

In order to assess national ozone benefits of implementation of alternative ozone standards, hourly ozone concentrations across the entire country are required. Because there are counties both within and outside of nonattainment areas for which no monitoring data exists, the centroid model is used to predict hourly ozone air quality concentrations in those nonmonitored counties. Additionally, given that some counties may have more than one monitor, the centroid approach can be used to assign a single hourly value to the monitored county centroid for each hour throughout the year. The centroid model is an interpolation method which permits data from monitors proximate to a county centroid to be interpolated to the centroid location (MathTech, 1997). This analysis uses the geographic centroid available from the Bureau of the Census (BOC, 1992) rather than the population centroid. "Proxy" monitors are assumed to be located at each geographic county centroid throughout the U.S. The centroid model is used to calculate hourly ozone concentrations for each of the "proxy" monitors for 2010.

4.5.5 Key Uncertainties Associated with 2010 Baseline Ozone Air Quality

There are many potential sources of uncertainty in the development of 2010 baseline ozone air quality. Although it is not possible to quantify the magnitude of the uncertainty, a qualitative discussion of uncertainties can be provided. In general, we believe that the national baseline ozone air quality results on net are not biased in either direction. Underestimates for individual nonattainment areas are balanced out by overestimates for other nonattainment areas. Given that the methodologies used in the assessment of national costs and benefits are not sufficient to capture unique characteristics of each individual nonattainment area, area-specific baseline air quality results have a higher probability of bias (U.S. EPA, 1997l).

Table 4.12 presents potential sources of uncertainty and associated biases in estimating national 2010 baseline air quality. As described in Sections 4.3.3 and 4.3.8, there are uncertainties related to development of the 1990 emissions inventory and projection of those emissions to 2010. Biogenic VOCs may be underestimated relative to the more recent BEIS2 estimates, but potential biases in anthropogenic NOx and VOC emissions are unknown.

The emissions projections are input to the ROM model to produce future year ozone air quality predictions. The ROM is a regional-scale air quality model that is used in this analysis to estimate area-specific air quality. By definition, urban-scale characteristics of individual nonattainment areas are not captured in the ROM modeling. This approach increases the level of uncertainty in the national analysis and may produce positive or negative bias for any specific area. However, it is unclear if there is an overall bias in air quality at the national level.

Additionally, the ROM modeling relied on 1987 meteorology. Despite geographic variability in the severity of the meteorological data, overall, 1987 is not an unusually conducive year for high ozone for the period 1986 - 1995. Although there is uncertainty in predicting future meteorological conditions, reliance on 1987 data is not believed to bias the ozone air quality estimates. Finally, evaluation of ROM modeling has indicated that ROM 1990 base case predictions are higher relative to ozone monitoring data for some locations (U.S. EPA, 1996b). However, it is unknown whether or not ROM overpredicts for the future year scenarios. Because the prediction of future year air quality through the ROM extrapolation approach is primarily driven by the 1990 ozone concentration values, it is unclear if 2010 baseline ozone air quality is biased given ROM overprediction in the 1990 base case.

There are a number of potential sources of uncertainty associated with the ROM extrapolation methodology. As discussed previously, the extrapolation method is used to develop air quality data for areas not covered by available air quality modeling. The extrapolation method employs one year of data for the year 1990. As discussed in section 4.5.2.2, there appear to be no biases introduced to the ozone analysis from these two potential sources of uncertainty.   There is no reason to believe that the regression equation used to factor in growth and emissions control between the base case and projection years is biased (MathTech, 1997). Because of the lack of air quality modeling, extrapolation of air quality modeling results from the East to the West is necessary. This clearly brings uncertainty to the baseline ozone air quality concentrations for the West, although as discussed in Section 4.5.2.3, this method is largely driven by base case 1990 ambient monitoring values. It is unclear if there is any bias to this extrapolation procedure.

An air quality adjustment procedure is used to to account for CAA-control emissions inventory changes between 2007 and 2010. For the most part, emissions are projected to decrease between 2007 and 2010. It is therefore reasonable to assume that air quality would improve as a result of these reductions. Because it is not possible to account for the air quality impacts of these changes outside of the nonattainment area, there may be a small overestimate in baseline air quality. Similary, the centroid model used to predict ozone concentrations in nonmonitored counties cannot fully account for ozone transport from nonattainment areas to downwind areas. The centroid model employs geographic interpolation between ozone concentration values in monitored counties to derive ozone concentrations in nonmonitored counties. The centroid model is not an air quality model and therefore any transport impacts from emission changes between 2007 and 2010 cannot be assessed. Thus there may be a small overestimate of ozone air quality in nonmonitored counties outside of nonattainment areas.

Table 4.12 Uncertainties and Possible Biases in Estimating National 2010 Baseline Ozone Air Quality

Potential Source of Uncertainty	Positive Bias? (Overestimate)	Negative Bias? (Underestimate)	Bias Unclear
Development of 1990 emissions inventories and 2010 projections		✓ (biogenic VOC)	✓
ROM Modeling - Use 1987 meteorology - Use of regional model to estimate city- specific air quality - ROM tendency to overpredict			 ✓ ✓ ✓
ROM Extrapolation Methodology - Use 1 year of monitoring data - Use 1990 monitored air quality data - Regression - ROM extrapolation from East to West			 ✓ ✓ ✓ ✓
Emissions Inventory Adjustments	✓ (small)		
Centroid Model to predict ozone concentrations in nonmonitored counties	✓ (small)		

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5.0 CONTROL MEASURES

5.1 INTRODUCTION

This chapter briefly discusses the control measures for ozone, particulate matter (PM_{10} and $PM_{2.5}$), and regional haze employed in this regulatory impact analysis (RIA). The Environmental Protection Agency (EPA) has attempted to identify and develop impact estimates for control measures covering emission sources in nearly every source category that contribute to PM and ozone formation and visibility impairment. These control measures are in addition to the measures described in Chapter 4 as part of the baseline. The measures discussed in the chapter consist primarily of controls already in use, and are intended as illustrative of measures that could be chosen by states or local areas. Generally, the measures involve more conventional control approaches (e.g., "add-on" control devices installed downstream from an air pollution source) that are proven effective at reducing air pollution. Pollution prevention measures such as material substitution, source minimization, and fuel switching are considered to a lesser degree. Several less conventional measures are also included, such as education and advisory programs, sulfur dioxide (SO_2) emissions trading programs for utilities, and transportation control measures designed to slow growth in vehicle miles traveled (VMT). Technologies emerging now, or to be developed in the future, will likely play a key role in attaining the new standards 10 to 15 years in the future. These new technologies may be more cost effective than control measures analzyed in this RIA, but have not been included in the analyses presented in Chapters 6, 7, and 8. Chapter 9 discussess the potential benefits of new technologies and more flexibile implementation strategies.

In this analysis, five major emitting sectors are delineated: 1) utility point sources, 2) non-utility stationary point sources, 3) stationary area sources, 4) on-highway mobile sources, and 5) nonroad mobile sources. For each of these source categories, a variety of control measures for primary PM_{10} and $PM_{2.5}$, $PM_{2.5}$ precursors (SO_2, nitrogen oxides (NOx), volatile organic compounds (VOC)), ozone precursors (VOC, NOx), and regional haze contributors (primary

PM, SO_2, NOx, VOC), have been analyzed[a]. The list of control measures included in this analysis is not exhaustive. Many other control measures may exist, but are not included in this analysis because: 1) the EPA is not able to obtain reliable cost and/or emission reduction estimates; 2) at a specific source, another control measure is identified that achieves equal or greater control efficiency at equal or lower overall cost; or 3) the measure is not currently being implemented for administrative or social reasons.

Appendix B.1 contains a table listing the control measures employed in the PM, regional haze, and ozone emission reduction and cost analyses. This table indicates the emissions source category that is impacted and the national *average annual incremental cost per ton* of reduction associated with the area-specific application of a control measure[b]. For this analysis, all cost and emission reduction estimates for a given control measure are calculated incremental to controls already in place, or incremental to the next less stringent new control measure. As shown in Appendix B.1, several control measures achieve reductions in more than one pollutant. These types of control measures may be especially beneficial in areas that need to address multiple pollution problems (i.e., ozone and $PM_{2.5}$, or $PM_{2.5}$ and regional haze).

The application of some control measures may result in cost savings (i.e., negative average annual incremental cost per ton values). In these cases, the estimated cost savings are due to the recovery of valuable products or switching to technologies with lower long-run operating costs. Where these control measures are selected, the estimated savings is credited. Further, some control measures are assigned a zero incremental cost per ton. These measures involve either a long-run transition to a substitute technology with equivalent capital and operating costs, or behavioral change-inducing public information programs for which cost information could not

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a Controls for ammonia emissions were not included because: 1) ammonia emissions are not a particle-limiting pollutant in the formation of $PM_{2.5}$, and 2) ammonia emissions in the National Particulate Inventory used in this analysis are more uncertain than emissions of VOC, NOx, SO_2, and primary PM.

b For purposes of this analysis, *average annual incremental cost per ton* is defined as the *difference* in the annual cost of a control measure and the annual cost of the baseline control (if any), divided by the *difference* in the annual mass of pollutant emissions removed by the control measure and the emissions removed by the baseline control.

be found or easily developed.

Appendix B.2 contains a table listing all control measures included in this analysis, along with a document reference where the reader can find a more detailed discussion of how a specific control measure is developed. The table in Appendix B.2 indicates which control measures have been added or revised since the RIAs for the proposed NAAQS. Of the more than 200 source category-control measure combinations shown, more than half have been added or revised for this RIA.

In developing control efficiency estimates, it is assumed that control measures on average achieve 95 to 100 percent of their intended effect. This differs from EPA's recommended default rule effectiveness assumption of 80 percent. The EPA currently allows States to develop alternate rule effectiveness methods for control measures included in NAAQS implementation plans as long as they follow certain basic requirements as described in the 1992 and 1994 guidelines for rule effectiveness (U.S. EPA, 1992b and 1994). The EPA has routinely accepted plan provisions with 95 to 100 percent control measure effectiveness assumptions.

The degree of effectiveness applied to each measure depends on a variety of factors including the extent of monitoring and recordkeeping requirements, difficulty of control equipment maintenance, extent of over-control achieved by "margin of safety" engineering, and gross noncompliance (PQA, 1997). Generally, stack pollutants like NOx are more easily measured and monitored than, for instance, VOC emissions from fugitive sources. For that reason some NOx control measures may be expected to have a higher control measure effectiveness than some VOC control measures. Also, it may be easier to enforce effectively a handful of point sources than a large number of area sources. For that reason, control measures affecting a small group of point sources may have a higher control measure effectiveness than measures affecting a large group of area sources.

In order to derive county-specific cost and control efficiency estimates for mobile and area source control measures, it is necessary to estimate the degree of *rule penetration*. In this context, rule penetration refers to the percentage of the county-level mobile or area source emissions inventory that is affected by the control measure. As used here, rule penetration effectively accounts for applicability constraints, such as size cut-offs. For example, a penetration rate of more than 90 percent indicates that the control measure applies to nearly every major emitting source within the source category. Conversely, a penetration rate of less than 10 percent indicates that only a few emitting sources may be affected. Rule penetration estimates generally are taken from published reports from state and local agencies.

The final emission reduction factor attributable to mobile and area source control measures is a combination of the estimated control efficiency, control measure effectiveness, and rule penetration. For example, an area source control measure with a 50 percent control efficiency, 95 percent control measure effectiveness, and 60 percent rule penetration rate, results in an emission reduction factor of 28.5 percent (0.5 * 0.95 * 0.6).

5.2 UTILITY POINT SOURCE CONTROL MEASURES

Under the Clean Air Act (CAA), the EPA's primary focus has been further controls on NOx and SO_2. Table 5.1 summarizes the controls in the baseline for the analysis of national ambient air quality standards (NAAQS) revisions. This baseline, which is estimated for the year 2010, assumes that all of the CAA's Title IV requirements are in effect, tighter new source controls are in place than exist in 1997 (based on today's best available control technology (BACT) decisions that have occurred in New Source Review), and a NOx cap-and-trade program has been implemented in the 37 Eastern States in the Ozone Transport Assessment Group (OTAG).

The EPA examined a number of additional NOx and SO_2 control measures for the utility sector. These include more stringent NOx reductions for the utility cap-and-trade program in the OTAG states, and more stringent SO_2 reductions for the nationwide Title IV utility cap-and-trade program. For the analysis presented in Chapters 6 and 7 of this RIA, it was decided not to include any additional NOx reductions for utilities beyond the levels currently required under Title IV and the levels recently recommended by the OTAG states. However, for the purpose of reducing $PM_{2.5}$ formation on a broad geographic scale, the EPA is including in the analysis presented in Chapter 6 of this RIA a cost-effective control strategy that reduces the Title IV SO_2 emissions cap for utilities and large industrial boilers.

Table 5.1 Levels of Federal NOx and SO_2 Controls for Electric Power Generation in the Baseline for the Analysis of NAAQS Revisions

Pollutant	Baseline CAA Requirements for the Analysis of NAAQS Revisions
SO_2	Existing units: Comply with the Acid Rain Allowance Trading Program under Title IV of the 1990 CAA with phased-in requirements. Phase I covers the largest 110 coal-fired power plants beginning in 1995. All other units above 25 megawatts are covered in Phase II beginning in 2000. New units: Comply with the more stringent of New Source Performance Standards (NSPS) set in 1978, BACT/Lowest achievable emission rate (LAER) requirements, and the Acid Rain Allowance Trading Program under Title IV of the CAA 1990.
NOx	Existing units: Application of Reasonably Available Control Technology (RACT) occurred in 1995 in the Ozone Transport Region and all ozone non-attainment areas. Many States filed for and received waivers from RACT requirements. Compliance by coal-fired units with the Title IV NOx requirements that are phased in over time, or RACT, whichever is more stringent. Group 1/Phase I units comply with the Title IV emission limitations in 1996. Group 1/Phase II units and Group 2 units comply with the Title IV requirements in 2000. Collective action of the 37 Eastern States in OTAG leads to further summer season requirements on NOx emissions throughout the eastern US via a cap-and-trade program. New units: Comply with the more stringent of NSPS, BACT, and the Title IV standards for coal-fired units, whichever is more stringent. Units are also covered by the OTAG requirements of a cap-and-trade program.

To meet existing Title IV requirements and the more stringent SO_2 cap modeled for the new NAAQS, the EPA has modeled the following SO_2 control options:

1. Scrubber Installation. New coal-fired units must install scrubbers in accordance with the NSPS, but do have some freedom on how much SO_2 reduction they obtain above the limitations in the NSPS. Existing units can install them. Those operating units that already have scrubbers can choose to increase the scrubber's performance levels to avoid purchasing allowances, or to free up allowances to trade with other operators of other units.

2. Fuel switching. Select coals or fuel oils with sulfur contents that will allow operators to minimize costs. Cost factors include the cost of scrubbers, the cost of allowances that operators may need to purchase if they continue using the same grades of fuel, and the prices of fuels with lower sulfur contents.

3. Repowering. Repower existing coal-fired or oil-fired units to natural gas combined-cycle, or switch to natural gas. (This choice reflects the fact that the units can simultaneously reduce NOx and SO_2 emissions to minimize the total cost of both sets of pollution controls.)

4. Natural Gas Replacement. Retire existing coal-fired, or oil-fired units and replace them with combined cycle natural gas units. (This choice also reflects the fact that units can reduce both NOx and SO_2 emissions simultaneously.)

5. Purchase Emission Allowances. Operate units so that they do not exceed allowance levels, or purchase of limited numbers of allowances.

Several types of hybrid actions are also possible. Notably, the modeling framework allows units to install both NOx and SO_2 pollution controls (under Title IV) together where it would economically make sense for a unit to do so. The costs and performance of scrubbers, repowering, and adding new capacity appear in EPA's Analyzing Electric Power Generation under the CAA (U.S. EPA, 1996).

For the analysis of the alternative $PM_{2.5}$ NAAQS, the EPA has modeled a trading and banking control strategy that reduces the annual SO_2 emissions cap by 60 percent to 3.58 million tons in 2005. In this report, this control strategy is referred to as the National $PM_{2.5}$ Strategy. The National $PM_{2.5}$ Strategy is a 60 percent reduction beyond Title IV Phase II levels, and is achievable with existing technology. It is assumed that lowering the SO_2 emissions cap would occur in 2005 and lead to nearly a 50 percent reduction nationwide of annual SO_2 emissions by 2010. Table 5.2 shows the regional emission reductions that EPA expects to occur by the analysis year 2010. Most of the SO_2 reductions occur in the Midwest/Northeast and Southeast control regions.

Table 5.2 Emission Reductions for National $PM_{2.5}$ Strategy: 60% Utility SO_2 Reduction from Title IV Phase II Levels (thousand tons per year)

PM Control Region[a]	**SO_2**	**NOx**	**VOC**	**Primary PM_{10}**	**Primary $PM_{2.5}$**	**SOA (tons per year)**
Midwest/Northeast	2,789.0	108.6	(1.0)	4.4	0.6	18
Southeast	1,290.4	86.7	(3.0)	10.4	(0.1)	11
South Central	354.1	(9.0)	(0.2)	0.9	0.2	5
Rocky Mountain	72.9	8.8	(0.1)	0.1	0.0	3
Northwest	4.5	0.1	0.0	1.6	0.6	0
West	0.0	(0.1)	0.0	0.0	0.0	0
Nation	4,510.9	195.1	(4.3)	17.4	1.2	36

a See Chapter 6 for a discussion of PM Control Regions

Since utilities are predicted to over control emissions initially and bank allowances for later use, the SO_2 emissions level in 2010 is expected to be 5.2 million tons, or a 47 percent reduction from the NAAQS baseline. The additional 13 percent reduction is expected to be realized sometime after 2010. The estimated annual incremental cost in the year 2010 of implementing this regional SO_2 reduction strategy for the electric power industry is $2.6 billion (1990$).

It is important to note that regional shifts in power generation due to utility deregulation, and regional shifts in emissions control responsibility due to emissions trading can mean that reductions in NOx and SO_2 emissions are not realized in specific locations. For instance, note that Table 5.2 indicates minor increases in NOx emissions in the South Central and West control regions.

5.3 NON-UTILITY STATIONARY POINT SOURCE CONTROL MEASURES

The non-utility stationary point source category contains a diverse group of sources including combustion sources at various manufacturing operations and institutional facilities, larger surface coating operations, and process fugitive dust sources at mineral processing plants. Examples of stationary point source control measures include "add-on" stack controls (such as fabric filters and carbon adsorbers), process fugitive controls (e.g., wet dust suppression), and combustion modifications (low-NOx burners, etc.). Control costs for these measures are estimated at either the point source or source category level. Where sufficient source data are available for point sources, the cost is calculated using control measure and process size-specific cost equations based on a size indicator available in the emissions inventory. Examples of this indicator include stack gas volumetric flowrate and boiler design capacity.

Other point source emission reduction and control cost estimates are developed from information contained in published reports from state and local agencies. Every effort is made to verify that the estimates derived from these published reports are broadly applicable in a nationwide analysis, and that sound engineering cost procedures are used to develop the published estimates.

5.4 STATIONARY AREA SOURCE CONTROL MEASURES

The stationary area source category also contains a diverse group of sources including smaller combustion sources at various manufacturing operations and institutional facilities, surface coating operations, and fugitive dust sources like paved and unpaved roads. Examples of area source control measures include combustion modifications (low-NOx burners, etc.), fugitive controls (vacuum sweeping and wet dust suppression), add-on stack controls (incineration), and VOC content limits for coatings and various consumer products.

Since the National Particulate Inventory (NPI) does not contain source-specific information on area sources, emission reduction and control cost estimates are developed from information contained in published reports from state and local agencies. In a few cases, the area source categories correspond to point source categories where control efficiency and control cost estimates are already developed. For example, the cost for low-NOx burner controls on industrial coal, oil, and gas combustion is adapted from low-NOx burner controls for industrial point source boilers. In these cases, the point source control efficiency and cost estimates, expressed in dollars per ton of pollutant reduced, are applied to the area source control. An effort is made, if appropriate, to use the point source data associated with the source size expected to be present in the area source category. Also for a few control measures, control efficiency and control cost estimates are transferred from similar, but not identical, applications. For example, the VOC control measure for metal can coating is transferred from industrial surface coating categories.

5.5 MOBILE SOURCE CONTROL MEASURES

The mobile source control measures employed in this analysis are classified in two groups: national measures and local measures. Mobile source control measures that are based on changes in vehicle or engine emission standards are best applied at the national level. It would be expensive and difficult for vehicle and engine manufacturers to comply with a patchwork of standards applied at the local level, and, because motor vehicles and engines are mobile, much of the benefit of vehicle or engine emission standards applied at the local level would be lost to immigration of dirtier vehicles or engines into the local area. In contrast, control measures like vehicle inspection and maintenance (I/M) programs, cleaner burning fuels, and VMT management programs are more effectively implemented at the local level.

5.5.1 National Mobile Source Control Measures

Several potential mobile source control measures involving the creation of new emissions standards for on-highway and nonroad mobile sources were examined. Many of these measures, particularly those involving nonroad and heavy duty engines, have the potential to result in significant long-term reductions in NOx, VOC, and/or PM emissions. However, given the implementation schedules of current and planned standards which are already included in the 2010 CAA baseline, most of these new measures can not be implemented soon enough to provide substantial reductions by 2010. As a result, only one mobile source control measure, tighter exhaust emissions standards for light duty trucks, is included in this analysis. This control measure is applied here as an ozone control measure, and the cost of the program is attributed to the ozone standard. However, the VOC and NOx reductions from this measure may also benefit the $PM_{2.5}$ NAAQS and regional haze.

The baseline of this analysis assumes the existence of a voluntary National Low Emission Vehicle (NLEV) program. The NLEV program in the baseline is based on California emission standards that are more stringent than the standards required in the CAA (referred to as "Tier 1" standards). However, the EPA has the option to require still more stringent standards (referred to as "Tier 2" standards) beginning as early as the 2004 model year. The CAA requires the EPA to conduct a "Tier 2" study to determine if additional reductions in emissions from light duty gasoline vehicles (LDGV) and light duty gasoline trucks (LDGT), beyond the Tier 1 standard reductions required in the CAA, are necessary to meet the NAAQS.

The required study is not yet complete, and it is not the intent of this analysis to prejudge the outcome of the study. However, if the study concludes that additional reductions are needed, one likely way to get these reductions would be to target the four categories of light duty trucks for more stringent standards. Motor vehicle sales statistics indicate that light duty trucks are becoming a greater proportion of the light duty motor vehicle fleet. At the same time, they are subject to less stringent exhaust emissions standards than passenger cars. Further, the heavier categories of light duty trucks (those with a gross vehicle weight rating of 6,000 to 8,500 pounds) are not included in the NLEV program, while the lighter categories could have emissions standards tightened to more closely match those for passenger cars.

The following limits are assumed for passenger cars and light duty trucks beginning with the 2004 model year:

Category	NMOG (grams/mile)	NOx (grams/mile)
LDGV	0.075	0.20
LDGT1	0.075	0.20
LDGT2	0.100	0.20
LDGT3	0.195	0.40
LDGT4	0.195	0.40

These standards are chosen to maximize the NOx benefits of the potential Tier 2 program. The non-methane organic gases (NMOG) and NOx standards used in this analysis for the LDGV and LDGT1 categories are identical to those in the NLEV program. The standards for the LDGT2 category are the same for NMOG, but a tighter NOx standard is used in this analysis. The heavier categories of light duty trucks, LDGT3 and LDGT4 categories, are not included in the NLEV program. The LDGT3 standard included in this analysis is less stringent than the equivalent California LEV standard for NMOG but more stringent for NOx. The LDGT4 standard is identical to the equivalent California LEV standard for NMOG but more stringent for NOx. Emission reductions associated with these standards are modeled using MOBILE5a with alternate basic emission rate equations.

Costs for these standards are based on estimates developed by the California Air Resources Board (CARB) for its LEV program. CARB estimates the incremental per vehicle cost to achieve LEV standards at $120. Because the LDGV and LDGT1 standards are equivalent to the NLEV standards, no incremental cost is assumed for these vehicles. For the LDGT2 category, it is assumed that because only the NOx standard is further tightened, the additional cost will be half of CARB's estimate for achieving the LEV standard, or $60 per vehicle. For the LDGT3 and LDGT4 categories an incremental cost of $120 per vehicle is assumed.

5.5.2 Local Mobile Source Control Measures

In this analysis, local mobile source control measures include heavy duty engine retrofit programs, transportation control programs designed to reduce VMT, clean engine fleet vehicles, and clean burning fuels. Each of these control measures is discussed in this section.

5.5.2.1 <u>Heavy Duty Engine Retrofit Programs</u>

Heavy duty engine retrofit programs can be applied at the local level to target emission reductions where they are most needed. Heavy duty engines for both highway and nonroad vehicles are a significant source of PM emissions. Tighter standards for new engines (Tier 2 or Tier 3 standards depending on engine size classification), which are included in the 2010 CAA baseline, will help to reduce PM emissions from the heavy duty highway and nonroad fleets. However, because of slow fleet turnover rates for these engines, significant numbers of older engines certified to less stringent emissions standards will still be present in the fleet in 2010. One way to reduce the emissions of these engines is to upgrade or retrofit them with after-treatment devices. Upgrades or retrofits can be done when the engines are being rebuilt, which typically occurs at least once during their lifetimes.

The EPA has experience with these programs through the existing Urban Bus Retrofit Program. However, the costs and emission reductions associated with broader application of these programs is somewhat uncertain, particularly for nonroad engines. It is assumed that both highway and nonroad engines subject to the program can achieve a 25% reduction in PM emissions at a cost of $1,000 per engine. These estimates are based on EPA's experience to date with the existing Urban Bus Retrofit Program, which has achieved similar reductions at similar cost. The number of engine retrofit candidates will vary based on the design of the local program. Based on the limited period preceding the analysis year 2010 over which these programs can be phased in, it is assumed that 25% of all pre-1994 highway heavy duty engines still in the fleet in 2010 can be retrofitted. For nonroad engines, it is assumed that 25% of all pre-2001 engines can be retrofitted by 2010 (Dolce, 1997).

5.5.2.2 <u>Transportation Control Measures</u>

It has been shown in several pilot projects, most notably in the Portland, Oregon metropolitan area, that implementing innovative, voluntary transportation measures can directionally influence the growth rate of VMT. Due to the voluntary nature of these programs and the wide variety of transportation measures available to states and localities, it is difficult to estimate specific reductions in the growth rate of VMT, and hence emission reductions attributable to these measures. However, there is general agreement among expert sources that a nationwide 5% reduction in the rate of VMT growth over a ten year period (2000-2010) is reasonable. For instance, an area that had 2.0 percent annual VMT growth would instead experience 1.9 percent growth. The cost of transportation control measures (TCMs) is not easily estimated and will vary depending upon the collection of measures employed and many area-specific factors. For this analysis, the cost of an area-specific package of TCMs that reduces the growth rate of VMT by 5 percent is assumed to be $10,000 per ton of NOx reduced. (Dolce, 1997)

5.5.2.3 <u>Fleet ILEV Program</u>

The use of cleaner fuels could be a source of additional emission reductions for the light duty vehicle category. However, estimating the amount of additional exhaust reductions associated with burning cleaner fuels when compared to normal gasoline fueled vehicles already meeting the baseline NLEV standards is uncertain. Certain liquid fuels that have relatively low vapor pressures or gaseous fuels that must be contained in pressurized fuel systems provide clear advantages over normal gasoline with respect to evaporative emissions. Vehicles that properly use these fuels and, as a result, have zero evaporative emissions, are referred to as Inherently Low Emission Vehicles (ILEVs).

This analysis assumes that localities could impose requirements that all centrally-fueled light duty fleet vehicles meet ILEV standards by 2010. These ILEVs are assumed to have no evaporative emissions, to comprise 3% of the light duty vehicle and truck VMT, and to have a lifetime incremental cost of $1800 per vehicle. (U.S. EPA, 1992a)

5.5.2.4 **Reformulated Gasoline**

Beginning with the year 2000, more stringent standards will take effect for all reformulated gasoline (RFG) areas. These standards require that VOC emissions be reduced by about 27.5 percent, and that NOx emissions be reduced by 6.8 percent, on average, relative to the emissions of baseline gasoline as defined in the CAA. These more stringent standards, called Phase II standards, also require a 21.5 percent year-round reduction, on average, in air toxics, which is based on mass reductions in benzene, formaldehyde, 1,3-butadiene, acetaldehyde, and polycyclic organic matter (POM). The EPA had previously determined that the overall cost for Phase II RFG, incremental to the cost of the baseline fuel and including the required addition of oxygen and removal of much of the benzene, would be 5.1 cents per gallon (U.S. EPA, 1993).

The costs reflected in Appendix B.1 were developed prior to the development of the 2010 CAA baseline projection. Based on the subsequently false assumption that most major cities east of the Mississippi River would be out of attainment for the proposed ozone NAAQS, the EPA assumed RFG would be chosen as a control strategy over most of this region of the country. The estimated incremental cost for implementing the RFG program under this scenario is 6.7 cents per gallon, reflecting the higher costs associated with reformulating a greater fraction of the gasoline pool. However, based on the 2010 CAA baseline projection, the number of areas which ultimately might use the RFG program represent a much smaller portion of U.S. gasoline consumption than originally assumed. Thus, the costs are overestimated by as much as 1.6 cents per gallon (6.7 minus 5.1 cents per gallon). If a lower cost had been used in this analysis, the average incremental cost per ton for the RFG program would be lower than indicated in Appendix B.1.

In addition, the manner in which the full costs of the RFG program are allocated to either VOC control or to NOx control results in the program appearing to be less cost effective than previous EPA projections have indicated. When finalizing the RFG program, EPA evaluated the costs of the VOC and NOx standards independently using only the incremental cost associated with meeting each standard (U.S. EPA, 1993). The EPA thus concluded that the Phase II RFG NOx standard is cost-effective (about $5,000 per ton of NOx controlled), while the VOC standard similarly is determined to be cost-effective (about $500 per ton of VOC reduced). The remaining costs of the program were attributed to the toxics reductions achieved. Clearly, in this RIA where the full costs of the program are allocated to either NOx or VOC control, the cost-effectiveness value will be larger than shown in previous work. The EPA does not view the costs in Appendix B.1 to be inconsistent with previous work because the bases for the analyses are so different.

5.6 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

The cost and emission control effectiveness estimates for the control measures used in this analysis are developed using inputs from several reliable data sources and using best engineering judgement. Cost and effectiveness values may vary significantly among specific applications due to a variety of source-specific variables. Air pollution officials in airshed planning regions will decide exactly how the area-specific control measures are applied. Their actions will ultimately determine the actual costs and effectiveness of these measures, and of the overall air pollution control program.

The NPI characterizes the emission sources that may potentially be affected by control measures. Because of the vast number of emission sources for most pollutants (e.g., VOC emissions from filling gasoline storage tanks), data are not developed for each individual emission source. Control measure cost estimates are developed by applying cost algorithms to the available information in the NPI. The lack of detailed information in the NPI reduces the level of confidence in the cost estimates, but does not necessarily introduce systematic bias.

For some point source categories appearing in the NPI, data are available for a range of model plant sizes. In such cases, cost equations are developed relating size of the emission production activity to costs. For example, costs for flue gas desulfurization (FGD) scrubbers on

SO_2 emission sources are based on a spreadsheet model that relates input parameters such as stack gas flowrate and annual operating time to costs for FGD scrubbers. These variables are available for many point sources in the NPI. For other point source categories and all area and mobile source categories, an average incremental cost-effectiveness value (dollar per ton of emission reduction) or other similar average cost value (cents per gallon of gasoline) is used. Costs are developed at the source category level for these sources because the readily available data do not provide enough information to differentiate costs by emission source size or other cost differentiating parameters. Another limitation relates to many of the PM area source control measures. For many of the area source PM control measures it is sometimes necessary to estimate the PM_{10} cost effectiveness from total suspended particulate (TSP) cost-effectiveness data.

Another source of uncertainty is associated with the fact that costs are estimated for a projected year of 2010 (in 1990 dollars). The projected level of emissions and level of learning and technological innovation that will occur in emission control industries between now and 2010 are inherently uncertain.

Another limitation associated with the cost estimation procedure involves the transfer of cost information, which was developed for other purposes, to this analysis. The extent of this limitation is largely a function of the available cost data. Given the vast number of control measures and potentially affected sources, it is not possible to develop detailed control cost estimates for each individual emission source or even each source classification code (SCC). Cost information is taken from or developed using EPA costing manuals and guidance documents, State and local agency attainment plans, background documents for New Source Performance Standards (NSPSs), and other sources. Cost methods, where they are adequately documented, are reviewed to verify that correct procedures are used. However, some potential data sources provide emission reduction and cost estimates with little or no supporting documentation. For this reason, several measures lacking sufficient supporting documentation are excluded from this analysis. The extent to which such measures can achieve genuine reductions at the costs estimated is unknown.

In addition, many of the available cost estimates are based on cost studies that were conducted in the 1980s. For this analysis, these estimates are adjusted to reflect 1990 price levels using an appropriate price index. It would be possible, with a significant additional time commitment, to develop current estimates that would reflect any production-oriented advances that may have affected these costs (e.g., any scale production/cost effects that may have occurred from increased demand for the control technology). As noted above, no attempt is made to account for the potential effects of future technological innovations.

5.7 REFERENCES

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6.0 EMISSIONS, AIR QUALITY, AND COST IMPACTS OF $PM_{2.5}$ ALTERNATIVES

6.1 RESULTS IN BRIEF

Based on projected emission levels for the year 2010 this analysis estimates that 102 counties need additional reductions beyond those currently mandated in the Clean Air Act (CAA) and beyond those needed to partially attain the current ozone and coarse particulate matter (PM_{10}) standards to meet the selected fine particulate matter ($PM_{2.5}$ 15/65) national ambient air quality standard (NAAQS). The control cost associated with achieving full attainment in 72 of these counties and partial attainment in 30 counties is estimated to be $8.6 billion (1990 dollars). Due to overlap between projected $PM_{2.5}$ nonattainment counties and projected ozone nonattainment areas, some control measures may produce air quality benefits for both standards, and result in cost efficiencies.

The additional cost associated with control measures modeled to achieve partial attainment of the newly revised PM_{10} NAAQS is estimated to be $440 million (1990 dollars). This partial attainment control cost is less than half the partial attainment cost associated with the current PM_{10} standard, confirming that the newly revised PM_{10} standard is less stringent than the current PM_{10} standard.

6.2 INTRODUCTION

This chapter presents the methodology and results for the PM NAAQS alternatives emissions, air quality, and control cost impacts analysis. This analysis estimates the projected emission reductions and air quality improvements resulting from additional controls needed by the year 2010 to meet the alternative PM standards presented in Chapter 3. Emissions and air quality changes are inputs to the benefits analysis presented in Chapter 12. This analysis also estimates the projected costs (in 1990 dollars) of installing, operating, and maintaining additional controls. These control costs are inputs to the economic impact analysis presented in Chapter 11. Chapter 9 addresses the potential cost of full attainment, including the benefits of technological innovation and flexible implementation strategies. The administrative cost of the selected standard is addressed in Chapter 10. The following sections in this chapter cover:

- Methodology for estimating emissions, air quality, and cost impacts for PM alternatives;
- Emission reduction, air quality improvement, and control cost results for PM alternatives; and
- Analytical uncertainties, limitations, and potential biases.

6.3 EMISSIONS, AIR QUALITY, AND COST ANALYSIS METHODOLOGY

This analysis estimates the emission reductions and control costs for achieving air quality improvements to meet the newly revised PM_{10} NAAQS and alternative $PM_{2.5}$ NAAQS in projected nonattainment counties. The 2010 baseline air quality reflective of CAA-mandated controls is the primary input to the cost analysis. Chapter 4 explains the bases of, and assumptions pertaining to, the 2010 emissions and air quality projections. The cost and emission reductions for each $PM_{2.5}$ alternative are estimated from a “layered” control baseline that incorporates the 2010 baseline air quality *plus* partial attainment of the current ozone NAAQS *plus* partial attainment of the current PM_{10} NAAQS. From this baseline, three $PM_{2.5}$ annual average/daily average standards are examined: 16/65, 15/65, and 15/50. The new PM_{10} standard, which is a relaxation of the current PM_{10} standard is also examined. The baseline for the analysis of the new PM_{10} standard incorporates the baseline air quality *plus* partial attainment of the current ozone NAAQS.

Figure 6.1 shows the analysis steps that make up these baselines.

Figure 6.1 PM Analysis Baselines

$PM_{2.5}$ Analysis Baseline

2010 CAA Baseline ------------> Attain Current O_3 NAAQS --------------> Attain Current PM_{10} NAAQS

New PM_{10} Analysis Baseline

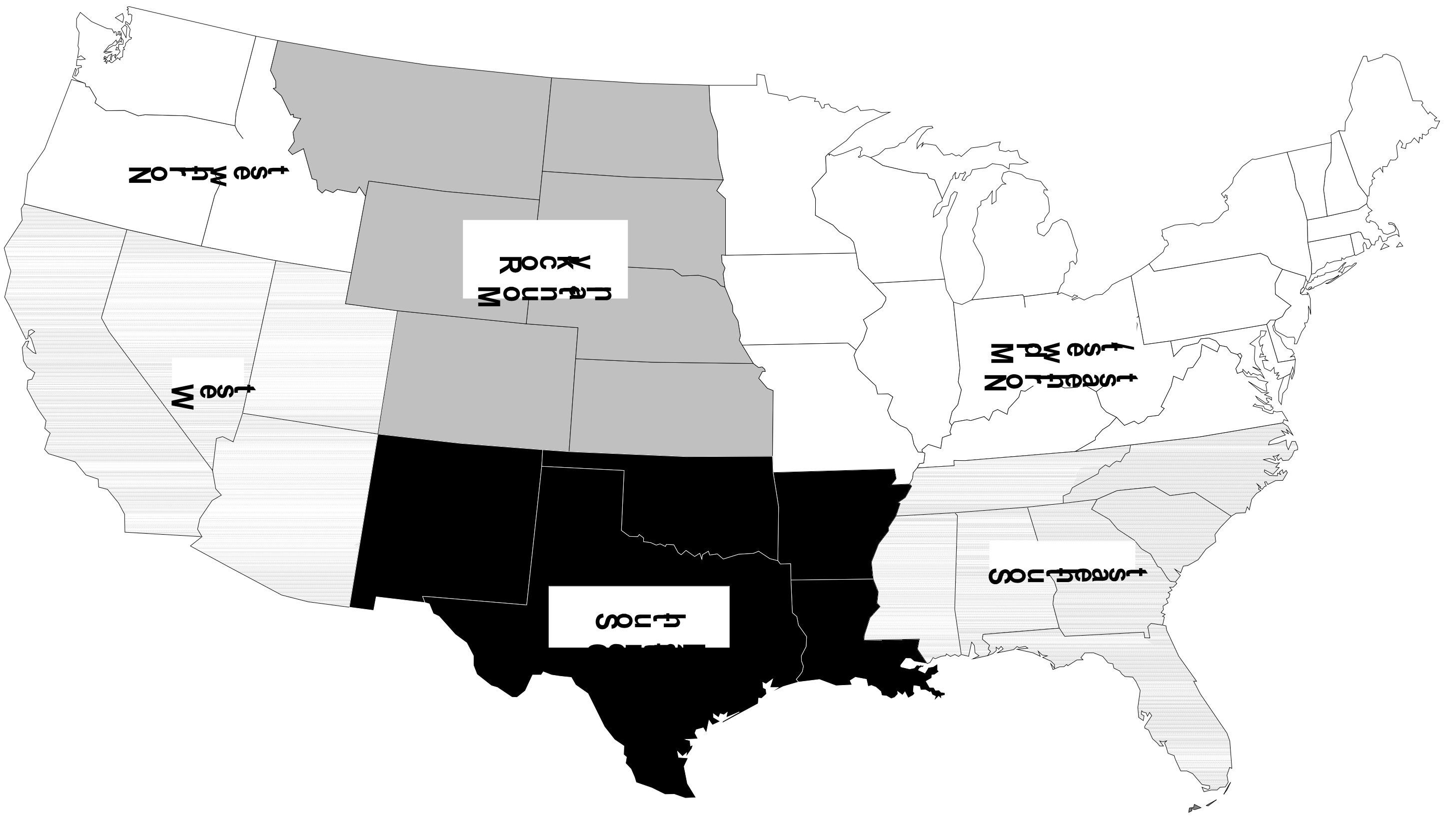
2010 CAA Baseline ------------> Attain Current O_3 NAAQS

Since the 2010 CAA baseline projection indicates that 45 counties do not attain the current PM_{10} standard, control measures are first applied to address nonattainment of the current PM_{10} standard. In the analyses of both the current and new PM_{10} standards, control measures affecting only those PM_{10} emissions sources located inside the boundaries of each projected PM_{10} nonattainment county are evaluated. This *local* approach to control measure application is believed to be consistent with current implementation practices. The results of the current PM_{10} standard analysis are presented and discussed in Appendix C.

For achieving alternative $PM_{2.5}$ standards, control measure selection is modeled using a broader *regional* approach that is more appropriate for addressing air quality problems caused by trans-boundary pollution transport. The fine particle precursors that make up $PM_{2.5}$ can be transported over long distances by prevailing winds. Since sources outside of projected nonattainment counties may significantly contribute to elevated $PM_{2.5}$ concentrations in the nonattainment counties, controls may be imposed on sources outside the boundaries of counties projected to be out of attainment. Given the long-range transport of $PM_{2.5}$ precursors, air quality changes will be realized in nonattainment counties and counties outside nonattainment counties, some of which initially attain the standards. Ultimately, state and local air pollution control authorities, in cooperation with federal efforts, will devise implementation strategies that achieve air quality goals in a manner that minimizes negative impacts.

As discussed in Chapter 4, this analysis is confined to those projected nonattainment counties from a subset of 504 counties currently monitored for PM_{10} in the 48 contiguous States. The set of projected nonattainment counties is subdivided into six regions, the boundaries of which are depicted in Figure 6.2. The boundaries of these regions are delineated to reflect both the meteorological conditions that influence the long-range transport of $PM_{2.5}$ precursors and the locations of their major sources (e.g., electric utilities). The control regions in this analysis have been revised from the control regions used in the 1996 analysis of the proposed NAAQS. For this analysis, the former California Coastal and West regions have been merged to form a single West region. Therefore, in this analysis there are six rather than seven control regions. This consolidation is made recognizing that the major urban areas in the former California Coastal region have an effect on air quality in areas hundreds of miles eastward. Control measure selection is optimized within each control region to bring projected $PM_{2.5}$ nonattainment counties within each region into attainment at the lowest possible cost.

The costs in this analysis reflect *real, before-tax, 1990 dollars* and a *7 percent real interest (discount) rate*. "Real" dollars are those uninfluenced by inflation; in other words, a "1990 dollar" is assumed to be worth the same today as it was in 1990. "Before-tax" means that the cost analysis does not consider the effects of income taxes (State or federal). Because income taxes are merely transfer payments from one sector of society to another, their inclusion in this cost analysis would not affect total cost estimates. The year 1990 was selected as the cost reference date to be consistent with the analysis base year. Finally, to be consistent with the real-dollar analytical basis and in accordance with Office of Management and Budget guidance, a 7 percent real interest rate is used to annualize capital costs.



6.3.1 Selecting $PM_{2.5}$ Control Measures Using the PM Optimization Model

This analysis uses two methods for selecting control measures that reduce emissions of $PM_{2.5}$ precursors; one method is used for the utility sector and another method is used for all other emissions sectors. This analysis assumes a National $PM_{2.5}$ Strategy for utilities that reduces the SO_2 emissions cap beyond Title IV Phase II levels. The allocation of SO_2 control responsibility and the control measures selected for sources in the utility sector are analyzed using the Integrated Planning Model (IPM) (U.S. EPA, 1996). Control measures for all other emissions sectors are selected using the PM optimization model. The types of control measures available to both utility and non-utility sources is discussed in Chapter 5 of this report.

The remainder of this section describes the optimization model used for selecting non-utility control measures in each of the $PM_{2.5}$ control regions. The optimization model uses several inputs to determine which control measures to apply to meet alternative $PM_{2.5}$ standards. These inputs are the: 1) Incremental Control Measure Data File, 2) Source-Receptor (S-R) Matrix, and 3) Receptor Input File. Each of these inputs will be described below, after which the optimization procedure will be discussed.

6.3.2 Incremental Control Measure Data File

This file contains the incremental precursor pollutant emission reductions and the total annual cost (in 1990 dollars) for each individual control measure-emission source combination. Each of the emission sources is given a "source number" that is indexed to the S-R matrix (described below). A significant number of control measures are either added or revised since the Regulatory Impact Analysis (RIA) for the proposed NAAQS was published. Chapter 5 presents and discusses the control measures used in this analysis.

The incremental control measure data file is created via optimization on *average annual incremental cost per ton.* For purposes of this analysis, average incremental cost per ton is defined as the *difference* in the annual cost of a control measure and the annual cost of the baseline control (if any), divided by the *difference* in the annual mass of pollutant emissions removed by the control measure and the emissions removed by the baseline control.

The average annual incremental cost per ton is calculated at the source or unit level for point source control measures and at the county level for area and mobile source control measures. For any individual source (e.g., boiler), only the control measures that are most cost-effective at reducing the $PM_{2.5}$ precursor emissions are included in the incremental control measure data base. This step eliminates inefficient solutions.

Consider, for example, a furnace that emits 1000 tons per year of primary $PM_{2.5}$. Suppose that this source could be controlled by one of three control devices: 1) high-energy scrubber; 2) fabric filter; or 3) electrostatic precipitator (ESP). Further suppose that the associated annual costs, emission reductions, and the average annual incremental cost per ton for these devices is shown in Table 6.1.

Table 6.1 Hypothetical Furnace Control Measures

Control Device	Annual Cost ($/year)	$PM_{2.5}$ Emission Reduction (tons/year)	Average Annual Incremental Cost per Ton ($/ton)
Scrubber	700,000	950	740
Electrostatic Precipitator	600,000	970	620
Fabric filter	800,000	990	810

In this illustration, the ESP would be the most cost-effective option ($620 per ton), as it provides the most emission reduction at the lowest annual cost. Because the scrubber provides the lowest emission reduction at a cost greater than that of the ESP, it would never be selected. The fabric filter provides the highest emission reduction (990 tons per year), but its annual cost is also the highest of the three options. Because it provides a higher emission reduction than the ESP, even at a higher cost, the fabric filter would be retained in the control measure data base.

6.3.3 Source-Receptor Matrix

The S-R matrix, which is discussed in more detail in Chapter 4, provides a link between emission reductions and resulting air quality concentrations. When a control measure from the incremental control measure data file is applied at a source, PM concentrations are reduced by some amount at *all* associated receptors (i.e., counties) regardless of their distance from the source.

The S-R matrix was developed from an air quality model that divides sources into two general categories: *elevated point sources* and *area/mobile sources*. In turn, the elevated point sources are aggregated into three categories: 1) sources with effective stack (release) heights less than 250 meters; 2) sources with heights between 250 and 500 meters; and 3) sources with heights above 500 meters. Except for the last category, all sources are assumed to be situated at the population centroid of the county in which they are located. The >500 meter sources are sited according to their individual longitude/latitude coordinates.

The S-R coefficients for a given source and all receptors determine the concentration reductions that occur in proportion to the emission reductions provided by a given control measure. The PM optimization model calculates the reduction in concentration for the least average annual incremental cost per ton measure for each unique source-pollutant combination. A comparison is then made between each of these unique source-pollutant combinations to determine the most cost-effective measure on the basis of cost per microgram per cubic meter $PM_{2.5}$ reduced. The most cost-effective measure is selected, concentration is reduced at each associated receptor, and the process is repeated until all receptors are in compliance or all remaining measures exceed a specified threshold expressed in terms of the *cost per microgram per cubic meter* $PM_{2.5}$ *reduced*.

For example, the order of selection on an average incremental cost per ton basis for controlling VOC emissions in a hypothetical county may be: 1) pressure/vacuum vents and vapor balancing for Stage I service station refueling, 2) VOC incineration for metal can coating operations, and 3) VOC content limits and improved transfer efficiency for autobody refinishing operations. However, each of these individual measures has the same S-R coefficient and source number, because all area sources in a county are assumed to release their emissions at the same height and location (the county centroid). Consequently, the cost per microgram per cubic meter reduced--which, within a given aggregation of sources, is directly proportional to the cost per ton reduced--will follow the same order of selection as the *average incremental cost per ton* of precursor reduced. Table 6.2 provides an indication of the magnitude of the S-R coefficients for a hypothetical receptor (Acme County).

Table 6.2 Simple Illustration of S-R Coefficients For The Hypothetical Acme County Receptor

Source (all in the county)	**Primary $PM_{2.5}$ Coefficient**	**Nitrate Coefficient**	**Sulfate Coefficient**	**Ammonia (NH_3) Coefficient**
Point (0-250m)	0.154×10^{-7}	0.191×10^{-8}	0.392×10^{-9}	0.147×10^{-7}
Point (250-500m)	0.258×10^{-8}	0.243×10^{-9}	0.518×10^{-10}	0.277×10^{-8}
Area Sources	0.224×10^{-7}	0.267×10^{-8}	0.546×10^{-9}	0.215×10^{-7}

The units of the coefficients are *seconds per cubic meter*. S-R matrix coefficients generally decrease with distance, dropping off rapidly beyond a one or two county layer from the receptor county. To illustrate how these coefficients are used to calculate changes in air quality, consider a 1000 ton per year reduction in primary $PM_{2.5}$ emissions from area sources in Acme County. The change in $PM_{2.5}$ concentration is calculated as follows:

$$\text{Reduction} = (1{,}000 \text{ tons/year})(0.224 \times 10^{-7} \text{ sec/m}^3)(28{,}767 \text{ micrograms-yr/ton-sec})$$

$$= 0.644 \text{ micrograms per cubic meter,}$$

where 28,767 is the micrograms-yr/ton-sec conversion factor.

6.3.4 Receptor Input File

This file contains the starting total county-level normalized PM_{10} and $PM_{2.5}$ concentrations for the 2010 CAA baseline emissions scenario. The normalization procedure used to calibrate predicted concentrations to actual monitor data is described in Chapter 4.

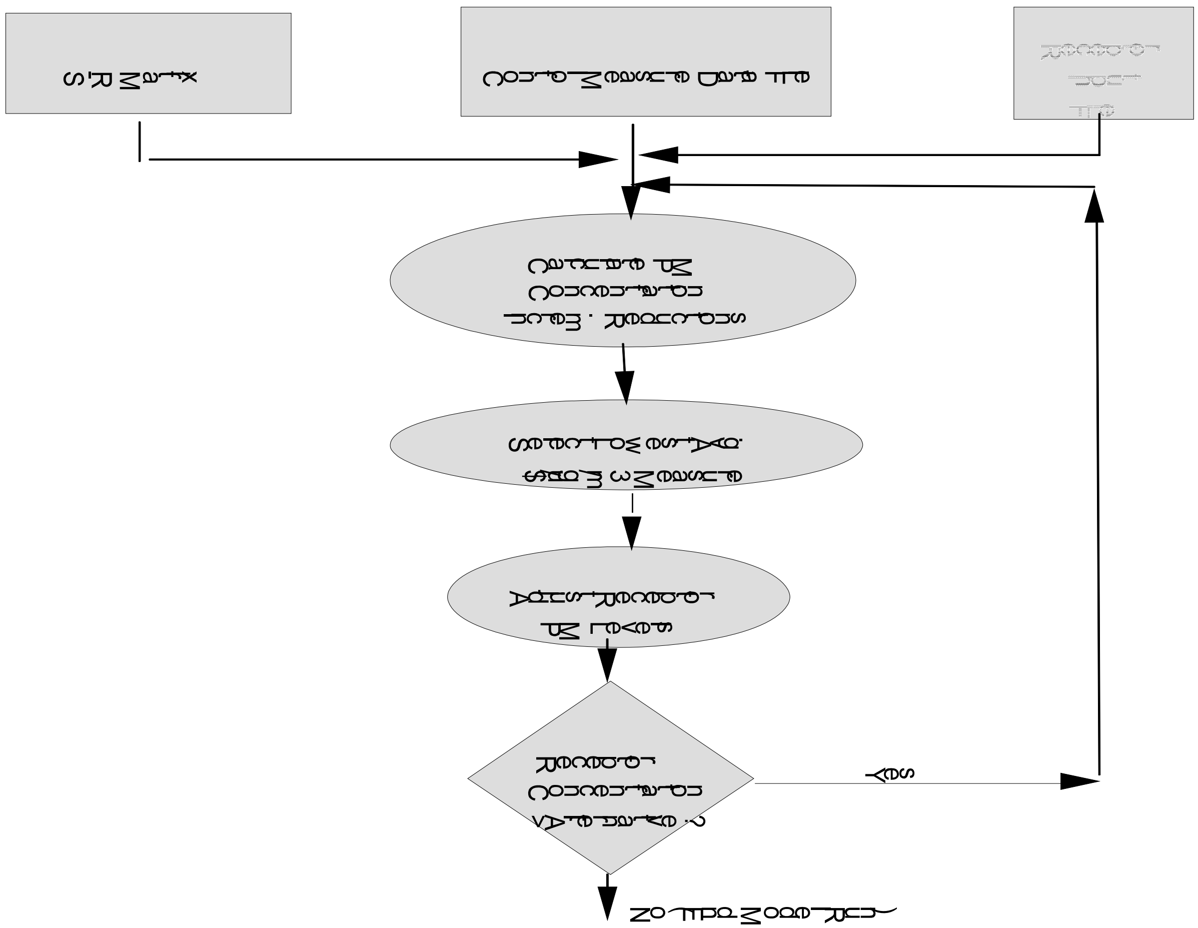
6.3.5 Optimization Routine

The optimization routine developed for this analysis is illustrated in Figure 6.3, and employs the following steps:

Step 1. The incremental control measure data file is sorted by source number, precursor pollutant controlled, and increasing average incremental cost per ton of pollutant reduced.

Step 2. The *incremental* reduction in $PM_{2.5}$ concentration is calculated *for each associated receptor* for the least costly (on a cost per ton basis) control measure for each individual source-pollutant combination. As explained above, while control measure selection is made on a cost per microgram per cubic meter basis, for a given source-pollutant combination, the measure with the least cost per ton may also be least costly on a cost per microgram per cubic meter basis. The number of these selections equals the number of source-pollutant combinations analyzed. This number, in turn, varies based on the control region to which the optimization model is applied.

FIGURE 6-3
PM OPTIMIZATION MODEL STEPS



Step 3. The cost per *average* microgram per cubic meter reduced across *all receptors out of compliance with the standard* is calculated for each control measure. Thus, for a receptor already meeting the target alternative standard, the impact of a control measure on that receptor is *not* counted so that measures which impact receptors already in compliance are not selected. In addition, any reduction in excess of that needed to meet the standard is *not* counted in the calculation of the cost per average microgram reduced. This prevents application of measures that would give emission reductions in excess of those required to meet the standard when measures with lower overall cost and less over control are still available. However, these reductions *are* carried through in the final analysis of *all* receptor concentrations.

Step 4. The measure with the *lowest cost per average microgram per cubic meter reduced* is selected and the $PM_{2.5}$ concentration at each receptor is adjusted to reflect implementation of the selected measure.

Step 5. Steps 2 through 4 are repeated until all input receptors meet the target level *or* the minimum cost per microgram reduced threshold is exceeded by all remaining measures.

Step 6. Adjust final post-control air quality predictions in all regions to account for the trans-boundary effect of control measures selected outside each control region.

To illustrate steps 3 and 4, consider the example shown in Table 6.3. This table lists three control measures (A, B, and C) and four receptors (counties 1, 2, 3, and 4). The annual cost (in millions of 1990 dollars per year) is given for each control measure. Also listed for each measure is the reduction in $PM_{2.5}$ concentration at each receptor that result if that measure is applied. For control measure A, these reductions range from 0.1 to 0.3 micrograms per cubic meter, and average 0.23 micrograms per cubic meter (column 2). Listed below these reductions are the cost-per-microgram-per-cubic meter ratios for each of the four receptors. These ratios are obtained by dividing the annual cost for control measure A by each of the four $PM_{2.5}$ reductions. The last number in column 2 is the ratio of the annual cost for control measure A divided by the average microgram per cubic meter $PM_{2.5}$ reduction among the four receptors.

Similar calculations are made for control measures B and C, in turn.

Table 6.3 Simple Illustration of the Calculation of Cost per Average Microgram per Cubic Meter Reduced

	Control Measure A	Control Measure B	Control Measure C
Cost (million $/yr)	1.0	1.5	1.5
$PM_{2.5}$ Reduced ($\mu g/m^3$)			
Receptor 1	0.20	0.30	0.80
Receptor 2	0.30	0.40	0.10
Receptor 3	0.10	0.50	0.10
Receptor 4	0.30	0.40	0.25
Average	0.23	0.40	0.25
Cost per microgram per cubic meter			
Receptor 1	5.0	5.0	1.9
Receptor 2	3.3	3.8	15.0
Receptor 3	10.0	3.0	15.0
Receptor 4	3.3	3.8	--
Average	4.4	3.8	6.0

The control measure selected in this optimization scheme is the one that gives the lowest cost per average microgram per cubic meter reduction. Based on this decision criterion, control measure B is selected first, followed by measure A and measure C, as needed. But suppose, for instance, that the application of measure B brought receptors 2 through 4 into compliance with the NAAQS alternative of interest. If that is the case, the next iteration of the optimization model results in the selection of measure C, in preference to measure A. Why? Since control measure B brought receptors 2 through 4 into compliance, they are longer included in the calculation of the cost per average microgram reduced. This leaves only receptor 1 under consideration. And, as Table 6.3 shows, control measure C has the lowest annual cost per microgram per cubic meter reduction ratio for receptor 1. (Note: Because there is only one receptor, this ratio also equals the lowest annual cost per average microgram per cubic meter). Consequently, measure C is selected.

Because the optimization model only includes receptors out of compliance in the calculation of the cost per average microgram reduced, selection of measures that have little or no impact in reducing concentrations in non-complying areas is avoided. Finally, the reader should keep in mind that the scope of this example has been kept small for purposes of illustration. During each iteration of the PM optimization model, the control measure selections are made from literally thousands of measure-receptor combinations.

6.3.6 Dollar Per Microgram Per Cubic Meter Reduction Control Measure Selection Threshold

In this analysis, a maximum cost per microgram per cubic meter reduction threshold is used to eliminate control measures that either: 1) have little or no effect on air quality at a non-complying receptor; or 2) are extremely costly relative to the air quality benefit they achieve at a non-complying receptor. The minimum (or most cost-effective) cost per microgram is calculated as the *cost per microgram reduced for the receptor that achieves the most reduction from a control measure*. This analysis uses a threshold of $1 billion per microgram per cubic meter reduced. If the cost per microgram reduced exceeds this value for all associated receptors currently out of compliance, the measure is not selected. If all remaining measures exceed this value, the simulation ends.

The $1 billion per microgram per cubic meter reduced threshold is taken from the analysis performed for the 1996 RIA of the proposed $PM_{2.5}$ standard. In that analysis, a value above $1 billion was tested for the Midwest/Northeast control region, and the conclusion was that only a minor air quality improvement is achieved at a higher cut-off (Pechan, 1996). However, for the current analysis the effect of a $500 million and $2 billion per microgram per cubic meter control measure selection threshold is examined. The results of this sensitivity analysis are presented in Appendix D. These results indicate that the number of nonattainment counties, air quality results are not highly sensitive to the alternative cut-off levels that are evaluated. However, the nationwide incremental cost is somewhat sensitive to the threshold level. As the threshold level is doubled from $500 million to $1 billion, the incremental cost also nearly doubles. When the threshold is doubled again from $1 billion to $2 billion, the incremental control cost increases by only 16 percent.

6.3.7 Number of Monitored Counties

This analysis selects control measures with the goal of reducing $PM_{2.5}$ concentrations in projected nonattainment counties from a subset of counties currently monitored for PM_{10}. There are over 700 counties that currently contain monitors capable of measuring PM_{10} air quality, however, only 504 of these monitors meet what is referred to in this analysis as *Tier 1* criteria. Chapter 4 provides a more detailed discussion of the monitoring criteria used to establish tiers. It is possible that additional counties will contain monitors to measure $PM_{2.5}$ concentrations, and therefore the number of potential nonattainment counties could be greater than the number of counties included in this analysis. A sensitivity analysis on the number of monitored counties included in the analysis is presented in Appendix D.

6.4 EMISSION REDUCTION AND AIR QUALITY IMPACT RESULTS

This section presents the emission reduction and air quality impact results for the analysis of the newly revised PM_{10} standard and alternative $PM_{2.5}$ standards. The $PM_{2.5}$ results presented in this section are incremental to partial attainment of the current ozone and current PM_{10} standards. The results for the newly revised PM_{10} standard are incremental to partial attainment of the current ozone standard. This section includes estimates of the emission reductions and PM air quality improvements resulting from control measures selected in each control region, and estimates of the change in the attainment status for the initially projected PM nonattainment counties.

Table 6.5 presents the emission levels associated with the alternative standards. The emissions represent the level of emissions after modeled control measures are applied. The emission levels corresponding to the National $PM_{2.5}$ Strategy include reductions from measures modeled to meet the current ozone and PM_{10} standards, as well as reductions achieved by the National $PM_{2.5}$ Strategy. The emission levels do not account for potential increases in emissions due to the small additional energy requirements for producing, installing, and operating selected control devices.

Table 6.6a presents the projected number of initial and residual nonattainment counties for each $PM_{2.5}$ alternative. For the 16/65 and 15/65 standards, only a few counties (8) initially violate the 24-hour average concentration standard. The number of counties that initially violate the 24-hour average concentration standard increases to 47 when the 24-hour average concentration standard is tightened to 50 $\mu g/m^3$. For the 16/65 and 15/65 alternatives, the estimated residual nonattainment counties are driven by annual average rather than 24-hour average violations. For the 15/50 alternative, the number of counties violating the 24-hour average after control increases from 6 to 22.

Table 6.6b presents the projected number of initial and residual nonattainment counties for the new PM_{10} 50/150 (99th percentile) standard. The West control region contains the majority of projected initial and residual nonattainment counties.

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
NOx	**Midwest/Northeast**	Area	982,080	975,588	921,777	912,513	909,455
		Mobile	2,539,129	2,529,735	2,488,984	2,470,900	2,448,567
		Nonroad	731,096	731,096	731,096	731,096	731,096
		Point	598,963	590,682	571,373	568,147	567,850
		Utility	1,961,858	1,853,260	1,853,260	1,853,260	1,853,260
		TOTAL	**6,813,127**	**6,680,361**	**6,566,490**	**6,535,917**	**6,510,229**
	Southeast	Area	390,015	389,888	384,946	383,027	383,027
		Mobile	1,208,578	1,208,578	1,208,578	1,201,445	1,201,445
		Nonroad	354,961	354,961	354,961	354,961	354,961
		Point	340,664	340,664	340,503	339,722	339,722
		Utility	749,463	662,790	662,790	662,790	662,790
		TOTAL	**3,043,681**	**2,956,881**	**2,951,778**	**2,941,946**	**2,941,946**
	South Central	Area	1,008,261	1,003,845	992,901	992,115	989,242
		Mobile	729,764	715,165	708,499	708,497	708,497
		Nonroad	387,424	387,424	387,424	387,424	387,424
		Point	597,899	590,695	559,362	557,623	557,580
		Utility	463,977	419,915	419,915	419,915	419,915
		TOTAL	**3,187,325**	**3,117,044**	**3,068,100**	**3,065,573**	**3,062,657**
	Rocky Mountain	Area	339,259	338,270	327,557	323,972	320,287
		Mobile	344,110	343,753	333,163	333,093	323,492
		Nonroad	166,444	166,444	166,444	166,444	166,444
		Point	146,006	131,758	101,370	93,799	89,829
		Utility	429,778	233,740	233,740	233,740	233,740
		TOTAL	**1,425,598**	**1,213,966**	**1,162,274**	**1,151,049**	**1,133,792**
	Northwest	Area	92,296	91,741	90,867	90,867	89,249
		Mobile	274,413	274,281	274,281	274,281	264,682
		Nonroad	84,343	84,343	84,343	84,343	84,343
		Point	93,831	88,027	88,027	88,027	72,953
		Utility	27,781	7,761	7,761	7,761	7,761
		TOTAL	**572,663**	**546,153**	**545,279**	**545,279**	**518,987**
	West	Area	208,701	193,310	185,400	185,214	184,862
		Mobile	478,403	469,834	462,766	460,448	460,416
		Nonroad	338,405	338,405	338,405	338,405	338,405
		Point	180,188	121,744	106,344	105,999	105,080
		Utility	122,236	32,476	32,177	32,177	32,177
		TOTAL	**1,327,934**	**1,155,770**	**1,125,093**	**1,122,243**	**1,120,940**

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
PM_{10}	**Midwest/Northeast**	Area	14,943,811	14,885,028	13,664,341	13,243,888	13,209,030
		Mobile	90,992	90,967	90,785	90,700	90,678
		Nonroad	124,690	124,674	124,351	124,260	124,235
		Point	541,272	534,965	476,330	454,017	450,566
		Utility	111,048	88,803	88,803	88,803	88,803
		TOTAL	**15,811,814**	**15,724,436**	**14,444,610**	**14,001,667**	**13,963,312**
	Southeast	Area	7,830,399	7,825,067	7,805,131	7,689,958	7,689,958
		Mobile	39,480	39,480	39,480	39,457	39,457
		Nonroad	69,608	69,608	69,607	69,557	69,557
		Point	264,104	264,052	261,750	257,615	257,615
		Utility	96,748	47,752	47,752	47,752	47,752
		TOTAL	**8,300,340**	**8,245,959**	**8,223,720**	**8,104,338**	**8,104,338**
	South Central	Area	11,602,813	11,487,945	11,139,934	10,712,825	10,691,327
		Mobile	24,548	24,533	24,494	24,498	24,495
		Nonroad	80,443	80,437	80,303	80,286	80,274
		Point	225,738	218,377	184,396	180,201	180,142
		Utility	29,571	28,606	28,606	28,606	28,606
		TOTAL	**11,963,112**	**11,839,899**	**11,457,733**	**11,026,416**	**11,004,843**
	Rocky Mountain	Area	7,393,394	7,316,194	6,699,502	6,588,270	6,486,080
		Mobile	10,738	10,731	10,710	10,699	10,688
		Nonroad	26,596	26,586	26,553	26,539	26,502
		Point	34,200	32,316	28,634	27,977	27,466
		Utility	22,653	15,348	15,348	15,348	15,348
		TOTAL	**7,487,582**	**7,401,176**	**6,780,746**	**6,668,833**	**6,566,084**
	Northwest	Area	2,008,191	1,967,074	1,967,073	1,967,073	1,744,208
		Mobile	8,325	8,314	8,314	8,314	8,299
		Nonroad	16,108	16,100	16,100	16,100	16,066
		Point	63,546	58,110	58,110	58,110	34,267
		Utility	3,670	2,002	2,002	2,002	2,002
		TOTAL	**2,099,841**	**2,051,600**	**2,051,599**	**2,051,599**	**1,804,841**
	West	Area	2,686,636	2,638,386	2,400,241	2,396,093	2,360,974
		Mobile	29,486	29,321	29,194	29,175	29,103
		Nonroad	33,927	33,847	33,757	33,754	33,742
		Point	41,000	36,779	27,353	27,039	25,526
		Utility	12,979	6,744	6,744	6,744	6,744
		TOTAL	**2,804,029**	**2,745,076**	**2,497,289**	**2,492,804**	**2,456,088**

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
$PM_{2.5}$	**Midwest/Northeast**	Area	1,108,152	1,105,657	994,215	967,697	964,434
		Mobile	62,934	62,917	62,770	62,706	62,689
		Nonroad	107,290	107,275	106,979	106,895	106,872
		Point	302,883	300,689	274,494	265,153	263,387
		Utility	43,050	39,775	39,775	39,775	39,775
		TOTAL	**1,624,310**	**1,616,313**	**1,478,233**	**1,442,225**	**1,437,157**
	Southeast	Area	751,982	751,650	748,252	733,567	733,567
		Mobile	27,541	27,541	27,541	27,523	27,523
		Nonroad	59,236	59,236	59,235	59,189	59,189
		Point	189,276	189,225	187,560	184,406	184,406
		Utility	32,497	23,870	23,870	23,870	23,870
		TOTAL	**1,060,533**	**1,051,521**	**1,046,457**	**1,028,554**	**1,028,554**
	South Central	Area	652,871	646,859	607,168	591,118	588,857
		Mobile	17,034	17,025	16,993	16,996	16,993
		Nonroad	68,230	68,224	68,101	68,085	68,074
		Point	156,143	150,221	124,594	121,823	121,811
		Utility	17,873	17,568	17,568	17,568	17,568
		TOTAL	**912,151**	**899,898**	**834,425**	**815,590**	**813,303**
	Rocky Mountain	Area	465,065	459,214	420,454	413,862	404,453
		Mobile	7,545	7,539	7,522	7,514	7,505
		Nonroad	21,762	21,754	21,723	21,710	21,676
		Point	22,334	21,632	18,679	18,210	17,885
		Utility	10,570	8,017	8,017	8,017	8,017
		TOTAL	**527,276**	**518,156**	**476,395**	**469,314**	**459,537**
	Northwest	Area	270,725	259,686	259,686	259,686	188,928
		Mobile	5,809	5,801	5,801	5,801	5,788
		Nonroad	12,426	12,418	12,418	12,418	12,387
		Point	48,611	43,452	43,452	43,452	23,423
		Utility	2,140	1,493	1,493	1,493	1,493
		TOTAL	**339,711**	**322,850**	**322,850**	**322,850**	**232,019**
	West	Area	246,787	239,924	207,058	206,847	202,979
		Mobile	19,987	19,874	19,777	19,762	19,702
		Nonroad	24,971	24,898	24,815	24,812	24,801
		Point	24,376	22,199	16,725	16,571	15,409
		Utility	5,238	4,064	4,064	4,064	4,064
		TOTAL	**321,359**	**310,959**	**272,439**	**272,055**	**266,955**

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
SO_2	Midwest/Northeast	Area	767,035	767,035	767,035	767,035	767,035
		Mobile	183,136	183,092	183,036	182,968	182,960
		Nonroad	63,052	63,052	63,052	63,052	63,052
		Point	2,870,350	2,827,546	1,955,450	1,836,590	1,790,145
		Utility	5,570,030	2,781,020	2,781,020	2,781,020	2,781,020
		TOTAL	**9,453,603**	**6,621,745**	**5,749,593**	**5,630,666**	**5,584,212**
	Southeast	Area	293,314	293,314	293,314	293,314	293,314
		Mobile	78,096	78,096	78,096	78,084	78,084
		Nonroad	27,555	27,555	27,555	27,555	27,555
		Point	1,020,543	1,020,543	1,014,779	967,240	967,240
		Utility	2,253,170	962,810	962,810	962,810	962,810
		TOTAL	**3,672,679**	**2,382,319**	**2,376,554**	**2,329,003**	**2,329,003**
	South Central	Area	259,423	259,423	259,423	259,423	259,423
		Mobile	49,107	49,074	49,072	49,072	49,072
		Nonroad	64,117	64,117	64,117	64,117	64,117
		Point	1,335,048	1,315,486	1,252,721	1,225,970	1,225,970
		Utility	1,192,120	838,040	838,040	838,040	838,040
		TOTAL	**2,899,814**	**2,526,139**	**2,463,373**	**2,436,622**	**2,436,622**
	Rocky Mountain	Area	105,470	105,470	105,470	105,470	105,470
		Mobile	21,020	21,016	21,006	21,002	20,994
		Nonroad	10,307	10,307	10,307	10,307	10,307
		Point	306,995	297,775	244,919	230,623	205,326
		Utility	583,874	510,944	510,944	510,944	510,944
		TOTAL	**1,027,666**	**945,512**	**892,645**	**878,346**	**853,041**
	Northwest	Area	71,995	71,995	71,995	71,995	71,995
		Mobile	16,454	16,447	16,447	16,447	16,444
		Nonroad	14,663	14,663	14,663	14,663	14,663
		Point	140,764	138,432	138,432	138,432	132,874
		Utility	32,170	27,670	27,670	27,670	27,670
		TOTAL	**276,045**	**269,206**	**269,206**	**269,206**	**263,646**
	West	Area	22,163	22,163	22,163	22,163	22,163
		Mobile	61,419	61,165	61,080	61,071	61,065
		Nonroad	56,766	56,766	56,766	56,766	56,766
		Point	316,087	314,841	272,540	272,285	272,285
		Utility	114,290	114,300	114,300	114,300	114,300
		TOTAL	**570,726**	**569,235**	**526,849**	**526,586**	**526,580**

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
VOC	**Midwest/Northeast**	Area	3,387,272	3,296,818	3,110,178	3,067,793	3,058,994
		Mobile	1,691,373	1,681,922	1,619,912	1,593,951	1,566,579
		Nonroad	759,617	759,616	759,616	759,616	759,616
		Point	1,101,612	1,098,967	1,097,996	1,097,996	1,097,996
		Utility	20,257	21,244	21,244	21,244	21,244
		TOTAL	**6,960,132**	**6,858,567**	**6,608,947**	**6,540,600**	**6,504,429**
	Southeast	Area	1,641,703	1,641,355	1,598,843	1,582,897	1,582,897
		Mobile	1,019,816	1,019,816	1,019,816	1,009,609	1,009,609
		Nonroad	359,685	359,685	359,685	359,685	359,685
		Point	428,138	428,138	427,976	427,976	427,976
		Utility	10,632	13,648	13,648	13,648	13,648
		TOTAL	**3,459,974**	**3,462,643**	**3,419,969**	**3,393,816**	**3,393,816**
	South Central	Area	1,059,321	1,040,429	986,916	985,038	981,813
		Mobile	568,203	550,930	540,687	540,685	540,685
		Nonroad	328,952	328,952	328,952	328,952	328,952
		Point	422,698	422,551	422,551	422,551	422,551
		Utility	10,317	10,565	10,565	10,565	10,565
		TOTAL	**2,389,491**	**2,353,426**	**2,289,671**	**2,287,791**	**2,284,566**
	Rocky Mountain	Area	550,376	546,095	507,600	501,216	493,682
		Mobile	255,614	255,233	238,916	238,838	227,175
		Nonroad	118,730	118,730	118,730	118,730	118,730
		Point	66,639	66,639	66,499	66,499	66,499
		Utility	4,129	4,223	4,223	4,223	4,223
		TOTAL	**995,487**	**990,920**	**935,967**	**929,505**	**910,308**
	Northwest	Area	373,140	365,636	360,593	360,593	321,672
		Mobile	195,725	195,597	195,597	195,597	185,187
		Nonroad	89,223	89,223	89,223	89,223	89,223
		Point	56,018	56,018	56,018	56,018	56,018
		Utility	1,296	1,287	1,287	1,287	1,287
		TOTAL	**715,402**	**707,762**	**702,718**	**702,718**	**653,388**
	West	Area	769,202	717,558	693,558	693,150	689,704
		Mobile	215,160	206,318	197,694	195,040	195,023
		Nonroad	231,545	231,545	231,545	231,545	231,545
		Point	89,364	86,908	86,894	86,894	86,867
		Utility	3,313	3,292	3,292	3,292	3,292
		TOTAL	**1,308,585**	**1,245,620**	**1,212,983**	**1,209,921**	**1,206,431**

Table 6.5 National Summary of Projected Emission Impacts for Alternative $PM_{2.5}$ Standards: Baseline and Post-Control Emission Levels

Pollutant	Region	Sector	2010 Baseline Emissions	National $PM_{2.5}$ Strategy	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
SOA	**Midwest/Northeast**	Area	33,153	32,324	26,857	26,117	25,975
		Mobile	11,342	11,284	10,906	10,748	10,581
		Nonroad	9,304	9,304	9,304	9,304	9,304
		Point	11,627	11,627	11,618	11,618	11,618
		Utility	262	245	245	245	245
		TOTAL	**65,688**	**64,784**	**58,930**	**58,031**	**57,723**
	Southeast	Area	15,050	15,044	13,556	13,038	13,038
		Mobile	6,686	6,686	6,686	6,624	6,624
		Nonroad	4,785	4,785	4,785	4,785	4,785
		Point	7,234	7,234	7,233	7,233	7,233
		Utility	95	84	84	84	84
		TOTAL	**33,851**	**33,833**	**32,344**	**31,764**	**31,764**
	South Central	Area	8,623	8,398	6,522	6,457	6,373
		Mobile	3,890	3,784	3,722	3,722	3,722
		Nonroad	4,436	4,436	4,436	4,436	4,436
		Point	3,734	3,732	3,732	3,732	3,732
		Utility	63	58	58	58	58
		TOTAL	**20,746**	**20,409**	**18,470**	**18,405**	**18,322**
	Rocky Mountain	Area	4,738	4,630	3,485	3,386	3,275
		Mobile	2,015	2,012	1,913	1,912	1,841
		Nonroad	1,594	1,594	1,594	1,594	1,594
		Point	738	738	737	737	737
		Utility	54	52	52	52	52
		TOTAL	**9,138**	**9,026**	**7,779**	**7,680**	**7,498**
	Northwest	Area	5,334	5,114	4,956	4,956	3,417
		Mobile	1,287	1,286	1,286	1,286	1,223
		Nonroad	1,145	1,145	1,145	1,145	1,145
		Point	979	979	979	979	979
		Utility	4	4	4	4	4
		TOTAL	**8,748**	**8,528**	**8,370**	**8,370**	**6,768**
	West	Area	5,945	5,350	4,652	4,648	4,607
		Mobile	1,699	1,645	1,592	1,576	1,576
		Nonroad	3,057	3,057	3,057	3,057	3,057
		Point	861	828	828	828	827
		Utility	14	14	14	14	14
		TOTAL	**11,576**	**10,894**	**10,143**	**10,123**	**10,081**

Table 6.6a Summary of Projected Initial and Residual $PM_{2.5}$ Nonattainment (Number of Tier 1 Monitored Counties)

Control Region	$PM_{2.5}$ 16/65					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	38	38	3	6	5	1
Southeast	8	8	0	0	0	0
South Central	5	5	0	2	2	0
Rocky Mountain	8	8	0	3	3	0
Northwest	0	0	0	0	0	0
West	11	10	5	8	7	5
Nation	70	69	8	19	17	6

Control Region	$PM_{2.5}$ 15/65					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	56	56	3	10	9	1
Southeast	16	16	0	1	1	0
South Central	7	7	0	2	2	0
Rocky Mountain	11	11	0	6	6	0
Northwest	0	0	0	0	0	0
West	12	11	5	11	10	5
Nation	102	101	8	30	28	6

Control Region	$PM_{2.5}$ 15/50					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	58	56	12	11	9	4
Southeast	16	16	0	1	1	0
South Central	8	7	3	2	2	0
Rocky Mountain	18	11	10	8	6	2
Northwest	6	0	6	4	0	4
West	16	11	16	15	10	12
Nation	122	101	47	41	28	22

Table 6.6b Summary of Projected Initial and Residual Nonattainment for the New PM_{10} 50/150 (99th percentile) Standard (Number of Tier 1 Monitored Counties)

Control Region	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	2	1	2	2	1	2
Southeast	0	0	0	0	0	0
South Central	1	1	0	1	1	0
Rocky Mountain	1	0	1	1	0	1
Northwest	1	0	1	1	0	1
West	6	4	3	4	2	3
Nation	11	6	7	9	4	7

Table 6.7a presents the average baseline and post-control $PM_{2.5}$ concentrations for the subset of counties in each control region that are projected to initially violate the $PM_{2.5}$ alternatives. Table 6.7b presents the same information for the new PM_{10} 50/150 (99th percentile) standard.

Table 6.8a presents the average baseline and post-control $PM_{2.5}$ concentrations for the subset of counties in each control region that are residual nonattainment for the $PM_{2.5}$ alternatives. Table 6.8b presents the same information for the new PM_{10} 50/150 (99th percentile) standard. The approximate average difference between the predicted post-control PM concentration and the attainment level in each control region can be calculated from this table. For instance, for the 15/65 alternative presented in table 6.8a, the South Central control region contains 2 residual nonattainment counties with an average post-control annual $PM_{2.5}$ concentration of 16.1 μg/m^3. This is roughly 1.1 μg/m^3 above the 15 μg/m^3 standard after accounting for the rounding convention (i.e., 15.05 μg/m^3 is considered nonattainment).

Table 6.7a Average Baseline and Post-Control $PM_{2.5}$ Concentrations for Projected Initial $PM_{2.5}$ Nonattainment Counties (μg/m³)

Region	No. of Counties	$PM_{2.5}$ 16/65			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	38	18.0	48.7	15.1	40.9
Southeast	8	17.3	36.3	15.5	32.4
South Central	5	17.2	44.9	15.9	41.6
Rocky Mountain	8	18.4	48.1	16.3	42.9
Northwest	0	--	--	--	--
West	11	17.6	69.0	16.8	65.9
Nation	70	17.6	50.1	15.6	44.1

Region	No. of Counties	$PM_{2.5}$ 15/65			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	56	17.2	45.0	14.1	36.9
Southeast	16	16.4	35.2	14.2	30.5
South Central	7	16.7	40.9	15.0	36.6
Rocky Mountain	11	17.5	43.4	15.5	38.5
Northwest	0	--	--	--	--
West	12	17.5	67.7	16.7	64.5
Nation	102	17.1	45.7	14.6	39.3

Region	No. of Counties	$PM_{2.5}$ 15/50			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	58	17.1	45.3	13.9	37.0
Southeast	16	16.4	35.2	14.2	30.5
South Central	8	15.8	42.5	14.2	38.2
Rocky Mountain	18	14.7	47.6	13.1	42.9
Northwest	6	11.1	55.8	10.1	50.8
West	16	16.7	65.2	15.9	62.0
Nation	122	16.2	47.3	13.9	41.0

Table 6.7b Average Baseline and Post-Control PM_{10} Concentrations for Projected Initial PM_{10} Nonattainment Counties: New PM_{10} 50/150 (99th percentile) Standard (µg/m^3)

Control Region	No. of Counties	Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	2	49.9	356.7	41.8	276.9
Southeast	0	--	--	--	--
South Central	1	57.0	127.7	51.7	115.8
Rocky Mountain	1	15.8	235.8	15.2	227.1
Northwest	1	38.5	175.5	37.6	171.4
West	6	49.0	207.2	48.2	204.9
Nation	11	45.9	226.9	43.4	208.8

Table 6.8a Average Baseline and Post-Control $PM_{2.5}$ Concentrations for Projected Residual $PM_{2.5}$ Nonattainment Counties ($\mu g/m^3$)

Region	No. of Counties	$PM_{2.5}$ 16/65			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	6	20.4	79.0	17.5	68.0
Southeast	0	--	--	--	--
South Central	2	18.1	49.6	16.7	46.2
Rocky Mountain	3	20.9	50.8	18.1	44.3
Northwest	0	--	--	--	--
West	8	18.1	74.3	17.4	71.5
Nation	19	19.2	69.5	17.5	63.4

Region	No. of Counties	$PM_{2.5}$ 15/65			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	10	19.7	68.0	16.6	57.6
Southeast	1	17.3	41.6	15.2	36.5
South Central	2	18.1	48.6	16.1	43.3
Rocky Mountain	6	18.9	49.2	16.7	43.6
Northwest	0	--	--	--	--
West	11	17.6	69.1	16.9	66.3
Nation	30	18.6	62.5	16.6	56.3

Region	No. of Counties	$PM_{2.5}$ 15/50			
		Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	11	19.3	67.9	16.2	56.9
Southeast	1	17.3	41.6	15.2	36.5
South Central	2	18.1	48.6	16.1	43.2
Rocky Mountain	8	17.1	51.5	15.1	45.8
Northwest	4	10.8	57.5	9.7	51.7
West	15	16.7	66.0	16.0	63.1
Nation	41	17.0	61.4	15.2	55.3

Table 6.8b Average Baseline and Post-Control PM_{10} Concentrations for Projected Residual PM_{10} Nonattainment Counties: New PM_{10} 50/150 (99th percentile) Standard (µg/m^3)

Control Region	No. of Counties	Baseline Concentration		Post-Control Concentration	
		Annual	24-Hour	Annual	24-Hour
Midwest/Northeast	2	49.9	356.7	41.8	276.9
Southeast	0	--	--	--	--
South Central	1	57.0	127.7	51.7	115.8
Rocky Mountain	1	15.8	235.8	15.2	227.1
Northwest	1	38.5	175.5	37.6	171.4
West	4	47.4	236.9	47.2	235.7
Nation[a]	9	44.6	244.4	41.9	223.4

a All 9 projected residual nonattainment counties are also projected to be residual nonattainment for the current PM_{10} standard.

For each alternative standard, Tables 6.7a and 6.8a indicate that the most persistent nonattainment problem occurs with counties in the West region, where less than a handful of the initial nonattainment counties are able to attain after control measures are applied. This apparent insensitivity to control can be explained in part by the high predicted background biogenic concentrations in this region. For the $PM_{2.5}$ 15/65 standard, the S-R matrix predicts that annual average biogenic organic concentrations for residual nonattainment counties in these regions ranges from 2.7 to 8.6 µg/m^3. However, the PM Staff Paper indicates the range of *total* background concentrations (i.e., organics, nitrates, sulfates, soil dust) in the western United States is 1 to 4 µg/m^3 (U.S. EPA, 1996, p. IV-13). The IMPROVE monitoring network's measurements of soil dust generally shows average concentrations less than 1 µg/m^3. Therefore, it is not unreasonable to expect biogenic concentrations in the western United States to generally be below 3 µg/m^3. If the biogenic component of the air quality in residual nonattainment counties located in the western United States (i.e., counties in the Rocky Mountain, Northwest, and West control regions) is capped at 3 µg/m^3 and total post-control $PM_{2.5}$ concentrations recalculated, the total number of residual nonattainment counties for the $PM_{2.5}$ 15/65 alternative declines to 18.

Some of the residual nonattainment counties also are predicted to have high 2010 CAA baseline and post-control levels of fugitive dust. Many of these counties contain large urban areas, where the fugitive dust fraction of total $PM_{2.5}$ mass is expected to be smaller than in rural areas. For a typical eastern urban area, recent speciated monitoring data indicate that the soil component is 5% of $PM_{2.5}$ mass. Primary $PM_{2.5}$ emissions from paved roads and construction sites account for this ambient contribution (U.S. EPA, 1997). In contrast, for the 4 eastern urban counties from the set of 30 residual nonattainment counties, the fugitive dust component of $PM_{2.5}$ averages 24%. This illustrates the propensity of the air quality model to over predict the impact of fugitive dust sources in some cases and suggests that the actual number of residual nonattainment counties may be lower. Chapter 4 discusses this aspect of the $PM_{2.5}$ air quality modeling and how it may affect the cost analyses.

6.5 COST IMPACT RESULTS

This section presents the incremental annual control cost associated with control measures modeled to meet alternative $PM_{2.5}$ standards. These results are incremental to partial attainment of the current ozone and PM_{10} standards. There are two components that make up the incremental cost results for the $PM_{2.5}$ alternatives. The first component is the cost associated with the National $PM_{2.5}$ Strategy. The second component is the cost associated with application of control measures in each of the six PM control regions. The costs reported in this analysis *do not* represent the present value of the annual cost of control measures applied on a year-by-year basis from 1997 through 2010. Rather, the costs are derived from a static framework that compares two “states”; the first state being the future year 2010 in the absence of a new $PM_{2.5}$ standard, and the second state being the year 2010 with actions taken to meet a new $PM_{2.5}$ standard. The costs reported in this analysis represent the difference in cost between these two states.

Table 6.9 presents the control cost associated with meeting alternative $PM_{2.5}$ standards, as well as the new PM_{10} standard. These costs represent partial attainment of the alternative standards, since not all projected $PM_{2.5}$ nonattainment counties are predicted to attain the alternative standards using the control measures available in the incremental control measure database. For all alternative standards, the greatest fraction of the national incremental cost for partial attainment is concentrated in the Midwest/Northeast control region.

Table 6.9 National Partial Attainment Cost for New PM_{10} and Alternative $PM_{2.5}$ Standards--Total Annual Cost[a] (Million 1990$)

Region	PM_{10} 50/150 (99th Percentile)	$PM_{2.5}$ 16/65	$PM_{2.5}$ 15/65	$PM_{2.5}$ 15/50
Midwest/Northeast	220	1,800	3,100	3,300
Southeast	--	14	130	130
South Central	170	340	1,800	1,800
Rocky Mountain	5	450	640	840
Northwest	20	0	0	340
West	27	280	310	380
National $PM_{2.5}$ Strategy	--	2,600	2,600	2,600
National Total[b]	440	5,500	8,600	9,400

a Costs for new PM_{10} standard are incremental to partial attainment of the current ozone standard. Costs for the alternative $PM_{2.5}$ standards are incremental to partial attainment of the current ozone and current PM_{10} standards.

b The national totals for $PM_{2.5}$ include the cost of the National $PM_{2.5}$ Strategy. However, the Integrated Planning Model (IPM) used to estimate utility sector impacts does not include the same control region definitions used in the PM Optimization Model, so the incremental $PM_{2.5}$ cost shown for each control region does not include the cost of the National $PM_{2.5}$ Strategy. All totals may not agree due to rounding.

6.6 ESTIMATING $PM_{2.5}$ IMPACTS AFTER ATTAINMENT OF AN ALTERNATIVE OZONE NAAQS

Many NOx and VOC control measures selected to reduce ozone concentrations also can affect concentrations of $PM_{2.5}$. Therefore, it is possible to reduce the overall cost of addressing the combination of ozone and $PM_{2.5}$ nonattainment if control strategies can be thoughtfully designed to reduce concentrations of both pollutants simultaneously. Table 6.10 indicates the potential for this type of cost savings by showing the projected number of initial ozone nonattainment areas and $PM_{2.5}$ nonattainment counties and the potential overlap. For the 0.08

5th Max. alternative, from 10 to 13 of the initial 15 ozone nonattainment areas contain at least one county projected to be nonattainment for the $PM_{2.5}$ alternatives listed. For the 0.08 3rd Max. alternative, from 15 to 20 of the initial 28 ozone nonattainment areas contain at least one county projected to be nonattainment for the $PM_{2.5}$ alternatives listed. Not shown in the table is the fact that several projected $PM_{2.5}$ nonattainment counties are located near (i.e., within a one or two county radius), but not in, projected ozone nonattainment areas. The NOx and VOC reductions occurring in ozone nonattainment areas that are near $PM_{2.5}$ nonattainment counties may also influence $PM_{2.5}$ air quality in the nearby $PM_{2.5}$ nonattainment counties.

Table 6.10 Projected $PM_{2.5}$ Nonattainment Counties Located in Projected Ozone Nonattainment Areas

Ozone-$PM_{2.5}$ Standard Combination		Number of Initial Ozone Nonattainment Areas (Counties)[a]	Number of Initial $PM_{2.5}$ Nonattainment Counties[b]	Number of $PM_{2.5}$ Nonattainment Counties Located In Ozone Nonattainment Areas[c]
0.08 5th Max.	**$PM_{2.5}$ 16/65**	15 (167)	70	20 (10)
	$PM_{2.5}$ 15/65	15 (167)	102	25 (11)
	$PM_{2.5}$ 15/50	15 (167)	122	28 (13)
0.08 3rd Max.	**$PM_{2.5}$ 16/65**	28 (278)	70	26 (15)
	$PM_{2.5}$ 15/65	28 (278)	102	35 (18)
	$PM_{2.5}$ 15/50	28 (278)	122	39 (20)

a Number of initial ozone nonattainment areas and counties incremental to the 2010 CAA Baseline.
b Number of initial $PM_{2.5}$ nonattainment counties incremental to partial attainment of the current PM_{10} standard; Tier 1 monitored counties only.
c There may be more than one $PM_{2.5}$ nonattainment county located in an ozone nonattainment area. The number in parentheses indicates the number of projected ozone nonattainment areas containing at least one projected $PM_{2.5}$ nonattainment county.

Appendix D of this report contains an analysis that estimates the potential effect that compliance with the 0.08 3rd Max. ozone alternative has on attaining the $PM_{2.5}$ 15/50 alternative. Following the selection of ozone control measures, the S-R matrix is used to assess the improvement in $PM_{2.5}$ air quality that is achieved by those measures. The control measures selected in the ozone analysis are not available for selection again in the PM optimization to eliminate double counting of the emission reductions and costs of a control measure. The analysis indicates that some cost savings is likely to accrue, but the level of estimated savings is small (roughly $100 million) due to projected residual nonattainment of the ozone standard. Full attainment of the 0.08 3rd Max. ozone standard is likely to further reduce the incremental cost of control for $PM_{2.5}$ alternatives.

6.7 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

Because a quantitative uncertainty cannot be assigned to every input, the total uncertainty in the emission reduction, air quality, and cost outputs cannot be estimated. Nonetheless, the individual uncertainties can be characterized qualitatively.

Air quality projections to 2010 embody several component uncertainties, such as uncertainties in emission data, emission growth rates, baseline air quality data, and air quality modeling. These uncertainties are addressed in Chapter 4. The application of control measures and their associated costs are affected by the propensity of either the emissions projection methodology or the air quality prediction methodology to overstate or understate initial nonattainment in specific areas.

As noted previously, the optimization model annual cost inputs are in the form of average incremental cost per ton reduced. Even if these cost per ton estimates are adjusted to account for source size differences (as is done for some point source controls), these adjustments do not account for other important cost-determining variables, such as source status (new versus retrofit), annual operating hours, equipment, materials of construction, and unit prices for utilities, materials, and labor.

Also, the optimization seeks least cost solutions for attainment of alternative $PM_{2.5}$ standards. Political, institutional, and social constraints may prevent the type of least cost strategies modeled in this analysis from being implemented in reality.

The least-cost optimization model also introduces a measure of uncertainty. For instance, when calculating the cost per average microgram per cubic meter reduced, the model does not count any emission reductions that are in excess of those needed to meet a specified standard. This assumption could cause the cost per average microgram per cubic meter—and, in turn, the final control costs—to be overstated or understated depending upon whether control of the precursor was beneficial.

6.8 REFERENCES

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7.0. EMISSION REDUCTION AND COST IMPACTS FOR OZONE ALTERNATIVES

7.1 RESULTS IN BRIEF

Based on projected emissions levels for the year 2010, this analysis estimates that 10 nonattainment areas (112 counties) are projected to need additional reductions beyond those currently mandated in the Clean Air Act (CAA) and those needed to partially achieve the current ozone standard, to meet the selected 0.08 4th Max. ozone national ambient air quality standard (NAAQS). The control cost associated with achieving partial nationwide attainment of the selected ozone NAAQS is estimated to be $1.1 billion (1990 dollars). Due to overlap between projected $PM_{2.5}$ nonattainment counties and ozone nonattainment areas, some control measures may produce air quality benefits for both standards that result in cost efficiencies.

7.2 INTRODUCTION

This chapter presents the methodology and results for the ozone NAAQS alternatives emissions and control cost impacts analysis. This analysis projects emission reductions resulting from additional controls needed by the year 2010 to attain the alternative ozone standards presented in Chapter 3. Emissions changes, which are translated into air quality changes, are inputs to the benefits analysis presented in Chapter 12. This analysis also estimates the projected costs (in 1990 dollars) of installing, operating, and maintaining additional controls. These control costs are inputs to the economic impact analysis presented in Chapter 11. Chapter 9 addresses the potential cost of full attainment, including the benefits of technological innovation and flexible implementation strategies. The administrative cost of the promulgated standard is addressed in Chapter 10. The following sections in this chapter cover:

- Methodology for estimating emissions and cost impacts for ozone alternatives;
- Emission reduction and control cost results for ozone alternatives; and
- Analytical uncertainties, limitations, and potential biases.

7.3 EMISSION REDUCTION AND COST IMPACT ANALYSIS METHODOLOGY

This analysis estimates the emission reductions and control costs for achieving air quality improvements necessary to attain alternative ozone NAAQS in projected nonattainment areas. The analysis methodology uses the nonattainment area-specific emissions inventory, the nonattainment area-specific emission reduction targets for volatile organic compounds (VOC) and nitrogen oxides (NOx), and the database of available control measures.

Since the 2010 CAA baseline projection indicates that several areas do not attain the current ozone standard, control measures are applied to address nonattainment of the current ozone standard. The methodology used to assess the impact of the current ozone standard is identical to the methodology used for the new ozone standard alternatives. The results of the current ozone standard analysis are presented and discussed in Appendix C.

Control measure selection for the alternative 8-hour ozone standards is not incremental to the current 1-hour ozone standard, consequently the current and new ozone standards are evaluated incremental to the 2010 CAA baseline. The analysis is designed this way because in some areas, the 8-hour standards are modeled to require significantly different emission reduction targets. For instance, to attain the current ozone standard in at least one of the modeled areas, both VOC and NOx reductions must be achieved from the 2010 CAA baseline. For the least stringent 8-hour standard analyzed, this same area is modeled to require only VOC reductions from the 2010 CAA baseline. For areas like this example, some control measures selected to meet the multiple pollutant goals of the current ozone standard may not be optimal for making progress toward the proposed 8-hour standards. Since both the current and new ozone standards are evaluated incremental to the 2010 CAA baseline, to obtain the incremental cost of the new standards, the cost of area-specific control measures that are duplicated in the 8-hour analysis is subtracted from the cost of the 8-hour standards.

Table 7.1 indicates the number of initial projected ozone nonattainment areas for which control measures are selected for the analysis year 2010. The first set of columns in this table shows the number of projected areas relative to the 2010 CAA baseline. The third column shows the number of projected nonattainment areas that are not also projected to be nonattainment for the current ozone standard.

Table 7.1 Initial Projected Number of Ozone Nonattainment Areas (and Associated Counties)

Standard	Incremental to 2010 CAA Baseline	Unique to Alternative Standard[a]
0.08 5th Max.	15 (167)	5 (85)
0.08 4th Max.	19 (203)	10 (112)
0.08 3rd Max.	28 (278)	19 (189)

a Number of areas that are not initially projected to be nonattainment for the current ozone standard.

7.3.1 Control Measure Selection in Projected Ozone Nonattainment Areas

Control measure selection in this analysis is modeled using an approach for achieving the ozone standards that simulates current ozone standard implementation practices. Ultimately, state and local air pollution control authorities, in cooperation with federal efforts, will devise implementation strategies that achieve air quality goals in a manner that minimizes negative impacts.

This analysis relies on a combination of national and local control measures to achieve incremental improvements in ozone air quality from the 2010 CAA baseline. Air quality goals are translated into area-specific VOC and NOx emission reduction targets. The targets are established based on air quality modeling and recent ambient ozone monitoring data. The methodology used to establish these emission reduction goals improves upon methods used in the 1996 Regulatory Impact Analysis (RIA) of the proposed ozone NAAQS, and in some areas results in significantly different targets. Emission reduction targets are developed from a series of Regional Oxidant Model (ROM) matrix runs (i.e., simulations of across-the-board VOC and NOx reductions). The targets are expressed in terms of percent reduction in anthropogenic VOC and/or NOx emissions beyond emission levels corresponding to 2007 emission projections and

CAA-mandated controls (U.S. EPA, 1997a). Adjustments are made to these targets to account for the impacts of the regional NOx control strategy (i.e., the OTAG NOx cap and NLEV), and emissions growth and control to the year 2010 (U.S. EPA, 1997b). It should be noted that the solution set of emission reduction targets for projected nonattainment areas is not unique. This RIA models one emission reduction solution among many potential solutions.

A range of national measures that could be applied to reduce VOC and/or NOx on a broad scale were explored. Several VOC-oriented national measures such as more stringent VOC-content limits on consumer solvents and reformulated gasoline (RFG) were considered, but ultimately not included, because the national cost of implementing these measures was very high relative to the VOC reductions achieved in initially projected nonattainment areas. Though not included as national measures, the consumer solvent and RFG control measures are available in this analysis as *local* control measures.

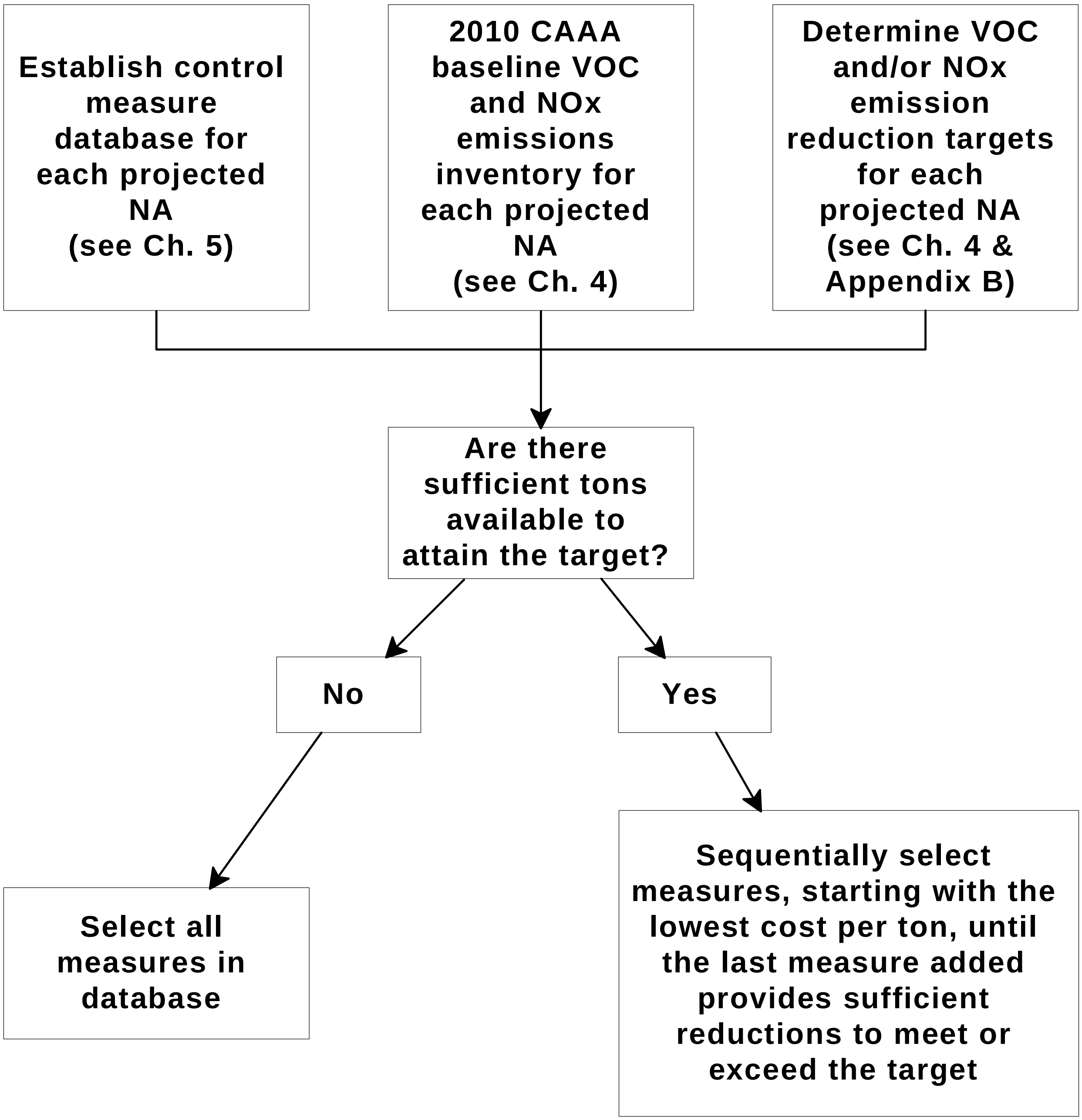
Changes in vehicle or engine emission standards were also explored. These measures are best applied at the national level because it would be expensive and difficult for vehicle and engine manufacturers to comply with a patchwork of standards applied at the local level. Also, because motor vehicles and engines are mobile, much of the benefit of vehicle or engine emissions standards applied at the local level could be lost to immigration of dirtier vehicles or engines into the local area. More stringent Tier 2 light duty truck standards are included as a national control measure to achieve widespread reductions in both VOC and NOx emissions. Chapter 5 contains a detailed discussion of this control measure. This control measure is referred to as the National Ozone Strategy in this RIA. Emission reductions for the National Ozone Strategy are estimated for every county in the nation, including counties in projected nonattainment areas. The reductions occurring in projected nonattainment areas are credited toward achievement of the areas' emission targets.

After reductions due to the National Ozone Strategy are credited in each projected nonattainment area, local control measures are applied. Figure 7.1 shows the basic elements of the local nonattainment area control strategy selection process. Local measures are rank ordered by increasing average annual incremental cost per ton of reduction of the target pollutant[1]. Control measures are restricted to those with an average annual incremental cost of $10,000 per ton or less. Section 7.3.2 provides further discussion of this control measures selection threshold. Control measures are selected from this list until the sum of all reductions meets or exceeds the targeted reductions established for that nonattainment area. In areas with both VOC and NOx targets, both targets must be met. In many instances, for the analysis presented in this chapter, all available measures are selected before the emissions target is reached resulting in *residual nonattainment* of the NAAQS.

After the initial round of control measure selection, areas that achieve their targets are reviewed to determine where over control can be reduced. For areas where the last measure selected results in over control, measures with a higher average annual incremental cost per ton (with less reduction) are evaluated, or less costly measures eliminated in order to minimize over control. Changes to the initial set of selected control measures are only made if the total annual cost for the area also declines.

See Chapters 5 and 6 for a discussion of average annual incremental cost per ton and how it relates to control measure selection.

Figure 7.1
Local Ozone Control Strategy Selection Process



In areas with both VOC and NOx reduction targets, a review is also conducted to determine whether unselected measures reducing both VOC and NOx are more cost-effective than selected measures that reduce only one pollutant. Changes to the initial set of selected control measures are only made if the total annual cost for the area also declines.

7.3.2 Control Measure Selection Cost per Ton Threshold

Control measures with an average annual incremental cost per ton of VOC or NOx of $10,000 (1990 dollars) or less are the only ones considered for the analysis results reported in this chapter[1]. Since the ozone cost analysis is generally designed to simulate current implementation practices, this threshold provides a realistic estimate of the highest incremental cost impact that affected entities might face. To date, States generally have not chosen to require existing sources to apply control measures with incremental costs above this threshold. For instance, the South Coast Air Quality Management District (SCAQMD), which manages the most severe ozone nonattainment area in the United States, does not currently apply VOC or NOx control measures with an average annual incremental cost above $11,100 per ton (1990 dollars) (SCAQMD, 1996).

Since most areas do not have an ozone problem as severe as the South Coast (i.e., $10,000 may be too high for some areas), and because it is possible that future implementation of more stringent ozone standards may require more costly control measures (i.e., $10,000 may be too low for some areas in the future), Appendix D includes a sensitivity analysis on a range of control measure selection thresholds. Thresholds of $7,000 per ton, $20,000 per ton, and no cut-off are examined. Generally, given the full set of control measures in the control measure database and the target sets for each projected nonattainment area, the level of reductions achieved and progress toward full attainment is relatively insensitive to the alternative cost

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The control measure database used in this analysis does contain control measures with an average annual incremental cost per ton greater than $10,000. These are generally measures affecting point sources that have low-concentration pollution streams and/or relatively stringent baseline control levels. The $10,000 average annual incremental cost per ton threshold was not used in the 1996 RIA of the proposed ozone NAAQS.

thresholds.

7.4 EMISSION REDUCTION IMPACT RESULTS

This section presents the emission reduction results for the analysis of alternative ozone standards. Included are estimates of the total emission reductions from each projected ozone nonattainment area resulting from national and local control measures, and the estimated change in the attainment status for the areas initially projected not to attain alternative ozone standards. The costs reported in this analysis *do not* represent the present value of the annual cost of control measures applied on a year-by-year basis from 1997 through 2010. Rather, the costs are derived from a static framework that compares two “states”; the first state being the future year 2010 in the absence of a new ozone standard, and the second state being the year 2010 with actions taken to meet a new ozone standard. The costs reported in this analysis represent the difference in cost between these two states.

Table 7.2 presents the estimated ozone season daily VOC and NOx emission reductions achieved by the National Ozone Strategy (more stringent Tier 2 light duty truck standards) and local control measures for each alternative ozone standard. The National Ozone Strategy provides only a small fraction of the total VOC emission reductions, but a slightly larger fraction (8 to 10 percent) of the total NOx emission reductions.

Table 7.2 Summary of Ozone Season Daily VOC and NOx Reductions in Ozone Nonattainment Areas

Standard	National Ozone Strategy Reductions[a] (ozone season tons per day)		Local Control Measure Reductions (ozone season tons per day)			
			Incremental to 2010 CAA Baseline		Incremental to Current Ozone Standard	
	VOC	NOx	VOC	NOx	VOC	NOx
0.08 5th Max.	16	46	1,146	393	536	111
0.08 4th Max.	18	53	1,422	582	812	297
0.08 3rd Max.	24	71	1,862	803	1,252	518

a Reductions are incremental to the 2010 CAA baseline.

Table 7.3 shows the national summary of ozone nonattainment area emission reduction targets and the reductions achieved in the analysis of each alternative standard. Both the number of projected ozone nonattainment areas increases and the amount of reduction needed in each area increases with the level of stringency of the standard. This table shows that the combination of the National Ozone Strategy and local control measures that meet the average annual incremental cost per ton control measure selection threshold of $10,000 are able to achieve on average from 37 to 43 percent of the VOC reduction target, and 22 to 24 percent of the NOx reduction target. Since areas that are estimated to be in residual nonattainment for the current ozone standard are a subset of the areas included in the 0.08 5th Max. and 0.08 3rd Max. analyses, full attainment of the current ozone standard would increase the average percent reduction achieved for the alternative ozone standards relative to the targets.

Table 7.3 National Summary of Local VOC and NOx Emission Reduction Targets and Reductions Achieved[a]

Standard	2010 CAA Baseline Emissions (tons per day)		Target Reductions (tons per day)		Reductions Achieved Relative to Targets (tons per day)		Percent Achieved Relative to Targets	
	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx
0.08 5th Max.	7,450	5,143	2,667	1,722	1,149	408	43%	24%
0.08 4th Max.	7,913	6,040	3,455	2,529	1,308	582	38%	23%
0.08 3rd Max.	10,278	8,022	4,598	3,648	1,706	803	37%	22%

a Emission reduction targets and achieved reductions are incremental to the 2010 CAA Baseline. Reductions in pollutants not targeted in each area are not included in this table since in the methodology used in this analysis they are not assumed to reduce ozone concentrations. Only control measures with an average annual incremental cost of $10,000 per ton or less are included in this analysis.

Table 7.4 provides more detail on the distribution of reductions achieved as a percent of reductions needed for each alternative standard. For the 0.08 5th Max. standard, 3 out of 15 areas are projected to reach full attainment. For the 0.08 3rd Max. standard, 1 out of 28 areas is projected to reach full attainment. The nonattainment areas represented for the current ozone standard are a subset of the nonattainment areas presented for the set of alternative 0.08 ppm standards. Areas that are in residual nonattainment for the current standard make little or no additional progress under the alternative 0.08 ppm standards.

Table 7.5 indicates the number of projected nonattainment areas that do not reach the target reduction levels after all control measures less than $10,000 per ton are selected. These residual nonattainment areas are counted incremental to both the 2010 CAA baseline and to the nonattainment areas for the current ozone standard.

Table 7.4 Distribution of VOC and NOx Emission Reductions Achieved as a Percent of Reductions Needed[a]

Standard	Number of Initial Nonattainment Areas Achieving the Specified Progress[b]						Total Number of Areas
	< 20%	20 - 40%	40 - 60%	60 - 80%	> 80%	Full Attain-ment	
Current Standard	1	3	3	0	1	1	9
0.08 5th Max.	3	7	2	0	0	3	15
0.08 4th Max.	3	9	2	2	1	2	19
0.08 3rd Max.	6	13	5	1	2	1	28

a Reductions achieved as a percent of reductions needed for target pollutants only (see Table 7.3).
b Number of areas incremental to the 2010 CAA baseline. Only control measures with an average annual incremental cost of $10,000 per ton or less are included in this analysis.

Table 7.5 Number of Residual Ozone Nonattainment Areas

Standard	Incremental to 2010 CAA Baseline	Unique to Alternative Standard[a]
0.08 5th Max.	12	6
0.08 4th Max.	17	10
0.08 3rd Max.	27	19

a Number of areas that are not projected to be residual nonattainment for the current ozone standard.

7.5 COST IMPACT RESULTS

This section presents the incremental annual control cost associated with additional control measures modeled to meet alternative ozone standards. Two components comprise the incremental annual cost. The first component is the cost of the National Ozone Strategy (more stringent Tier 2 light duty truck standards). The second component is the cost associated with application of local VOC and/or NOx control measures in each of the projected ozone nonattainment areas.

Table 7.6 presents the national costs of the alternative ozone standards. These costs are calculated incremental to partial attianment of the current ozone standard. Using the additional control measures modeled for this analysis, not all areas are projected to attain the alternative standards. For this reason, the costs presented in this section are characterized as *partial attainment* costs. The national cost of the National Ozone Strategy (i.e., more stringent Tier 2 light duty truck standards) is estimated to be $300 million (1990 dollars). The total cost of partial attainment of the ozone standards, including both national and local control measures, is estimated to be $890 million to $1.4 billion (1990 dollars).

Table 7.7 National Summary of Partial Attainment Control Cost for Alternative Ozone Standards

Control Measure	Annual Control Cost (Millions 1990$)[a]		
	0.08 5th Max.	0.08 4th Max.	0.08 3rd Max.
National Ozone Strategy	330	330	330
Local Control Measures	560	780	1,000
Total	890	1,100	1,400

a Costs are incremental to partial attainment of the current ozone standard. Only control measures with an average annual incremental cost of $10,000 per ton or less are included in this analysis. Totals may not agree due to rounding.

7.6 ESTIMATING OZONE IMPACTS AFTER ATTAINMENT OF AN ALTERNATIVE $PM_{2.5}$ STANDARD

Many of the VOC and NOx control measures selected in the $PM_{2.5}$ cost analysis can also reduce ozone concentrations. Any $PM_{2.5}$-related VOC and/or NOx reductions occurring both inside and outside ozone nonattainment areas may impact ozone air quality, and the number or stringency of "ozone-specific" emission control measures that must be employed to meet new ozone standards. Therefore, it is possible to reduce the overall cost of addressing the combination of ozone and $PM_{2.5}$ nonattainment if control strategies can be thoughtfully designed to reduce concentrations of both pollutants simultaneously. Table 7.8 indicates the potential for this type of cost savings by showing the projected number of initial ozone nonattainment areas and $PM_{2.5}$ nonattainment counties and the potential overlap. For the 0.08 5th Max. alternative, from 10 to 13 of the initial 15 ozone nonattainment areas contain at least one county projected to be nonattainment for the $PM_{2.5}$ alternatives listed. For the 0.08 4th Max. alternative, 14 of the initial 19 ozone nonattainmet areas contain at least one county projected to be nonattainment for the selected $PM_{2.5}$ 15/65 alternative. For the 0.08 3rd Max. alternative, from 15 to 20 of the initial 28 ozone nonattainment areas contain at least one county projected to be nonattainment for the $PM_{2.5}$ alternatives listed. Not shown in the table is the fact that several projected $PM_{2.5}$ nonattainment counties are located near (i.e., within a one or two county radius) but not in projected ozone nonattainment areas. The NOx and VOC reductions occurring outside but near ozone nonattainment areas due to $PM_{2.5}$ control may also influence ozone air quality inside ozone nonattainment areas.

Table 7.8 Projected $PM_{2.5}$ Nonattainment Counties Located in Projected Ozone Nonattainment Areas

Ozone-$PM_{2.5}$ Standard Combination		**Number of Initial Ozone Nonattainment Areas (Counties)[a]**	**Number of Initial $PM_{2.5}$ Nonattainment Counties[b]**	**Number of $PM_{2.5}$ Nonattainment Counties Located In Ozone Nonattainment Areas[c]**
0.08 5th Max.	**$PM_{2.5}$ 16/65**	15 (167)	70	20 (10)
	$PM_{2.5}$ 15/65	15 (167)	102	25 (11)
	$PM_{2.5}$ 15/50	15 (167)	122	28 (13)
0.08 4th Max.	**$PM_{2.5}$ 15/65**	19 (203)	102	30 (14)
0.08 3rd Max.	**$PM_{2.5}$ 16/65**	28 (278)	70	26 (15)
	$PM_{2.5}$ 15/65	28 (278)	102	35 (18)
	$PM_{2.5}$ 15/50	28 (278)	122	39 (20)

a Number of initial ozone nonattainment areas and counties incremental to the 2010 CAA Baseline.

b Number of initial $PM_{2.5}$ nonattainment counties incremental to partial attainment of the current PM_{10} standard; Tier 1 monitored counties only.

c There may be more than one $PM_{2.5}$ nonattainment county located in an ozone nonattainment area. The number in parentheses indicates the number of projected ozone nonattainment areas containing at least one projected $PM_{2.5}$ nonattainment county.

Appendix D of this report contains an analysis that estimates the potential effect that compliance with the $PM_{2.5}$ 15/50 alternative has on attaining the 0.08 3rd Max. ozone alternative. Reductions occurring inside ozone nonattainment areas from control measures selected in the $PM_{2.5}$ analysis are credited toward each ozone nonattainment areas' targets. The control measures selected in the $PM_{2.5}$ analysis are not available for selection again in the ozone analysis to eliminate double counting of the emission reductions and costs of a control measure. The analysis indicates that some cost savings is likely to accrue, but the level of estimated savings is small (roughly $100 million) due to projected residual nonattainment of the ozone standard. Full attainment of the $PM_{2.5}$ 15/50 alternative is likely to further reduce the incremental cost of control for the 0.08 3rd. Max. ozone alternative.

7.7 ANALYTICAL LIMITATIONS, UNCERTAINTIES, AND POTENTIAL BIASES

Because a quantitative uncertainty cannot be assigned to every input, the total uncertainty in the emission reduction and cost outputs cannot be estimated. Nonetheless, the individual uncertainties can be characterized qualitatively.

Air quality projections to 2010 embody several component uncertainties, such as uncertainties in emission data, emission growth rates, baseline air quality data, and air quality modeling. These uncertainties are addressed in Chapter 4. The application of control measures and their associated costs are affected by the propensity of either the emissions projection methodology or the emission target methodology to overstate or understate initial nonattainment in specific areas.

To model the costs of achieving potential air quality standards, control measures are selected from the control measure database using incremental cost effectiveness as the sole criterion. As noted previously in Section 6.7, cost-effectiveness, as used in this analysis, is a limited metric. Even if these cost per ton figures are adjusted to account for source size differences (as is done for some point source controls), these adjustments do not account for other important cost-determining variables, such as source status (new versus retrofit), annual operating hours, equipment, materials of construction, and unit prices for utilities, materials, and labor. State and local agencies may use criteria other than cost effectiveness in selecting control measures, and given more time and knowledge of local conditions, should be able to more accurately estimate the costs and emission reductions of the control options modeled in this analysis.

In areas where there is both a $PM_{2.5}$ and an ozone concern, States may recognize solutions that jointly address these problems, thereby reducing the overall cost of implementing both standards. Further, the analysis presented in this chapter does not adequately account for the potential effect on ozone air quality of control measures modeled in the $PM_{2.5}$ analysis. This is due both to shortcomings in available ozone air quality modeling, and the fact that only partial attainment of $PM_{2.5}$ standards is modeled.

7.8 REFERENCES

U.S. Environmental Protection Agency (1997a), Modeling Procedures Underlying the Revised Regulatory Impact Analysis for Proposed Revisions to the NAAQS for Ozone. Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; July.

U.S. Environmental Protection Agency (1997b), Methodology for Estimating Baseline and Post-Control Ozone Air Quality Concentrations for July 1997 Ozone/PM/RH RIA. Working paper. Office of Air Quality Planning and Standards; Research Triangle Park, N.C.; July.

South Coast Air Quality Management District (1996), Final 1997 Air Quality Management Plan. November.

8.0. VISIBILITY AND COST IMPACT ANALYSIS OF PROPOSED REGIONAL HAZE ALTERNATIVES

8.1 RESULTS IN BRIEF

The proposed regional haze (RH) program is designed to ensure reasonable progress toward the national visibility goal. It allows broad discretion on the part of the States in determining control measures to be imposed based on statutory criteria. Under the structure of the proposed RH rule, the States are able to consider the cost of emission reduction strategies in light of the degree of visibility improvement to be achieved. For this Regulatory Impact Analysis (RIA) the individual decisions on effectiveness of each of the control strategies applied in each region is modeled in a very limited way. Therefore the cost estimates presented in this report for meeting the presumptive visibility target are likely high estimates of actual implementation costs. The actual control cost of the proposed RH rule is likely to lie somewhere between zero and the estimates for the presumptive targets presented in this report.

Based on projected emissions levels for the year 2010 and progress toward attainment of the current ozone standard and the new $PM_{2.5}$ NAAQS (as estimated in Chapter 6), this analysis estimates that 76 mandated Class I areas need additional reductions to meet a presumptive target of improving the most impaired days (average of the 20 percent highest days) 1.0 deciview from 2000 to 2010. This analysis also estimates that 58 Class I areas need additional reductions to meet an alternative target of improving the most impaired days 1.0 deciview from 2000 to 2015 (i.e., an average of a 0.67 deciview improvement from 2000 to 2010). The additional cost of any implementation of the proposed RH rules will vary depending on the visibility targets submitted and approved as part of State plans. If targets are adjusted through that process to parallel the implementation programs for the new ozone and PM standards, the costs for meeting the adjusted targets in those areas will be borne by the ozone and PM programs. In this analysis costs are estimated assuming no changes in the presumptive target of 1.0 deciview improvement over 10 years for every mandatory Class I Federal area, or an alternative target of 1.0 deciview improvement over 15 years (i.e., an average 0.67 deciview improvement over 10 years). The additional control cost associated with meeting the presumptive 1.0 deciview target in 48 of these areas, and partial achievement in 28 areas is estimated to be $2.7 billion (1990 dollars). The additional control cost associated with meeting the alternative presumptive 0.67 deciview target in 41 of these areas, and partial achievement in 17 areas is estimated to be $2.1 billion (1990 dollars). In summary, the expected control cost associated with the proposed RH rule ranges from $0 to a maximum of $2.7 billion.

The estimate of the incremental cost of alternative presumptive visibility targets are also affected by: 1) an analysis baseline that understates the visibility progress achieved by CAA mandated controls and implementation of a new ozone standard over the period 2000 to 2010; 2) the inability to model full attainment of the selected $PM_{2.5}$ 15/65 standard; and 3) how close some of the residual Class I area counties are to natural background conditions. These factors suggest that the actual cost of achieving visibility improvements incremental to the selected ozone and $PM_{2.5}$ standards should be lower.

8.2 INTRODUCTION

This chapter presents the visibility improvements and cost impacts of proposed alternative RH targets. This analysis estimates the projected costs (in 1990 dollars) of installing, operating, and maintaining those additional controls needed by the year 2010 to meet the presumptive visibility targets in our nation's Class I designated areas. The following sections in this chapter cover:

- Cost analysis methodology;
- Visibility improvements and cost results for alternative RH targets; and
- Analytical uncertainties, limitations, and potential biases.

8.3 COST ANALYSIS METHODOLOGY

This analysis estimates the emission reductions and control costs for achieving the alternative presumptive visibility improvement targets described in Chapter 3. Since Class I areas rarely contain emissions sources, and because pollutants that degrade visibility can be transported over long distances by prevailing winds, controls must be imposed on sources located outside of Class I areas that contribute to visibility degradation in Class I areas.

The analysis is confined to the 141 Class I areas located in 121 counties in the 48 contiguous States. Further, the set of Class I areas is subdivided into the same six regions defined for the particulate matter (PM) analysis. The boundaries of these six control regions are depicted in Chapter 6 in Figure 6.2. The boundaries of these regions are delineated to reflect both the meteorological conditions that influence the long-range transport of visibility precursors and the locations of their major sources (e.g., electric utilities). Control measure selection is limited to emission sources in each control region. In addition, selection of some control measures that primarily affect coarse particles (i.e., particles greater than 2.5 microns) is limited to the county containing the Class I area. This limitation prevents control measures that have a minor affect on visibility (e.g., fugitive dust control for unpaved roads) from being selected in counties that are relatively distant from Class I areas.

The baseline for the RH analysis is the projected emissions inventory from the analysis of the selected $PM_{2.5}$ 15/65 standard and the remaining set of control measures that are not already selected in that analysis. Chapter 6 presents the analysis of the $PM_{2.5}$ 15/65 standard.

If the RH rule is finalized on schedule, the first period for which visibility improvements are to be evaluated is estimated to be the years 2000 through 2010. In order to evaluate visibility improvements, visibility monitors must be established in the Class I areas of concern, and it is likely to take a few years to establish these monitors. Ideally, this Regulatory Impact Analysis (RIA) would evaluate the potential improvements in visibility over the ten year period from 2000 to 2010, and would account for emission reductions achieved from current CAA mandated controls (e.g., Title IV sulfur dioxide (SO_2) cap on utility sources) and due to promulgated $PM_{2.5}$ and ozone NAAQS. However, this requires developing a year 2000 emissions inventory and a set of control measure impacts incremental to the year 2000. Instead, the RH analysis takes advantage of the 2010 emissions inventory and incremental control measure database established for the $PM_{2.5}$ and ozone analyses discussed in Chapters 6 and 7.

Control costs for attaining the alternative presumptive visibility improvement targets are evaluated incremental to attainment of the promulgated $PM_{2.5}$ standard. If a Class I area is projected to meet the presumptive visibility improvement target in the year 2010 as a result of $PM_{2.5}$-related control measures, no additional control is needed. However, if the goal is not met, additional control measures are modeled. This baseline provides conservative estimates (i.e., potentially overstates) of the cost of achieving alternative visibility goals for two reasons. First, the progress achieved by measures related only to $PM_{2.5}$ control through the year 2010 does not include progress achieved due to measures already mandated under the 1990 CAA, or progress achieved due to controls needed to meet the new ozone standard. These control measures, which are not in the baseline of the RH analysis, may contribute to further visibility improvement from 2000 to 2010. Second, applying the set of control measures included in the $PM_{2.5}$ analysis results in residual nonattainment for some areas. To the extent that these areas are actually able to achieve additional reductions to attain the $PM_{2.5}$ standard, further visibility improvements may also be realized.

The costs in this analysis reflect *real, before-tax, 1990 dollars* and a *7 percent real interest (discount) rate.* "Real" dollars are those uninfluenced by inflation; in other words, a "1990 dollar" is assumed to be worth the same today as it was in 1990. "Before-tax" means that the cost analysis does not consider the effects of income taxes (State or federal). Because income taxes are merely transfer payments from one sector of society to another, their inclusion in the cost analysis would not affect total cost estimates. The year 1990 was selected as the cost reference date to be consistent with the analysis base year. Finally, to be consistent with the real-dollar analytical basis, a 7 percent real interest rate was used, in accordance with Office of Management and Budget guidance.

8.3.1 Estimating Visibility

Decreases in visibility are often directly proportional to decreases in light transmittance in the atmosphere (Trijonis et al., 1990). Light transmittance is attenuated by scattering and absorption by both gases and particles. The light-extinction coefficient is a measure of the total fraction of light that is attenuated per unit distance (Sisler, 1996):

$$b_{ext} = b_{Ray} + b_{sp} + b_{ag} + b_{abs}$$

where:

b_{ext}	=	total light extinction coefficient (1/Mm),
b_{Ray}	=	light extinction coefficient due to natural Rayleigh scatter (1/Mm),
b_{sp}	=	light extinction coefficient due to scattering by particles (1/Mm),
b_{ag}	=	light extinction coefficient due to absorption by gases (1/Mm), and
b_{abs}	=	light extinction coefficient due to absorption by particles (1/Mm).

The light extinction coefficient is calculated by multiplying the concentration of an aerosol species by its light-extinction efficiency, and summing over all species.

The term b_{Ray} refers to the natural Rayleigh scatter from air molecules, mainly nitrogen and oxygen. Depending on altitude, this term has a value of 9 to 12 Mm^{-1} (inverse megameters) (Sisler and Malm, 1994).

The term b_{sp} can be broken into the various species of fine and coarse particles that scatter light. Because fine particles are much more efficient at light scattering than coarse particles, several fine particle species are specified, whereas coarse particles are kept as one category. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

A complicating factor for sulfates, nitrates, and some organic compounds is that these aerosols are hygroscopic, i.e., they absorb water, which greatly enhances their light-scattering abilities. The amount of water absorbed is a function of the relative humidity. A relationship between the relative humidity and scattering efficiency for ammonium sulfate aerosols has been developed, and is also applied to ammonium nitrate aerosols (Sisler, 1996). Recent research indicates that organics are not hygroscopic to weakly hygroscopic (Sisler, 1996) and thus in this analysis, the light scattering efficiency for organics is not assumed to be a function of the relative humidity.

A detailed expression for b_{sp} can thus be written (Sisler, 1996):

$$b_{sp} = 3f(RH) \cdot [SULFATE] + 3f(RH) \cdot [NITRATE] + 4[OMC] + 1[SOIL] + 0.6[CM]$$

where:

3	=	dry scattering efficiency of sulfate and nitrates (m^2/g),
f(RH)	=	function describing scattering characteristics of sulfates and nitrates, based on the relative humidity (unitless),
[*SULFATE*]	=	concentration of ammonium sulfate aerosols ($\mu g/m^3$),
[*NITRATE*]	=	concentration of ammonium nitrate aerosols ($\mu g/m^3$),
4	=	dry scattering efficiency of organic mass from carbon (m^2/g),
[*OMC*]	=	concentration of organic aerosols ($\mu g/m^3$),
1	=	dry scattering efficiency of soil (m^2/g),
[*SOIL*]	=	concentration of fine soil ($\mu g/m^3$),
0.6	=	dry scattering efficiency of coarse particles (m^2/g), and
[*CM*]	=	concentration of coarse particles ($\mu g/m^3$).

The function *f(RH)* is calculated as follows:

$$f(RH) = t_0 + t_2(1/(1-RH))^2 + t_3(1/(1-RH))^3 + t_4(1/(1-RH))^4$$

where:

RH	=	relative humidity, and
t_x	=	parameters presented in Table 8.1 below.

Table 8.1 Parameter Determining the Effect of Relative Humidity on Visibility

Season	t_0	t_2	t_3	t_4
Spring	0.7554	0.3091	-0.0045	-0.0035
Summer	0.5108	0.4657	-0.0811	0.0043
Autumn	-0.0269	0.8284	-0.1955	0.0141
Winter	1.1886	0.2869	-0.0332	0.0011
Annual	0.5176	0.5259	-0.0947	0.0056

Source: Table 5.1, Sisler, 1996.

The term b_{ag} represents absorption due to gases; NO_2 is the only major light-absorbing gas in the lower atmosphere. This component is assumed to be negligible since concentrations of NO_2 are expected to be negligible in rural areas (Sisler and Malm, 1994) which is generally applicable for Class I areas. However, this may be a poor assumption for locations close to significant NO_x emission sources, such as power plants or urban areas (Sisler, 1996).

The final term of the light-extinction coefficient equation, b_{abs}, represents absorption of light by elemental carbon. This term represents approximately 30 percent of the non-Rayleigh extinction budget (Sisler, 1996). Recent research has indicated that direct measurements of absorption by the laser integrated plate method (LIPM) are much more accurate than using absorption estimates based on mass concentrations of light-absorbing carbon. For that reason, this analysis bases b_{abs} on empirical data from monitored sites in the IMPROVE network.

Once the light-extinction coefficient is determined, the visibility index called deciview (*dv*) can be calculated (Sisler, 1996):

$$dv \ = \ 10 \ \cdot \ \ln(b_{ext} \cdot 10^{-3} / 0.01\, km^{-1})$$

where:

10^{-3} = constant to convert Mm^{-1} to km^{-1}.

A change of one *dv* represents a change of approximately ten percent in b_{ext}, "which is a small but perceptible scenic change under many circumstances" (Sisler, 1996, p.1-7).

8.3.2 Estimating the Effect of Control Measures on Visibility

Given the available data available from the IMPROVE monitoring network and the changes in sulfate, nitrate, and primary PM emissions modeled using the source-receptor (S-R) matrix described in Chapter 6, light extinction (b_{ext}) is calculated using the following equation:

$$b_{ext} = b_{Ray} + 3f(RH) \cdot [SULFATE] + 3f(RH) \cdot [NITRATE] + \\ 4[OMC] + 1[SOIL] + 0.6[CM] + b_{abs}$$

The S-R matrix provides concentration estimates of ammonium sulfate (SULFATE), ammonium nitrate (NITRATE), and coarse mass ($CM = PM_{10} - PM_{2.5}$). A common assumption for light scattering by background gases (b_{Ray}) is 10 Mm^{-1}. Appendix E provides estimates for f(RH), OMC, SOIL, and b_{abs} based on summary data from 43 relevant IMPROVE monitoring sites between 1992-1995. For Class I areas without monitoring data, values are assigned based on either the closest monitored site or an average of up to three proximate monitored sites. The values are assumed constant in this analysis, even though it is known that certain types of control measures may affect the baseline levels of OMC and b_{abs}. The exact relationship between these factors and specific control measures has not been established, and therefore these values are held constant.

8.3.3 Selecting Control Measures with the Regional Haze Optimization Model

The RH optimization model works in a manner similar to the PM optimization model discussed in Chapter 6. However, in this case, the receptor county of interest contains a Class I area, and reductions in $PM_{2.5}$ precursors at the receptor are translated into improvements in visibility (i.e., reductions in light extinction). Control measures that are not already selected in the PM analyses are available for the RH analysis.

The optimization routine developed for this analysis employs the following steps:

Step 1. The remaining control measures in the incremental control measure data file are sorted by source number, precursor pollutant controlled, and cost per ton of pollutant reduced.

Step 2. The *incremental* improvement in visibility is calculated *for each Class I area county* for the least costly (on a cost per ton basis) control measure for each individual source/pollutant combination.

Step 3. The measure with the *lowest average cost per increment of visibility improvement* is selected and the deciview levels at each receptor are adjusted to reflect implementation of the selected measure.

Step 4. Steps 2 through 3 are repeated until all input receptors meet the target level *or* all remaining measures are exhausted. The same $1 billion per microgram per cubic meter control measure selection threshold that is used in the PM optimization model is also used in the RH optimization model.

Step 5. Adjust final post-control visibility predictions in all Class I areas nationwide to account for the trans-boundary effect of control measures selected outside each control region.

8.3.4 Scaling Annual Average Deciview Values Relative to Average Peak Values

As proposed, the RH rule suggests a 1.0 deciview change in the average deciview value of the 20 percent worst days over a ten year period. However, the S-R matrix used to estimate pollution concentrations that contribute to RH formation, outputs annual average values for the pollutants of concern (ammonium sulfate, ammonium nitrate, and primary PM_{10} and $PM_{2.5}$). This analysis uses the most recent monitoring data from Class I areas to translate a 1.0 deciview change in the 20 percent worst days to an equivalent change for an annual average day. Appendix E contains the data used to make this calculation.

The average of the 20 percent worst days each year is also be referred to as the 90th percentile value, and can be compared to the annual average or mean value. The ratio of the 90th percentile deciview value to the mean deciview value varies by Class I area. Based on the most recent IMPROVE data, the average ratio of the 90th percentile deciview value to the mean deciview value for all Class I areas is 1.4. Therefore, a 1.0 deciview change in the average of the 20 percent worst days correlates to a 0.7 deciview change in the annual average day (1.0 divided by 1.4). Similarly, a 0.67 deciview change in the 20 percent worst days correlates to a 0.5 deciview change in the annual average day (0.67 divided by 1.4). These annual average equivalent targets are used in this analysis.

8.3.5 Baseline Visibility

The visibility baseline in this analysis is represented by the estimated visibility improvement between the 2010 CAA baseline case and the post-$PM_{2.5}$ 15/65 case. Table 8.2 summarizes the visibility measurements in terms of deciviews for the two cases. As the table shows, the average visibility improvement in the annual average deciview value for counties containing Class I areas in the Midwest/Northeast and the Southeast regions is more than the target of 0.7 deciviews.

Table 8.2 Projected Annual Average Deciview Values by Control Region

Region	No. of Counties Containing Class I Areas	2010 CAA Baseline	2010 Post-$PM_{2.5}$ 15/65	Average Annual Deciview Improvement
Midwest/Northeast	16	23.1	21.2	1.9
Southeast	13	22.5	21.1	1.4
South Central	14	16.8	16.4	0.4
Rocky Mountain	30	17.6	17.1	0.5
Northwest	18	19.3	19.0	0.3
West	30	17.8	17.3	0.5
Nation	121	19.1	18.3	0.8

Table 8.3 indicates the number of Class I area counties for which additional control measures may be needed incremental to the baseline (i.e., incremental to partial attainment of the $PM_{2.5}$ 15/65 standard). Nearly all Class I area counties in the Midwest/Northeast and Southeast regions are projected to meet the alternative presumptive visibility improvement targets without any additional controls beyond partial attainment of the selected $PM_{2.5}$ 15/65 standard. However, a majority of the Class I area counties located in the South Central, Northwest and West regions are projected to need additional reductions to meet the alternative goals. For the more stringent 1.0 deciview target, a majority of the Class I areas in the Rocky Mountain region are also

Table 8.3 Number of Class I Area Counties Not Achieving Alternative Visibility Goals in the Baseline

Control Region	Number of Class I Area Counties	Number of Class I Area Counties After $PM_{2.5}$ 15/65 Control	
		1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)	1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)
Midwest/Northeast	16	0	0
Southeast	13	0	1
South Central	14	11	11
Rocky Mountain	30	14	27
Northwest	18	17	18
West	30	16	19
Nation	121	58	76

projected to need additional reductions. These areas also have the highest proportion of predicted biogenic aerosol emissions, which places them closer to natural conditions than other regions. This would tend to support establishing alternative targets for these areas.

8.5 VISIBILITY IMPROVEMENT RESULTS

This section presents the incremental visibility improvements achieved for each alternative presumptive visibility improvement target in Class I area counties that did not achieve the goal in the baseline. Included are estimates of the additional number of Class I area counties that achieve the alternative presumptive visibility improvement targets, as well as the average improvement realized. As discussed in section 8.3.4, a 1.0 deciview improvement goal for the average 20 percent worst days is roughly equivalent to a 0.7 deciview improvement goal for the annual average day. Similarly, a 0.67 deciview improvement in the average 20 percent worst days is roughly equivalent to a 0.5 deciview improvement in the annual average day.

Table 8.4 presents the number of Class I area counties that initially do not achieve each alternative presumptive visibility improvement target and the estimated number of Class I area counties that are not able to achieve the goals after additional control measures are modeled.

Table 8.4 Estimated Number of Class I Area Counties That Do NOT Achieve Alternative Presumptive Visibility Improvement Targets and the Average Deciview Shortfall

Region	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)			1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)		
	Baseline[a]	Post-Control[b]	Average Deciview Shortfall	Baseline[a]	Post-Control[b]	Average Deciview Shortfall
Midwest/Northeast	0	0	--	0	0	--
Southeast	0	0	--	1	0	--
South Central	11	3	0.16	11	9	0.18
Rocky Mountain	14	3	0.06	27	4	0.22
Northwest	17	1	0.12	18	2	0.20
West	16	10	0.16	19	13	0.29
Nation	58	17	0.14	76	28	0.23

a Baseline represents counties that do not achieve sufficient progress toward the visibility goal after considering partial attainment of the selected $PM_{2.5}$ 15/65 standard.

b Post-control represents counties that do not achieve sufficient additional progress toward the visibility goal after considering additional controls not already selected in the $PM_{2.5}$ 15/65 analysis.

Also shown is the average deciview shortfall for the counties that do not reach the goal. This table indicates that 28 of the 76 initially noncompliant Class I area counties are not able to achieve the 1.0 deciview goal, and 17 of the 58 initially noncompliant counties are not able to achieve the 0.67 deciview goal. The areas not able to achieve the goal are concentrated in the West and South Central control regions. The majority of the West region areas are in central and southern California and Arizona. Several of these counties are also residually nonattainment in the $PM_{2.5}$ 15/65 analysis based on the results presented in Chapter 6.

For the 28 areas not achieving the 1.0 deciview goal after controls are applied, the region wide annual average deciview shortfall ranges from 0.18 to 0.29, meaning that on average these areas achieved from 0.41 to 0.52 (i.e., 59 to 72 percent) of the 0.7 deciview improvement needed to reach the goal. For the 17 areas not achieving the 0.67 deciview goal, the region wide annual average deciview shortfall ranges from 0.03 to 0.25, meaning that on average these areas achieved from 0.25 to 0.47 (i.e., 50 to 94 percent) of the 0.5 deciview improvement needed to reach the goal.

8.6 COST ANALYSIS RESULTS

This section presents the cost of achieving alternative regional haze goals incremental to control achieved in the $PM_{2.5}$ 15/65 analysis. Under the structure of the proposed RH rule, the States are able to take into account costs for emissions reductions strategies in light of the degree of visibility improvement to be achieved. Therefore, high cost control measures that have only minor effects on visibility can be avoided. For some Class I areas, there may not exist any cost effective control measures that can be applied in the time period covered by this analysis. In these areas the incremental control costs of the proposed RH rule will be zero. The actual control cost of the proposed RH rule is likely to lie somewhere between the zero and the estimates for the presumptive targets presented in this report. Based on the control strategies selected by the Grand Canyon Visibility Transport Commission, the majority of which are currently part of implementation plans for other criteria polutants, the costs will be on the lower end of this range.

The incremental cost of the RH rule presented in this RIA is compromised by the residual nonattainment projected to exist for the analysis of the selected $PM_{2.5}$ 15/65 standard. An analysis that models full attainment of the $PM_{2.5}$ standard should reduce the incremental cost of a RH rule in areas where there is significant overlap.

Table 8.5 shows the total annual control cost of alternative presumptive RH targets incremental to the selected $PM_{2.5}$ 15/65 standard. For both target levels the largest fraction of the control cost is realized in the Rocky Mountain and Northwest regions. This seems logical since there are relatively few counties projected to be nonattainment for the selected $PM_{2.5}$ 15/65 standard in these regions. Therefore, less control and accompanying visibility improvement is achieved in these regions in the baseline analysis.

Table 8.5 Regional Haze National Control Cost Summary--Total Annual Cost[a]
(million 1990 dollars)

Control Region	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)	1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)
Midwest/Northeast	--	--
Southeast	0 - 70	0 - 150
South Central	0 - 440	0 - 490
Rocky Mountain	0 - 580	0 - 670
Northwest	0 - 710	0 - 1,000
West	0 - 320	0 - 420
Nation	0 - 2,100	0 - 2,700

a Costs are incremental to partial attainment of the selected $PM_{2.5}$ 15/65 standard. Totals may not agree due to rounding.

8.7 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

Because a quantitative uncertainty cannot be assigned to every input, the total uncertainty in the emission reduction, air quality, and cost outputs cannot be estimated. Nonetheless, the individual uncertainties can be characterized qualitatively.

Air quality projections to 2010 embody several component uncertainties, such as uncertainties in emission data, emission growth rates, baseline air quality data, and air quality modeling. These uncertainties are addressed in Chapter 4.

As noted in Section 6.7 the optimization model annual cost inputs are in the form of average incremental cost per ton reduced. Even if these cost per ton estimates are adjusted to account for source size differences (as is done for some point source controls), these adjustments do not account for other important cost-determining variables, such as source status (new versus retrofit), annual operating hours, equipment, materials of construction, and unit prices for utilities, materials, and labor.

The least-cost optimization model also introduces a measure of uncertainty. For instance, when calculating the cost per average microgram per cubic meter reduced, the model does not count any emission reductions that are in excess of those needed to meet a specified visibility goal. This assumption could cause the cost per average microgram per cubic meter—and, in turn, the final control costs—to be overstated or understated depending upon whether control of the precursor was beneficial.

8.8 REFERENCES

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9.0 DISCUSSION OF FULL ATTAINMENT COSTS

9.1 RESULTS IN BRIEF

Bringing all areas of the country into attainment of the 0.08 4th Max ozone standard by the year 2010 is estimated to cost $9.6 billion annually in 2010. This cost is incremental to the costs associated with full attainment of the current hourly ozone standard, and includes the costs outlined in Chapter 7.0 associated with bringing a portion of the projected ozone nonattainment areas into attainment with the 0.08 4th Max standard. The costs beyond the partial attainment costs would be associated primarily with a relatively few areas of the country that suffer from the worst air pollution and are in need of additional emission reductions to reach attainment.

Bringing all areas of the country into attainment with the $PM_{2.5}$ 15/65 standard by the year 2010 is estimated to cost $37 billion annually in 2010. This cost is incremental to the cost associated with full attainment of the current PM_{10} standard, and includes the costs outlined in Chapter 6.0 associated with bringing a portion of the projected $PM_{2.5}$ nonattainment counties into attainment. As in the case of ozone, the costs beyond the partial attainment costs would be associated primarily with a relatively few areas of the country that suffer from the worst air pollution and are in need of additional emission reductions to reach attainment.

This regulatory impact analysis (RIA) is a snapshot of potential annualized costs for 2010, estimating both partial and full attainment. The partial attainment cost analyses presented in Chapters 6.0 - 8.0 do not include potential costs associated with arbitrarily forcing all areas into attainment prior to the maximum statutory deadlines. The full attainment analysis discussed in this chapter brings all areas into attainment by 2010, slightly before the deadlines currently in the Clean Air Act (CAA) for some areas.

9.2 INTRODUCTION

This chapter presents a full attainment scenario for both the $PM_{2.5}$ and ozone standards. The costs and emission reductions associated with the partial attainment analysis of $PM_{2.5}$ outlined in Chapter 6.0 and partial attainment analysis of ozone in Chapter 7.0 are incorporated into this chapter's analysis. This full attainment analysis brings all areas into attainment by 2010, slightly before deadlines currently in the Clean Air Act (CAA) for some areas.

In reviewing these full attainment cost estimates, it is useful to keep several factors in mind. First, no analyses can accurately predict costs of control strategies for attainment goals 10 to 15 years in the future. In the case of new air quality standards, full attainment will not be finally required for 10-12 years after area designations (2012 for ozone, 2014 for PM). For a number of reasons, this is simply too long a time over which to assume accurate information related to implementation of the CAA. Historically, compliance costs over long time periods have consistently been overestimated.

The history of implementation of the CAA provides some context for this statement. Since 1970, the CAA has in many ways been a "technology-forcing" law. The obligation to meet the national air quality standards has created pressures and market opportunities for technology breakthroughs and continuous improvements. The result has been continued, affordable improvements in air quality across the country, even in the face of continued growth in the number of air pollution sources. This history, as well as a review of currently developing technologies, provides a sound basis for anticipating that technological progress will continue in response to new standards. Perhaps the most notable example of technological improvement that made past air quality improvements affordable was the introduction of catalytic technology for automobiles in the early 1970s. Predictions of economic chaos accompanied the setting of tailpipe emissions standards in the 1970 CAA, yet inexpensive catalytic technology made those standards achievable and affordable within a few years. However, for some of the areas with the most difficult air quality challenges, substantial technological advance is needed. Given EPA's modeling capabilities and assumptions of reductions required for attainment, these areas achieve approximately one third of the reductions needed to attain the new standards in 2010.

It is very difficult to predict technological improvements and their associated effects on cost because we have insufficient knowledge of which new technologies will be successful enough to have a meaningful impact on costs over the next ten to fifteen years--though history tells us such innovations will occur. One catalyst for such innovations will be the investments made to control greenhouse gases for climate change which will create a more energy efficient and less polluting economy.

Another factor which may have a significant downward influence upon actual costs relative to predicted costs is the likely replacement of many command and control pollution control systems with market-based pollution control systems. Since 1990, we have seen dramatic cost reductions associated with market-based programs. Examples of market-based air pollution control and their costs are included later in this chapter. The success of efforts such as the acid rain program under Title III of the CAA have led EPA and others to place primary reliance for implementing revised standards on new or expanded market-based programs. As a result, these approaches will likely be incorporated into new and existing control strategies at the local, regional, and national levels. Again, however, there are no clear means of incorporating the likely cost savings from these programs into current cost estimates.

A third factor which makes long-term estimates difficult, is the nature of implementation as laid out in the CAA. Under the Act, the primary responsibility for achieving national ambient air quality standards (NAAQS) falls to the states. Upon the setting of a new standard, the states begin a multi-year, sequenced process of monitoring and planning; the results of which are ultimately found in State Implementation Plans (SIPs). These SIPs are the blueprint of control strategies through which states meet their responsibility. While the federal government maintains primary responsibility for certain sources which are best controlled nationally (e.g., motor vehicles), and the CAA does provide some additional requirements, most decisions about which control strategies to utilize fall primarily to the states. This approach allows control decisions, including costs associated with those decisions, to be appropriately considered at the state and local level. But the variety of control strategies that may then be utilized in the hundreds of air quality districts across the country becomes quite difficult to incorporate into national cost estimates.

Because of the difficulty in knowing the true costs of control strategies to be implemented 10 to 15 years in the future, policy makers seeking guidance from this RIA must weigh the potential significance of predictions that, although estimates of quantified partial benefits (through 2010) clearly exceed estimates of partial costs for both pollutants, a full attainment benefit-cost comparison carries less certainty.

Looking out 10-15 years, technological breakthroughs are hard to predict. The presence of health-based air quality standards have in the past and likely will in the future accelerate the introduction of new technologies. These standards also motivate greater reliance on innovative regulatory/non-regulatory approaches as well, such as market-based strategies, pollution prevention, environmental management systems and energy-efficiency. These approaches also have the benefits of reducing greenhouse gases. In short, the analysis contained herein provides a basis for believing that during the next decade benefits resulting from efforts to meet both new air quality standards are likely to exceed costs.

In order to more fully inform policy makers and the public about cost and benefit implications, EPA intends to periodically update the analysis contained herein, both as monitoring and redesignation information becomes more complete, and as the 5-year cycle of review is completed again in 2002.

9.3 METHODOLOGY AND RESULTS

To provide policymakers with as much information as possible to aid implementation planning, a full attainment analysis of both standards (0.08 4th Max and $PM_{2.5}$ 15/65) is carried out. To estimate full-attainment of the ozone standard, additional specified and unspecified control measures are assumed for areas still needing further reductions after the initial set of measures outlined in Chapters 5.0 - 7.0 are applied. The specified measures consist primarily of controls already in use, and are intended as illustrations of additional measures that could be chosen by states or local areas.

After application of the initial set of control measures analyzed in Chapter 7.0, seventeen areas are estimated to need further NO_x or VOC emission reductions to reach full attainment of the 0.08 4th Max ozone standard. Table 9.1 shows the estimated additional ozone season daily and annual emission reductions associated with full attainment of the 0.08 4th Max ozone standard. To reach full attainment, these areas are estimated to need approximately 1,000 tons per day of additional VOC emission reductions and 1,700 tons of additional NO_x emission reductions per day. Additional specified control measures would reduce this inventory by approximately 60 tons per day of VOC and 580 tons per day of NO_x. The average incremental cost effectiveness of the additional control measures included in this part of the analysis is approximately $3,200/ton of NO_x reduced and $4,000/ ton of VOC controlled. Emission reductions for the remaining tons (those not attributable to a specified control measure) are assumed to cost an average of $10,000/ton for both NO_x and VOC emissions.

The estimated full attainment annual cost of the 0.08 4th Max ozone standard is $9.6 billion (1990$) in the year 2010. This includes the $1.1 billion partial attainment cost estimate outlined in Chapter 7.0, and approximately $800 million of additional specified reduction costs and $7.7 billion of unspecified reduction costs. Characterization of full attainment costs should be considered more uncertain than cost estimates associated with the partial attainment analysis. Inclusion of control measures and their associated costs in this full attainment analysis does not

Table 9.1 Ozone 0.08 4th Max Estimated Full Attainment Emission Reductions

Pollutant/ Emissions Sector	Ozone Season Daily Tons					Annual Tons				
	2010 CAA Baseline Emission Level	Partial Attainment Emission Level[b]	Full Attainment Emission Level	Emission Reductions from Additional Measures[c]	Emission Reductions from Unspecified Measures	2010 CAA Baseline Emission Level	Partial Attainment Emission Level[b]	Full Attainment Emission Level	Emission Reductions from Additional Measures[c,d]	Emission Reductions from Unspecified Measures[d]
VOC										
Area	4,754	3,656		10		1,591,566	1,292,961		3,281	
Mobile	1,412	1,161		0		481,942	389,007		136	
Nonroad	1,403	1,400		9		452,781	452,426		2,890	
Point	900	884		40		328,637	322,760		13,651	
Utility	19	19		0		6,347	6,347		0	
TOTAL[e]	8,489	7,121	6,087	59	975	2,861,273	2,463,501	2,111,924	19,958	331,619
Shortfall[f]			1,034	975	0			351,577	331,619	0
NOx										
Area	1,158	1,085		0		499,705	447,274		0	
Mobile	2,699	2,441		8		969,975	882,104		3,061	
Nonroad	1,644	1,644		294		551,373	551,373		113,313	
Point	912	636		60		326,871	226,520		23,273	
Utility	554	554		218		350,786	350,539		83,795	
TOTAL[e]	6,967	6,359	4,657	580	1,122	2,698,710	2,457,811	1,802,556	223,442	431,812
Shortfall[f]			1,702	1,122	0			655,255	431,812	0

a Emissions and projected reductions needed for 17 areas projected to be residual nonattainment after application of control measures modeled in Chapter 7.0. Characterization of full attainment emission reductions and how such emission reductions would be achieved should be considered more uncertain than emission reduction estimates associated with the partial attainment analysis. Inclusion of control measures in this full attainment analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All emission reductions and shortfalls are estimated incremental to attainment of the current ozone standard.

b Emission level after application of control measures modeled in Chapter 7.0 and presented in Appendix B.

c Emission reductions from control measures discussed in Chapter 9.0 and presented in Appendix F.

d Annual tons estimated from ozone season daily tons by multiplying by 340 for VOC, and 385 for NOx. These conversion factors are derived from the average ratio of annual tons to ozone season daily tons identified in the 2010 CAA baseline and partial attainment analyses.

e Totals may not agree due to rounding.

f Shortfall represents emission reductions still needed to achieve the established target levels (see Chapter 4 for a more information on emission targets).

represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs are estimated incremental to attainment of the current ozone standard.

A rough full attainment annual cost estimate for the selected $PM_{2.5}$ 15/65 standard is $36.7 billion (1990$). This cost estimate is incremental to full attainment of the current PM_{10} standard and is obtained by using the information from the partial attainment analysis to derive an estimate of additional reductions needed in each control region to reduce $PM_{2.5}$ concentrations to the level of the selected standard. The full attainment analysis assumes that these additional emission reductions are obtained at $10,000/ton (as is assumed in the ozone full-attainment cost analysis). Tables 9.2 shows the estimate of additional emission reductions needed to fully attain the PM standard. The cost estimate was derived by the following steps:

<u>Step 1</u>: For each control region, the total NOx, SO_2, VOC, and direct PM_{10} emission reductions achieved by control measures employed in the partial attainment analysis (excluding the National PM2.5 Strategy) and the average annual $\mu g/m^3$ improvement realized in the 67 counties still violating the $PM_{2.5}$ standard after application of the National $PM_{2.5}$ Strategy were calculated.

<u>Step 2</u>: Using the information from Step 1, the $\mu g/m^3$/ton reduced in each region was calculated.

<u>Step 3</u>: The average annual average $\mu g/m^3$ shortfall in each region for the 30 residual nonattainment counties was calculated and each region's $\mu g/m^3$/ton reduced estimate (from Step 2) was multiplied by the average annual average $\mu g/m^3$ shortfall in each region to obtain an estimate of the additional emission reduction needed to eliminate the shortfall.

<u>Step 4</u>: This additional emission reduction estimate (from Step 3) was multiplied by $10,000 per ton to obtain a cost estimate incremental to a 2010 CAA baseline cost estimate of $38.5 billion (1990$).

Step 5: Eleven of 30 residual nonattainment areas for the $PM_{2.5}$ 15/65 standard are also projected to be in residual nonattainment for the current PM_{10} standard. The potential costs associated with the PM_{10} standard, \$10.4 billion, was subtracted from the \$38.5 billion estimate. The estimated annual cost of partial attainment of the $PM_{2.5}$ standard, \$8.6 billion (outlined in Chapter 6.0), was added to this result. The final result is a \$36.7 billion (1990\$) full attainment annual cost estimate of the $PM_{2.5}$ 15/65 standard incremental to the current PM_{10} standard.

This approach assumes that additional control measures will be identified that will achieve a similar ambient reduction in particle species across a given modeling region as is achieved in the partial attainment cost analysis. The emissions inventory and control measure set used in the partial attainment cost analysis are not intended to represent the complete inventory or the complete set of potential control strategies. Therefore, using the linear relationship between control measure effectiveness and air quality improvement modeled in the partial attainment analysis may over- or under-estimate the additional air quality improvement achieved by actual additional reductions beyond partial attainment.

Table 9.2 Estimate of Additional Emission Reductions Needed to Fully Attain the $PM_{2.5}$ 15/65 Alternative

Control Region	Initial Nonattainment Counties[a]			Residual Nonattainment Counties[b]	
	Emission Reductions Achieved by Regionally Applied Control Measures[c] (tons/yr) [A]	Average Annual µg/m³ Reductions Achieved by Regionally Applied Control Measures [B]	Average Emission Reductions per µg/m³ Reduction [C = A ÷ B]	Average Annual µg/m³ Shortfall [D]	Estimated Emission Reductions Needed to Eliminate Shortfall[d] (tons/yr) [E = C × D]
Midwest/Northeast	3,176,259	3.1	1,024,600	1.6	1,588,129
Southeast	278,700	2.2	126,682	0.2	25,336
South Central	1,020,106	1.7	600,062	1.1	630,066
Rocky Mountain	923,841	2.0	461,920	1.7	762,169
Northwest	5,918	0.0	--	--	0
West	364,147	0.8	455,184	1.9	842,090

a Estimates in these columns are for 66 counties projected to be nonattainment after application of the National $PM_{2.5}$ Strategy.

b Estimates in these columns are for 30 counties projected to be nonattainment after application of control measures modeled in Chapter 6.0, and do not include reductions and air quality improvements achieved by the National $PM_{2.5}$ Strategy.

c Total NOx, SO_2, VOC, and direct PM_{10} emission reductions achieved by application of control measures modeled in Chapter 6.0, not including reductions achieved by the National $PM_{2.5}$ Strategy. Combining all precursor pollutants into a single total represents a gross simplification since different precursors have, among other distinctions, different marginal costs of control and different potential marginal contributions to progress toward attainment.

d The estimate of the additional reductions required to overcome shortfalls and attain the PM standards are highly uncertain. The estimates presented in this table represent gross oversimplifications of critical variables and are useful only for illustrative purposes. More definitive estimates of region- and source category-specific reduction requirements will not be available until emissions inventories, air quality modeling, and SIP planning processes are completed for individual nonattainment areas. The values in this column are extremely crude estimates which reflect gross oversimplification of the relationships between changes in emissions of various precursors and changes in ambient concentrations. In particular, these estimates embed the unrealistic assumptions that precursor emissions would be reduced in identical proportions and that ambient concentrations would change linearly in response to those proportional reductions in precursors. Neither of these two assumptions are likely to actually obtain. Furthermore, the actual reductions required to achieve attainment would be highly dependent on the sources of the reductions. This is because reductions achieved by different source categories would be distributed differently in terms of both release height and spatial dispersion. For example, mobile source reductions would be spatially dispersed but occur essentially at the bottom mixing layer, whereas utility emissions reductions would be more spatially concentrated but would occur at higher levels above the ground. Both of these factors influence ambient particulate matter formation and atmospheric transport; therefore tonnage reductions required to achieve full attainment in all areas may be different depending on the relative contributions of precursor reductions from different source categories. Totals may not agree due to rounding.

The additional specified control measures analyzed in this chapter include conventional control approaches, pollution prevention techniques, cleaner fuels and combustion processes. The measures primarily address control of ozone precursors. Many of these measures are currently technically available to emission sources in most nonattainment areas. They are not included in the analyses in Chapters 6.0 - 8.0 because they are not needed in most areas except the most polluted ones, but represent a reasonable set of additional controls which are likely to be cost effective for certain areas. For some measures, technology is currently available to implement these controls. In the future, after improved $PM_{2.5}$ inventories and source-receptor relationships are developed, it should be possible to conduct similar analyses of specified control measures for fine particulates.

The control measures analyzed in this section are divided into three sectors: 1) stationary point sources; 2) stationary area sources; and 3) mobile sources (both on-road and off-road). The cost of each measure is generally determined by examining the change in costs for one unit of the controlled source (e.g., one engine for mobile source technology measures, one gallon of fuel for reformulated fuel measures) and the associated tons reduced from that unit. The level of emissions remaining from specific source categories in areas still needing further reductions after the application of the first tier of measures is determined. The potential emission reductions available from the application of a measure are determined by applying a control factor to that level of residual emissions. In some cases, potential further reductions from certain source categories are calculated by estimating the number of units (i.e., non-road heavy duty diesel engines) located in these areas. Control measures are then applied to those sources still needing reductions. For some source categories, there is more than one control strategy identified and choices are made as to the most appropriate. These choices may or may not reflect actual local control choices. Some of the control measures assessed in this part of the analysis include but are not limited to the following:

- repowering existing vehicles with natural gas;
- retrofitting existing engines with improved technology;
- selective catalytic reduction for certain commercial marine engines and locomotives;
- electric-powered airport gate service equipment;

- lower-sulfur fuels for residential, industrial, commercial and mobile applications;more stringent leak, process vent and wastewater controls for refineries, chemical manufacturing plants, and treatment, storage and disposal (TSDF) facilities; and
- more stringent emission limits for utility boilers and internal combustion engines.

Additional information on the effectiveness and costs associated with these additional control measures can be found in Appendix F.1. The EPA recognizes that states and localities may consider some of this information as they undertake planning efforts to implement the NAAQS. In doing so, they should bear in mind caveats elsewhere in this RIA about the information and estimates presented. Second, it is important to note that the cost-effectiveness of a measure for a particular nonattainment area may vary from EPA's estimate of the cost-effectiveness estimates for nonattainment areas nationally. Third, EPA suggests avoiding comparisons of cost-effectiveness figures in this RIA between measures that control different pollutants, between measures that apply nationwide and those that apply only in non-attainment areas, and between year-round and seasonal measures. Such comparisons may be misleading. In the draft RIA accompanying the proposed revision to the ozone NAAQS, EPA asked for comment on the Agency's traditional calculation of cost effectiveness and two alternative methods of calculating cost effectiveness that have been suggested to the Agency. The traditional calculation compares total annual costs with total annual emissions reductions. The first alternative would compare total annual cost with emission reductions in nonattainment areas only. The second alternative would compare total annual cost with emissions reductions in nonattainment areas during peak ozone months of the year. Despite the request for comment, the Agency received no comments on this issue in the context of the RIA. Based on its own preliminary analysis and comments received in a separate rulemaking (National VOC Emission Standard for Consumer Products. Federal Register, 1996), EPA has concluded that each of the methods -- the traditional approach and both suggested alternatives -- raise issues requiring further consideration. As a result, EPA has not decided whether to recommend one or more of these cost-effectiveness measures as a valid way to compare control measures that are dissimilar in geographic scope (nationwide versus non-attainment areas) or period of applicability (year-round versus seasonal). EPA will continue to evaluate this issue in future rulemakings.

9.4 THE ROLE OF NEW AND EMERGING TECHNOLOGY IN NAAQS ATTAINMENT

During the course of implementing the CAA, many new technologies have been developed to control air pollution. Because of ongoing needs to offset growth in emissions sources, and because in some respects the CAA has been a technology forcing statute, air pollution control and prevention technologies are continuously under development and improvement. The result is a fairly rapid pace of innovation in the air pollution control sector. Ten years ago, technologies such as those listed below might not even have been contemplated. Today, they are successfully in use across the U.S. and throughout the world.

- Selective Catalytic Reduction (SCR) for NO_x emissions from power plants
- Gas reburn technology for NO_x
- Scrubbers which achieve 95 percent SO_2 control on utility boilers
- Reformulated gasoline
- Low-Emitting Vehicles (LEVs) that are far cleaner than had been believed possible in the late 1980s (an additional 95 percent reduction over the 1975 controls)
- Energy-efficiency improvements in industrial processes, commercial, residential and appliance applications
- Reformulated lower VOC paints and consumer products
- Sophisticated new valve seals and detection equipment to control leaks
- Water and powder-based coatings to replace solvent-based formulations
- Safer, cleaner burning, wood stoves
- Dry cleaning equipment which recycles perchloroethylene
- CFC-free air conditioners, refrigerators and solvents

The air pollution control and prevention market is large and growing. The demand for cleaner products and cleaner production processes that lower overall costs, combined with the necessity for improved air quality, create strong incentives for technological innovation and a growing market for such innovations. As the demand for more innovative, cost-effective and cost-saving technologies increases, new technologies will move from the research and development or pilot program phase to commercial availability. Table 9.3 contains a sample of emerging technologies that could play a significant role in successful attainment strategies. A more comprehensive listing of technology examples can be found in Appendix F.2.

Table 9.3 Examples of Emerging Technologies for Lower Emissions and Cheaper Control of VOCs, NO_x, and PM

Example Source Categories	Technology Name(s)
Electricity Generation	Thin film photovoltaics: amorphous silicon, cadmium telluride, thin-layered crystalline-silicon
	Fuel cells: proton exchange membrane, molten carbonate, phosphoric acid, solid oxide
	Wind power: improved airfoil materials and manufacturing techniques
Small engines	Clean air 2-stroke engines, vaporizing carburetors, alternative fuels for commercial engines/vehicles
On-road and non-road vehicles	Exhaust aftertreatment technology : vacuum insulated catalyst, plasma treatment, non-thermal plasma reactor, oxygen enrichment membrane
	Alternative fuels: medium duty truck cng conversion kit, propane/butane fuel blends, LNG technology for locomotives;
	Electric vehicles & batteries: advanced inductive electric vehicle, advanced batteries and charging systems
	New vehicle designs: Partnership for New Generation Vehicle,
Industrial Adhesives	Water-based aerosol adhesive, dual cure photocatalyst technology, non-acrylate systems, electron beam-curable epoxy resins for composites
Surface Coating	Polyurethane reactive (PUR) technology, new applications of water and powder based coating, zero-VOC industrial maintenance metal coating, micro-emulsion technology, new photo initiator systems, advances in transfer efficiencies, supercritical CO2 as a paint solvent

As referenced above, new and emerging technologies are expected to play a key role in future air quality management programs. In the 1990 Amendments to the CAA (CAA section 182(e)(5)), Congress expressly recognized that areas with the most serious air pollution problems can rely on new and developing technologies that are not available in the short term for purposes of demonstrating that they will attain the standards. This provision establishes interim milestones and relies on the existing attainment date as incentives to assure development and deployment of advanced technologies. Use of this provision has promoted investment in advanced technology research in the Los Angeles area. Some areas that will have the most difficulty attaining the new ozone and fine particulate matter standards may find a similar approach appealing. Before considering such an approach, a state should demonstrate that it will not attain the standard based on all reasonably available controls and needs to rely on innovative technologies as the basis for the remainder needed to reach attainment. EPA wishes to pursue an approach analogous to that established by Congress in section 182(e)(5), where states can provide appropriate assurances that such technologies will be available to be implemented in sufficient time for the area to attain the standard.

Beyond the control measures and associated emission reductions referenced in 9.3, some areas require further reductions. Air quality management areas and sources in these areas will seek these further reductions in a number of ways. Existing technology will play a key role for some sources, emerging technology for others. Innovations in both environmental policies, as well as commercial and industrial environmental management, will also play a major role.

Most of the emerging technologies that are highlighted in this section and in Appendix F-2 should be available for application at specific sources in locations needing further emissions reductions. Some of these measures, due to the specific economic characteristics of the industries involved, may make sense to implement on a national basis. The size of the eventual market for these emerging technologies will depend on their emission reduction potential, their ability to displace existing technology, and their potential to become part of an optimal regional or national air quality management strategy.

This analysis assumes the average cost of reductions achieved through this variety of unspecified methods is \$10,000/ton. This compares with an average control cost for specified measures in this full attainment scenario of approximately \$3,200/ton for NO_x and \$4,000/ton for

VOC reductions. The relative high cost of the unspecified measures provides an ample margin to account for unknown analytical considerations associated with future projections and may tend to overestimate the actual final cost of full compliance.

The residual emission inventory present in areas after specified measures have been implemented will be comprised of a range of uncontrolled and controlled sources. Previously uncontrolled sources could be expected to utilize existing control strategies and technologies similar to those referenced in this analysis, among other solutions. Controlled sources may use emerging technologies designed to achieve even better environmental performance than the current level of technological control. Faced with a demand for lower emissions, industries often respond with more effective technological innovations like those outlined below. For example, the electric utility industry is considering moving from low-NOx burner designs to selective catalytic reduction of NOx emissions at potentially similar or reduced costs per ton and greater emissions reductions. The automotive industry employed a new generation of catalytic converter when required to reduce tailpipe emissions further.

This section provides a wealth of technological innovation examples actively being pursued for all types of sources of emissions. EPA believes that states and sources will utilize technologies that are the most cost effective and that act in synergy with the operations of the business or source itself. Although difficult to predict its eventual costs, future technologies will benefit from significant learning experience associated with present technological applications.

In addition to incremental innovations in the same type of pollution control technology (e.g., more efficient catalytic converters), many industries and sources seeking further improvements will implement altogether different types of solutions. A company or industry facing increasingly more stringent solvent emission limits, for example, is unlikely to seek ever more expensive add-on control devices. Instead they will seek substitutes such as non-volatile material inputs or process changes. Redesign of both products and processes becomes a likely operative part of this industry’s or company’s environmental solution. The advent of low- and zero-solvent paints and coatings is a prime example. Powder and water-based coating systems are being introduced in many industries, including the automotive manufacturing sector. Other substitutions, such as cleaner fuels, are commonplace and can be expected in the future as industries seek optimal solutions. Many companies find that these changes save them material, as well as, pollution control costs.

Such changes in environmental management practices are occurring today and will play a greater role in the future. Industrial environmental management strategies incorporate a broad spectrum of environmental solutions. Pollution prevention, material substitutions, cleaner process and product design, and improved material utilization are all acting to limit or eliminate the cost of pollution control. The demand for such innovations increases as the cost of traditional "add-on" solutions increases.

Environmental policy innovations are also being employed as efficient methods to provide cleaner air. Market-based policies, such as the acid rain emission trading system, are responsible for creating more efficient industry-wide environmental solutions. Localities, such as air quality management districts, are also implementing market-based emission reduction plans. Section 9.5.1 in this chapter describes how one such type of policy, "Clean Air Investment Funds," may contribute to a more efficient regional air quality management plan. EPA intends to strongly encourage these approaches as a means of minimizing compliance costs.

Given the breadth of environmental improvement solutions available, the significant number of emission control measures available for well under $10,000/ton of emissions reduced, and the wealth of active technological innovation underway, a $10,000/ton estimate for emission reductions beyond those specified in this analysis may be a conservative (i.e., high) estimate of future costs in some areas. EPA will encourage and facilitate flexible implementation approaches, such as emissions trading programs, to help areas eliminate barriers to utilizing the most cost-effective reductions.

9.5 TRENDS AND FACTORS LEADING TO MORE COST-EFFECTIVE IMPLEMENTATION

9.5.1 Major Economic and Social Trends Affecting Future NAAQS Attainment Strategies

As illustrated in the preceding discussions, predicting the specific costs of meeting the new NAAQS in the year 2010 is, by its very nature, analytically difficult. Dynamic trends in the U.S. economy, in air quality modeling and in air pollution control strategies must all be taken into account. While the emission inventories contained within this analysis incorporate certain rates of economic growth, the analysis projects a "static" picture of the precise makeup of U.S. economic activity. Major trends currently reshaping the U.S. and world economy will continue to profoundly affect the makeup of our future economy and its resultant environmental impact. A majority of these trends will enhance a region's ability to attain the new air quality standards.

Thirteen years from now, we could expect the U.S. economy to be more efficient in its production processes and use of materials. We could expect information technologies and high-value added sectors of the economy to grow at faster rates than traditional manufacturing and higher-polluting sectors of the economy. The fastest growing industries today and for the foreseeable future release less pollutants to the environment on an industry-wide basis than do the slowest or negative growing sectors of the economy.

Table 9.4 summarizes some of these major trends, their implications and the potential relative effect on attaining the new air quality standards. Following the table are brief descriptions of each trend or factor.

Table 9.4
Major Trends and Factors Leading to More Cost Effective Implementation

Trend	Implication	NAAQS Attainment Impact
Economic Trends		

Table 9.4 (continued)
Major Trends and Factors Leading to More Cost Effective Implementation

Trend	Implication	NAAQS Attainment Impact
1) Increasing knowledge-intensity of the U.S. economy	Shift towards less polluting manufacturing processes and services industries.	Enhance implementation & lower costs
2) Globalization of trade and investment	Growing market for high value U.S. business, financial and environmental services.	Enhance implementation & lower costs
3) Widespread adoption of advanced information technologies	Enhanced efficiency in manufacturing processes and growth of new, less polluting, technology and services industries.	Enhance implementation & lower costs
4) Geographic dispersion of business locations within the U.S.	Growth in mobile source pollution from increases in shipping and commuting distances.	Impede implementation & raise costs
Environmental Management & Policy Trends		
5) Increased use of market-based policies such as clean air funds & emission trading	Lower control costs, increased technology innovation and earlier compliance are all possible through economic incentive policies.	Enhance implementation & lower costs
6) Development and implementation of regional air pollution control strategies	Provides area-wide focus, leading to optimization of control strategies based on greater recognition of air emission transport and transformation. Fosters cooperation.	Enhance implementation & lower costs
7) Introduction of new regulatory mandates for international greenhouse gases and new categories and sources of toxic chemicals	Reduction in emissions of PM and ozone precursors as a side result of changes in industrial activities due to new mandates.	Enhance implementation & lower costs
8) Improved corporate environmental management strategies.	Pollution prevention programs, waste minimization schemes, environmentally-improved product and process design and ISO-14000 type programs	Enhance implementation & lower costs
Energy Trends		
9) Increased energy efficiency	Reduction of the energy intensity of the economy will reduce air pollution associated with energy generation and consumption.	Enhance implementation & lower costs
10) Deregulation of electric utility industry	Possible increase in energy demand and lower prices for electricity may increase demand for cleaner sources of power under regional agreements.	Enhance implementation
Societal Trends		

Trend	Implication	NAAQS Attainment Impact
11) Increasing public concern with quality and preservation of the natural environment	Greater public willingness to support environmental protection efforts.	Enhance implementation
12) Development of local, state, national and international programs to monitor environmental quality	Increased integration of environmental protection concerns into economic development and other policy making processes.	Enhance implementation

Economic Trends

1) Increasing Knowledge-Intensity of the U.S. Economy

Today's economy is becoming more "knowledge based" as high skill, information-intensive activities comprise a larger and increasingly important part of business and industrial activity. As a result, service and high-technology industries are growing and there is an increasing focus on higher value-added manufacturing activities. These changes have positive implications for NAAQS implementation because many of these growth sectors consist of low polluting industries.

As economic forces are leading to growth in higher value activities, there has been a related trend away from pollution intensive industries to cleaner, more energy efficient industries. Most of the fastest growing industries are in the services sector, particularly health care, transportation, and high value business services such as engineering and research. These industries are generally low emitters of SO_2 and NO_x have moderate VOC emissions. In comparison, many of the slowest growing industries are in heavy manufacturing and have relatively higher emissions of all three pollutants.

2) Globalization of Trade and Investment

Another key force behind the transformation of the U.S. economy is globalization. Globalization is manifested in a number of ways. New international production networks, for example, allow firms to increase efficiency by sourcing different stages of production in the most cost effective locations around the world, in effect, creating a new international division of labor in which the U.S. will continue to be the location for the most advanced business activities. Growth of foreign markets for environmental and other advanced technology products and services is another factor. Currently, environmental industries employ more than one million workers. The world environmental market is booming and is expected to grow at a 7.3 percent average annual rate according to studies released in April, 1995, by the National Commission for Employment Policy (NCEP).

Some of this growth in international trade is showing up as increased demand for products by relatively heavily polluting U.S. industries. However, broader trends towards concentration of high value business activities in the U.S. are positive for the reduction of pollution emissions.

3) Widespread Adoption of Advanced Information Technologies

The widespread adoption of advanced information technologies is one of the main factors driving the creation of information-intensive, often low-polluting industries. It is also a main driver in helping manufacturing become more efficient and hence cleaner. Both of these trends enhance the ability of the economy to implement the NAAQS. Technologies such as computers, software, semiconductors, telecommunications services, and communications equipment have diffused throughout the economy. In 1984, less than 25 percent of the U.S. workforce used a computer on the job. By 1993, this number had nearly doubled, to 46 percent. Even in manufacturing, the numbers have risen to the point that by 1993, 42 percent of all workers in manufacturing industries used computers at work.

4) Geographic Dispersion of Business Locations within the U.S.

The shift of jobs to the service sector now occurring in the U.S. economy has reduced the role of central cities within most metropolitan areas. In addition, the decline of large, vertically-integrated factories means that the flow of materials from one processing stage to the next requires external freight transportation at the same time that the location of manufacturing industries has spread throughout the U.S. As a result, there is continuing growth of mobile source pollution despite technological improvements to reduce vehicle emissions. As the contemporary economy becomes more complex, transportation demand increases on a per capita basis. Vehicle Miles Traveled (VMT) for all road vehicles has more than doubled, on a per capita basis, since 1960. Although such VMT growth is accounted for in EPA's analysis and growing investment in transport planning measures is expected, continuation of this trend potentially impedes NAAQS attainment efforts.

Environmental Management & Policy Trends

5) Increased Use of Market-Based Policies such as "Clean Air Investment Funds" and Emission Trading

In addition to changes in the level of environmental standards and the types of compounds and industries that are regulated, some sweeping changes are occurring in the way environmental standards are being implemented. Several efforts are underway to create new regulatory processes that afford greater flexibility with the goal of lowering the costs of meeting environmental protection goals. These efforts include a variety of market-based incentive systems. Market-based systems to reduce pollutant emissions have been promoted for many years as an alternative to fixed regulatory standards. Such systems are expected to reduce the costs of compliance and induce more technological innovation in methods of reducing pollution.

National and regional market-based programs such as emissions trading may achieve pollution control goals at dramatically less expense because they allow firms that face high costs to purchase "extra" reductions from firms facing below-average control costs. This RIA models a SO_2 cap and trade program, but due to data limitations, does not attempt to model other potentially cost saving market-based programs. However, the lead and chlorofluorocarbon (CFC) phase-out plans and the Acid Rain program are all examples of the ability of national market-based programs to provide environmental protection at lower cost. With pollution control efforts pegged to the going price of allowances, rather than to the highest cost source, these market-based programs can promote both cheaper and faster compliance.

Continued experience with market programs indicates that they do lead to greater cost savings. For example, the cost of reduction in the CFC phaseout program, which used an allowance system, was at least 30 percent less than predicted. EPA's 1988 RIA estimated a 50 percent CFC phase-out regulation would cost a total of $2.7 billion ($3.55 per kilogram). A subsequent analysis performed in a 1992 RIA estimated that a 100 percent phase-out by 2000 would cost a total of $3.8 billion ($2.20 per kilogram). The most recent analysis conducted by EPA in a 1993 RIA estimated a 100 percent phase-out by 1996 would cost $6.4 billion ($2.45

per kilogram) for faster reductions and enhanced environmental benefits. The CFC example illustrates that, although phasing-out CFCs seemed a daunting challenge a decade ago, firms have eliminated CFCs faster and at lower cost.

In addition to EPA's experience, at least one nonattainment area has implemented a market-based program. In 1993, California's South Coast Air Quality Management District (SCAQMD) developed a market incentive approach known as the SCAQMD Regional Clean Air Incentives Market (RECLAIM) as an alternative to traditional command and control regulation - RECLAIM is perhaps the first very large-scale, multi-industry emissions trading program.

The goal of RECLAIM is two-fold: provide facilities with added flexibility in meeting emission reduction requirements, and lower the cost of compliance. RECLAIM covers emissions of both NO_x and SO_x, for at least 70 percent of the Los Angeles basin's stationary source emitters, by establishing facility mass emission limits. RECLAIM allows sources the flexibility to achieve prescribed emission reduction targets through process changes, installation of control equipment, emissions trading, or other methods (SCAQMD, 1993). The Second Annual Audit Report describes RECLAIM's successes including meeting its emission reduction goals, and developing an active trading market with "average prices of RECLAIM Trading Credits (RTCs)...well below the back-stop price of $15,000 per ton...$154 per ton for 1996 NO_x RTCs; $1,729 per ton for 2010 NO_x RTCs; $142 per ton for 1996 SO_x RTCs; and $2,117 per ton for 2010 SO_x RTCs." (SCAQMD, 1997).

EPA is actively pursuing and encouraging adoption of innovative approaches to air quality control, including use of economic incentive programs. Areas are expected to adopt market-based systems to meet their PM, ozone, and regional haze (RH) air quality goals because such systems allow emission reductions to be achieved using the most cost-effective controls. In addition, market-based programs provide continuous and powerful incentives to develop new technologies while achieving emission reductions which otherwise would not be available under the typical regulatory approach.

EPA intends to place heavy reliance for implementing revised standards on new or expanded market-based programs. Market-based systems potentially in place 10 years from now include:

- Clean Air Investment Funds (see below);
- Cap-and-trade systems for NO_x in eastern (Ozone Transport Assessment Group (OTAG)) and western (Grand Canyon) regions;
- Cap-and-trade system for SO_2 to implement fine particles standard (building on the current acid rain program); and
- Cap-and-trade systems for volatile organic compounds (VOC) in major metropolitan areas (modeled on Chicago program now being adopted);
- "Open market" trading to bring in cost-reducing emission control opportunities from smaller or unconventional sources outside of the cap-and-trade programs.

As cited above, another example of a market-based strategy that could reduce control costs without sacrificing pollution control is an investment fund strategy. Through a "Clean Air Investment Fund," states or EPA could allow firms facing high costs to pay into a fund rather than control emissions themselves. Fund revenues may then be used to purchase additional emission reductions from lower cost sources. The net result of this approach would be to facilitate continued progress on reducing pollution while simplifying compliance for sources choosing to pay into the Fund.

Consider an area which, for example, after implementing a significant emission control program, is left short of the necessary emission reductions it needs for attainment. The residual emission inventory is dominated by two types of emission sources: (a) relatively well-controlled major sources where the next increment of emission control can only be obtained for a relatively high $/ton marginal cost (e.g., $15,000/ton) and (b) uncontrolled minor sources, where the cost per ton of emission control is relatively small ($2,000-$5,000/ton), but the sources are traditionally not subject to control because they are too small and numerous to incorporate or outside the scope of existing regulatory policies for other reasons. The high dollar-per-ton source, faced with a relatively high emission control cost, could make a contribution to the Clean

Air Investment Fund at a predetermined price instead. The price or “deposit” would be less than the control cost they were facing, but greater or equal to the marginal control cost faced by sources regulated in earlier phases of the attainment strategy.

The Clean Air Investment Fund would then use these revenues to encourage other more cost-effective sources in the area to make reductions. Such inducements could come in many forms. The Fund could provide rebates for the purchase of cleaner products to replace older more polluting sources. Large-scale small engine (lawn mowers and other such equipment) buy back programs or funding the cost of mass transit vehicle engine retrofits are such other examples. Other investment opportunities for the Fund include: utility and industrial boiler SO_2 and NO_x reductions beyond the acid rain program levels for SO_2 and beyond the 0.15 lb/MMBTU limit for $NO_{x,}$ use of more stringent leak detection programs to control fugitive emissions at chemical plants, refineries, and other large sources of ozone and PM precursors, and additional use of low- or no-VOC coatings.

A Fund would give states and localities the ability to achieve emissions reductions from sources not currently regulated (such as voluntary efforts, e.g., buy-back programs) and through reductions in energy consumption or vehicle miles traveled in exchange for economic incentives. Clean Air Investment Funds also provide powerful incentives to develop new technologies since the developers would know that the resulting emission reductions could be sold to the Fund.

Because Clean Air Investment Funds have an ability to reach out to otherwise unregulated sources, they could greatly increase a region’s ability to pull cost-effective emission reductions from a diverse set of sources into a strategy. A Fund with the authority to arrange for emission reductions from its own choice of unregulated sources is much more likely to succeed because of the incremental and selective nature of the program.

In addition to its active role in seeking out emission reductions, Clean Air Investment Funds have the advantage of facilitating the operation of a market-based system. The transaction costs of economic-incentive programs, such as locating potential sources of emission reductions and negotiating mutually agreeable terms, can be (or appear to be) large enough to discourage the use of trading systems. However, many of the difficulties in setting up emission allowance or cap and trade systems can be mitigated by a Clean Air Investment Fund because it allows sources to limit their dealings to an agency or third-party entity that is competitively neutral. The existence of a Fund also provides a limited guarantee that emission reductions will be available if needed, generally at a predictable cost. Thus, states may also choose to adopt a Clean Air Investment Fund as either a supplement to or a substitute for a cap and trade program.

A Clean Air Investment Fund is one example of innovative clean air policies that can help even the most difficult nonattainment areas improve their compliance situation. Current and proposed Fund programs, such as those in Sacramento, Ventura County California, Connecticut, Illinois, and El Paso, Texas/Juarez, Mexico, will provide invaluable experience for future programs. Over the next decade, economic incentive programs like Clean Air Investment Funds will likely become more commonplace as emission inventories are improved, experience expands, and the benefits associated with such systems are realized.

6) Development and Implementation of Regional Air Pollution Control Strategies

While national and local control strategies continue to be important in reducing air pollution, there is a relatively new focus on regional control strategies. On an area-wide level, we have learned through the work of the Ozone Transport Commission (OTC), OTAG, and the Grand Canyon Visibility Transport Commission, that air quality problems in many areas are a result of emissions transport and transformation and not local emissions alone. For example, OTC and OTAG developed potentially more cost-effective strategies than had been thought to be available -- both regions will be using a cap on NO_x emissions that should lower the overall cost. Consequently, regional measures are likely to be a critical component of many attainment strategies. Cooperative planning among all states, tribes, and localities contributing to common air quality problems is necessary to develop effective regional control plans.

In implementing the new PM and ozone NAAQS, EPA expects areas will develop regional control strategies unique to each area. These coordinated strategies should be carefully developed based on regional considerations. Thus, actual implementation strategies may be significantly more cost-effective than the local and broader-based strategies assessed in this RIA.

7) New Controls for International Greenhouse Gases and New Categories and Sources of Toxic Chemicals

Several new environmental policies, if implemented, would have an impact on future NAAQS implementation. These include:

- A potential new international agreement reducing greenhouse gas emissions would likely have significant impacts on ozone precursors and thus would further encourage types of emissions reductions related to the proposed new NAAQS. (See Trend 9 below).

- Introduction of new international regulatory regimes to govern Persistent Organic Pollutants (POPs) and Endocrine Disrupting Chemicals (EDCs). Actions on POPs and EDCs may affect plastics, manufacturing processes involving chlorine, agricultural pesticides containing cyclic organic substances, incineration of organic and chlorine compounds, and detergents. To some extent there is likely to be an interrelationship between control options for these substances and subsequent effects on PM and ozone.

- Expansion of reporting requirements under EPA's Toxic Releases Inventory System. Presently, seven more industries are being added to the TRIS: coal mining, metal mining, electric utilities, commercial hazardous waste treatment, petroleum bulk terminals, solvent recovery services, and chemical wholesalers. These industries are among some of the most significant producers of PM and ozone precursors. Based on previous TRI experience requiring these industries to report their toxics emissions will, by making the information public, lead to pollution reductions.

8) Improved Corporate Environmental Management Strategies

Corporations and other organizations are making a number of important changes to voluntarily contribute to the lowering of emissions through improved environmental management. Environmental management in business today is quickly becoming a vital part of overall business management strategies. Businesses are striving to reduce operating costs through improved efficiency, productivity, and reduced material and waste management costs. ISO 14000 Environmental Management Systems are expected to be an integral part of business strategies in the near future. Pollution prevention programs emphasizing source reduction and waste minimization are proliferating. Environmental accounting practices are identifying hidden, but previously unaccounted for, environmental costs associated with certain products and practices. This awareness is leading to a reduction or elimination of such costs. And finally, manufacturing processes and products themselves are increasingly being designed with environmental impacts in mind.

Energy Trends

9) Increasing Energy Efficiency May Lower Costs

The preceding analyses of the costs presented in this RIA are generally based on business-as-usual assumptions concerning the future demand for energy. Yet, energy consumption can be a major source of air pollution, including ozone and $PM_{2.5}$ precursors. To the extent that the energy intensity of the American economy can be significantly reduced through cost-effective investments in energy efficient technology, meeting any new emissions limitations will be easier and cheaper. One recent study, for example, suggested that the nation could cut the growth of energy use by 15 percent in the year 2010 at a net savings of about $530 per household per year. (Alliance to Save Energy, et al., 1997). Combined with the use of cleaner energy resources, this study indicated that energy efficiency investments would also lower NO_x and SO_2 emissions signficantly below their 1990 levels. This suggests that there is ample scope to increase the nation's energy efficiency, which will simultaneously improve overall economic productivity and reduce energy-related pollution.

The U.S. Climate Change Action Plan (CCAP) is an important step in an energy-related productivity strategy. The CCAP is designed to lower greenhouse gas (GHG) emissions which most scientists now believe contribute to global climate change. The majority of today's CCAP programs target end use energy demand in lighting, buildings, appliances, and industrial motors and processes. Current projections suggest that today's CCAP programs will reduce the expected growth of U.S. emissions that cause global climate change by 25 to 30 percent. The next stage of the U.S. national climate change mitigation policy will most likely continue to pursue a productivity-led investment strategy, but would do so in concert with policies that will unambiguously signal the need to avoid any increases in GHG emissions, and to even reduce emissions from current levels. In the international climate change negotiations, the U.S. is pursuing legally binding targets at a level considered to be "real and achievable." Such targets will help decrease not only GHG emissions, but also a variety of other air pollutants. Moreover, greater penetration of today's energy-efficiency technologies can also decrease American dependence on foreign oil, increase productivity of domestic industries, and promote U.S. leadership in the large and growing international market for advanced technologies. Perhaps most important, shifting capital from energy expenditures to new investments elsewhere in the economy would help drive economic growth, employment and consumer income.

10) Deregulation of Electric Utilities

The federal and state governments have taken steps to introduce deregulation into electric power markets. The Energy Policy Act of 1992 (EPAct) made several fundamental changes in the wholesale electricity markets, including: encouraging independent power producers to sell power in the wholesale market; allowing new market entrants such as power brokers and marketers to sell power; and ensuring open, non-discriminatory access to transmission services.

Similar actions at the retail level have encouraged greater competition, including provisions to allow consumers to choose the generation source and the local retail supplier of their electricity, much like consumers now choose their long-distance supplier in telecommunications. Due to the significant nature of these changes on how electricity is supplied to consumers, there is the great potential that consumers will opt for cleaner sources of electricity and markets will respond accordingly.

Societal Trends

11) Increasing Public Concern with Quality and Preservation of the Natural Environment

Increased affluence and mobility are creating a greater demand for communities with cleaner, safer environmental conditions. Indeed, “quality of life” is cited as an increasingly important criterion in business location decisions as firms, particularly in high-growth, technology-intensive industries, position themselves to compete for the best talent. This shift in public attitudes can be expected to have positive impact on NAAQS implementation as citizens become more willing to apportion the attention and resources necessary to address environmental problems.

Evidence of this trend in societal, and particularly, business attitudes is provided by a 1995 study by Arthur Andersen conducted as part of Fortune Magazine’s report on the “Best Cities for Business.” In this study, a selection of worldwide business leaders was asked about key factors in making site selection decisions for different types of business operations. The executives said that high quality of life was especially important for headquarters and research and development operations, i.e., for attracting knowledge-workers. Similarly, when Money Magazine polled a sample of readers about the things most important to them in selecting a place to live for the magazine’s annual survey of “The Best Places to Live Today,” clean water and clean air ranked at the top of the list above such things as low taxes, good schools, health care or local employment conditions.

12) Development of Local, State, National and International Programs to Monitor Environmental Quality

As the shift in public attitudes has become more pronounced, policy makers, economists, academics, and others have recognized a need to change economic and policy systems to incorporate new public attitudes and goals. As a result, there is increased integration of environmental protection concerns into economic development and other policy making processes. This change is reflected in the increasing inclusion of environmental data in measurement systems for ranking communities (e.g., the Well-Being Index published by American Demographics) and nations (e.g., the World Bank's sustainable wealth of nations measure). It is also reflected in the development of movements such as "sustainable communities" and EPA's Smart Growth Network. This shift in public attitudes and programs can be expected to have positive effects on the ability to implement new air quality standards as public interest in addressing environmental problems becomes more imbedded in customary decision making and planning processes.

9.5.2 Uncertainties in Estimating Compliance Costs Often Lead to Overestimates

Major environmental regulations, like other types of social regulation, entail social costs as well as benefits. However, under Congress' direction, some environmental regulations -- like the NAAQS -- must be based only on health considerations. The Agency believes that while it is inappropriate to consider costs in setting health based standards like the NAAQS, it is appropriate to consider the expected costs of implementation alternatives to guide states and localities as they make the difficult choices in deciding how to implement the standards. Developing accurate, unbiased estimates of the social costs of complying with or implementing a regulation is, thus, a key component in analyzing its likely impacts on society.

Many factors, however, such as the "static" nature of this analysis may lead to the overestimation of costs. For example, a firm's initial response to a new regulatory demand may be far less efficient than its later response to the same challenge. Analyses of this sort do not capture this learning curve effect and tend to overestimate costs. Similarly, technologies themselves change and become more optimal and efficient over time. These improvements and the effect they may have on lowering costs between early and mature stages of technology development are difficult to capture.

Concerning technology change, regulations themselves affect the rate and direction of technical innovation. As firms invest in new plants and equipment, they will take into account any regulatory changes that have occurred since the previous generation of investments was put in place. Less pollution intensive technologies or processes will become more attractive. Besides technological advances, another phenomenon affecting long-run compliance costs is the ability of the regulated community to learn over time to comply more cost-effectively with the requirements of the regulation. While in practice this effect is difficult to quantify separately from the effects of technological change, the combined effects on pollution abatement and control costs can be incorporated into regulatory compliance cost forecasts by applying an assumed rate of "learning" arising from both sources. This analysis does not incorporate such an assumption. The following discussion of the use of progress ratios for estimating future technology and compliance costs evaluates these notions further.

9.5.3 Use of Progress Ratios to Deflate Cost Estimates for Existing Technologies

As discussed in the preceding section, a more accurate cost estimate would account for technological advancement and learning curve effects. In fact, hundreds of studies confirm that new products and technologies decline in cost as they become accepted and widely adopted throughout the economy. The rate of decline varies among the different technologies. However, a common rule of thumb -- often referred to as a "Progress Ratio" -- is that each new doubling of output for a given technology will deflate the unit cost of that technology to about 80 percent of its previous value.

The fall in unit cost is the result of a variety of factors: (a) new knowledge that is continuously flowing into the production process; (b) economies of both scale and scope that can be achieved with increasing levels of output; (c) costs that fall with "learning by doing" even without any visible change in the physical capital used for production; and, finally, (d) the proliferation of service and distribution networks that reduce the cost to consumers using the new technologies. Thus, future estimates of energy and pollution control technology forecasts should anticipate some decline in the cost of these technologies over time; or more specifically, as a function of continued production and increased market share.

Estimates of Progress Ratios

Examples of progress ratios for various past and future technologies, either calculated or taken from the literature, are shown in the Table 9.5 below. Based upon the examples in this table, the progress ratios range from 67 to 98 percent. The example of a so-called "mature" technology such as the magnetic ballast shows a 98 percent progress ratio which means that costs are not falling very quickly at all. On the other hand, a more advanced technology for the same end use, in this case the more efficient electronic ballast, suggests a 90 percent progress ratio. The pollution control technologies in the above table -- including CFC substitutes and scrubbers -- appear to hover close to the 90 percent benchmark.

Table 9.5 Examples of Progress Ratios

Technology	Period	Cumulative Production	$COST_0$	$COST_t$	Progress Ratio
Electronic Ballasts	1986-1993	52.7 million	$37.65	$18.23	90%
Magnetic Ballasts	1977-1993	629.3 million	$7.86	$6.47	97%
Fluidized Bed Coal	1987-1992	n/a	n/a	n/a	95%
Gas Turbines	1987-1992	n/a	n/a	n/a	95%
Wind Turbines	1987-1992	n/a	n/a	n/a	90%
Integrated Circuits	1962-1968	$828 million	$50.00	$2.33	67%
Low-E Windows	1993-2010	11.3 bsf	$2.90	$1.20	86%
CFC Substitutes	1988-1993	8.9 billion tons	$3.55	$2.45	93%
Photovoltaics	1975-1994	516 MW	$75/watt	$4/watt	70%
Solar Thermal	1996-2020	800 MW	$3335/kW	$2070/kW	90%
Gasified Turbines	1997-2000	156 MW	$2000/kW	$1400/kW	84%
Scrubbers	1985-1995	85,700 MW	$129/kW	$122/kW	88%

<u>The Influence of Progress Ratios on Potential Technology Costs for the NAAQS</u>

In the current analysis only economies of scale are reflected in estimates of technology control costs in the year 2010. However, both the capital and operating costs of incremental control measures are likely to be affected by the impact of learning or experience curves. To the extent that experience curves are not reflected in such cost estimates, the cost of control technologies will be overstated. For example, let us assume that costs in the year 2010 are projected to be only 80 percent of the current projections -- because of cumulative experience in the production and installation of a given set of control technologies. If the year 2010 baseline cost projection is $1.5 million (in 1990 dollars) for a given technology, assuming a 20 percent drop as a result cumulative production experience would lower that cost estimate to $1.5 million * 0.80, or $1.2 million. The basis of this adjustment is the Progress Ratio.

9.6 REFERENCES

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10.0 ADMINISTRATIVE BURDEN AND COSTS ASSOCIATED WITH THE SELECTED OZONE AND PARTICULATE MATTER (PM) NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS), AND PROPOSED REGIONAL HAZE (RH) RULE

10.1 INTRODUCTION

10.1.1 Results in Brief

This chapter provides an estimate for the additional administrative cost of the joint ozone and PM NAAQS and RH rules to the Federal government, States, and sources of pollution (Federal and non-Federal). These additional costs are estimated relative to the analytical baseline of this regulatory impact analysis (RIA). In the prior ozone RIA, the Environmental Protection Agency (EPA) assumed the marginal administrative burden of the alternative ozone standards was not of sufficient magnitude to affect the discussion of total costs [US EPA 1996(b)]. This analysis supports that assumption. Given the national scope of the NAAQS and the degree of change in nonattainment areas (NA's), this section of the RIA estimates marginal costs of about $17 million for the selected ozone NAAQS, well within the range discussed in the previous RIA. While cost savings may occur between ozone and PM under a combined analysis, the administrative cost estimate for ozone is a reasonable approximation of the administrative cost for PM under a joint NAAQS scenario. Consequently, the 15/65 $PM_{2.5}$ marginal administrative cost estimates are of the same magnitude as those for ozone, or about $17 million. The $PM_{2.5}$ monitoring costs, for which EPA has agreed to pay, adds $20 million for a total $PM_{2.5}$ cost of about $37 million. The administrative strategy associated with the proposed RH target relies on PM efforts as much as possible. The expected additional administrative cost for RH is about $1 million.

10.1.2 Overview of Analysis

In addition to control costs, administrative burdens comprise one of the primary considerations when the EPA estimates the impact of a rulemaking. For industry-specific rulemakings, the Agency performs its burden analysis under the guidance of the Paperwork

Reduction Act (PRA), in a document entitled an Information Collection Request (ICR). An ICR provides policy makers with a tool for minimizing the administrative burden imposed by a rulemaking upon Federal Agencies, States, local governments, and sources of pollution.

In the case of NAAQS, States assume primary responsibility for designing the set of air quality management plans which will bring the State into attainment and/or keep it there. Once the Agency has set the standards, it must define the processes by which it will identify and oversee nonattainment areas. To aid in this process and make recommendations on implementation, the Agency has established a subcommittee on ozone, PM, and RH under the Federal Advisory Committee Act (FACA). Since this subcommittee has not completed its work, it has not provided final recommendations as to how the joint NAAQS should be implemented. Therefore, it is not possible to prepare an ICR at this time. Nevertheless, the Agency has estimated administrative costs to give the public some understanding of the possible implementation costs of these standards.

This RIA is not intended to fulfill the requirements of the PRA, nor should conclusions be drawn from it about the actual administrative burden and costs areas may incur as they develop attainment strategies that reflect different NA's economic, social, infrastructural, and political characteristics. This section presents an approximation of the additional administrative effects one might expect from the selected NAAQS and RH rule, based upon a hypothetical determination of NA's and control measures which may be selected by States when revising their State Implementation Plans (SIP's).

The remainder of this chapter contains sections which deal separately with each pollutant. Several sections at the end of this chapter have been reserved for combining all of the analyses and discussing limitations. Because monitoring is an integral part of the planning process, it is included in the following administrative burden analyses. The next section discusses the format and underlying assumptions applied to the NAAQS. Section 10.3 discusses the marginal administrative burden and costs for ozone. No change in the burden or cost of monitoring for ozone is anticipated.[1] Section 10.4 discusses the marginal administrative burden and costs associated with $PM_{2.5}$. Monitoring for PM has been estimated under a separate ICR [US EPA 1996(a)] and appears toward the end of the PM section. Section 10.5 discusses changes to the NAAQS format to accommodate differences in the RH rule, along with the incremental administrative burden and costs of the RH program. Since the Agency is proposing a separate rulemaking for RH, it will require a formal ICR. The results of that analysis are included in the RH section.

The concluding sections of this chapter discuss possible overstatements due to synergies between pollutants, potential over- and under-statements of administrative costs due to permitting considerations, and "bottom line" burden and cost estimates for the selected ozone and PM NAAQS and RH rule.

10.2 FORMAT

10.2.1 Respondent Types

For purposes of clarity in presentation this analysis follows the format generally used for ICR's, with several modifications. A typical ICR assesses burden and costs for three types of respondents - Federal, State, and Source. This analysis assesses burden and costs for four respondent groups:

- Administration and Oversight

  - **Federal Oversight** typically means the EPA, but for this analysis, it also includes the Department of Energy (DOE), the Department of Transportation (DOT), and other Federal organizations which oversee key pollutant source categories. For RH,

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[1] Personal conversations with OAQPS / EMAD, June 4, 1997 to June 5, 1997; documented in EPA memos (1 - 5) for the same days.

Federal oversight also includes Federal Land Managers (FLM's), who are responsible for maintaining air quality in Class I areas.

- **States**, NA's, and other levels of air quality management have been combined into one respondent category for this analysis, for reasons discussed in detail, below.

- Sources of Pollution

  - **Federally-owned sources of pollution**, (e.g., power plants on military bases), have special considerations which require separate analysis.

  - **Non-Federal respondents** include State and local government sources of pollution (e.g., unpaved county and local roads for PM and municipally-owned treatment works for ozone); non-profit sources of pollution, such as hospitals and clinics; and typical industrial and agricultural sources. Power generating utilities are not included in the ozone "Sources of Pollution" count because they have been included in the baseline and their administrative burden has been associated with other rules and guidances. However, $PM_{2.5}$ non-Federal sources include power generating utilities.

A third oversight respondent category was considered which would have assessed the burden imposed on NA's. However, upon further investigation, it was determined that while there are a number of examples where NA's have established their own management structure, there are probably just as many examples where they do not. Many counties in NA's perform their own analyses, most commonly with the help of State air quality analysts. Furthermore, while States do their own modeling and planning, many NA's do not, and those which model generally coordinate efforts with the States.[1] Consequently, good coordination of effort between States and their NA's is

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Personal conversation with OAQPS / OPSG 5/27, 1997; documented in EPA memos (6 and 7) 5/27/1997 and 5/28/1997.

assured and the analysis does not expand to include a separate respondent category for NA's. The burden associated with NA's and other local air quality management groups are included at the State respondent level without any loss of information.

Any area modeled as nonattainment in 2010 for PM or ozone, if it had been an NA at any time in the past for any criteria pollutant, is assumed to have a more developed air management infrastructure. Therefore, these areas should have burden levels consistent with existing NA's. All of the NA's identified for the three alternative ozone NAAQS had, at one time or another, been an NA for at least one of the criteria pollutants.[1] Therefore, it is not necessary to differentiate between new and existing ozone NA's for purposes of burden estimation.

Finally, while NA's work to reduce air pollution and meet Federally-determined minimum standards, areas in attainment may also monitor and evaluate air quality to avoid potential future costs associated with air quality degradation. Therefore, this analysis created an additional organizational subdivision to reflect these administrative differences, with each of the four respondent types represented within it. For sources in attainment areas, little additional burden is assumed. While States manage air quality in attainment areas, little additional responsibility will fall to sources as a result of changes in the NAAQS.

Most of the air quality related activities which may apply in attainment areas are already in place because of other parts of the Clean Air Act (CAA). Although there may be some unanticipated source burdens imposed by the new NAAQS in areas of attainment, this burden is assumed to be insignificant and this analysis does not assign burden hours to them.[2] For this chapter, two categories which could have an impact on attainment area sources are identified, both of which are subject to annualization.

Personal conversations with OAQPS / OPSG and Region IV, May 15, 1997; documented in EPA memos (#8, 9, and 10).

Personal conversation with OAQPS / OPSG 5/27, 1997; documented in EPA memos, (6 and 7), 5/27/1997 and 5/28/1997.

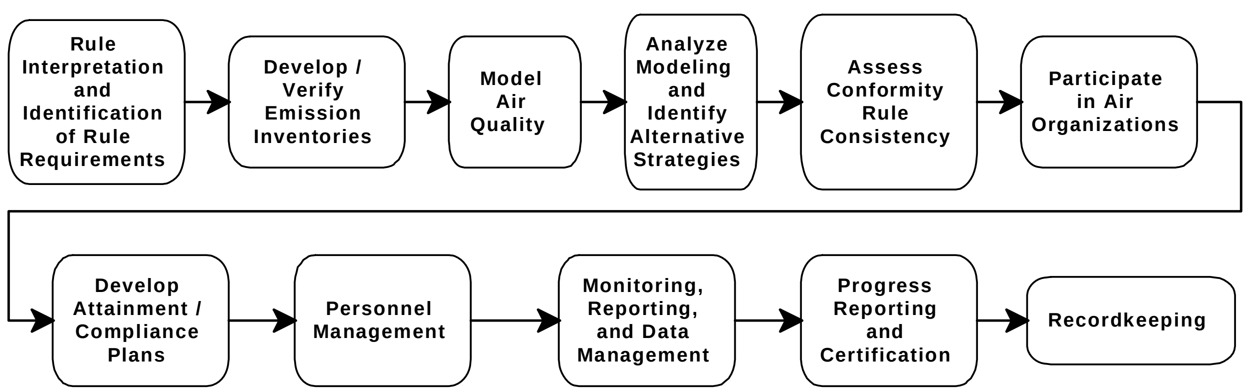
10.2.2. Definition of Burden Categories

To predict the steps necessary to fully implement the new PM and ozone NAAQS, the flow chart in Figure 10.1 is constructed. Each of the 11 blocks in the flow chart represents one or more of the burden categories attached to administration of the alternative ozone and PM standards listed in Tables 10.3 and 10.4. The flow chart and its associated burden categories present a reasonable approximation of what respondents are likely to do under the hypothetical scenario set up for this analysis.

10.2.2.1 <u>One-Time Administrative Costs</u>

Administrative costs are classified as either one-time or continuous or reoccurring costs. One-time costs relate to start-up activities which do not need to be repeated on a periodic basis. To create an annual cost of administration, reoccurring costs do not need to be adjusted to account for temporal differences. However, one-time costs reap benefits over the life of the program and should be spread out over that time frame. Therefore, the discounted net present value (NPV) of the cost is annualized into equal "payments" over the life of the program, using the following formulas: where

Figure 30.1 Flow Chart of Administrative Tasks



NPV is the cost associated with the one-time burden category, C_i is the cost incurred in year I, N is the life of the program, and AV is the annualized value. Costs within this analysis are in real $1990 dollars, subject to a 7 percent discount rate, in accordance with Federal requirements.

Figure 10.2 Annualization Formulas

$$\textit{Net Present Value:} \quad NPV = \sum_{i=0}^{N} \left(\frac{C_i}{1.07^i} \right)$$

$$\textit{Annualized Value:} \quad AV = NPV \left(\frac{.07\,(1.07^N)}{(1.07)^N - 1} \right)$$

Two burden categories were identified as one-time activities:

Interpret Rule / Identify New Requirements: This category includes research, acquisition, and assimilation of the rules and regulations necessary to understand the State's responsibilities with respect to meeting the alternative standards. Given promulgation of the PM and ozone NAAQS in 1997 and the projection of costs to the year 2010, this analysis applies a program life (N) of 13 years to this category.

Revise SIP's: Each State with an NA will have to revise its SIP. This burden category contains the data gathering, evaluation, and reporting necessary to develop new SIP's. Monitoring data necessary for determining areas of attainment and nonattainment for the new NAAQS will probably not allow SIP's to be revised until 2005. Therefore, this analysis amortized SIP revisions over a five year program life. No additional burden for States without ozone or PM NA's is assumed. Currently, 36 States have SIP's for visibility protection of mandatory Class I Federal areas. The RH provision will expand that requirement to all 50 States.

10.2.2.2. Reoccurring Administrative Costs

The Agency identified 14 burden categories which occur on an annual basis:

Evaluate / Improve Inventories: States create and manage inventories for SIP purposes, so the source burden for this category has been set at zero. As the requirement for new control measures increases with the selected NAAQS, States may need to develop new inventories, especially to mitigate air quality degradation in attainment areas. This category includes the additional hours necessary to develop and improve relevant inventories.

Data Gathering and Assembly: Other data need to be selected and formatted, along with the inventory data. These data include meteorology, often by the hour, including temperature, humidity, cloud cover, wind direction and speed, and the chemical composition of the air column. This category includes the burden of collecting and preparing such data.

Run Model: Running models includes set-up, dry runs, running the model, and troubleshooting activities for the output data derived from it. The PM and ozone require different models. The RH can utilize PM modeling and monitoring, as long as the data are speciated to a degree which allows for RH post processing to determine visibility changes. This category attempts to capture the economies of scale which occur between $PM_{2.5}$ modeling and monitoring and that of RH.

Evaluate / Interpret Modeling Results: This category includes the marginal change in quality assurance and reporting necessary for cross-pollutant purposes. This category also includes the development of technical documents and the evaluation and correction of reports made by others which reference model methodology and output. The same considerations discussed for economies of scale under the category "Run Model" apply here, as well.

Identify Alternative Control Strategies: Typically, NA's can achieve a given target by a number of alternative strategies. This category includes the identification, evaluation, and selection of alternative strategies.

Evaluate Strategies for Conformity: Federal and State management agencies must evaluate each alternative for its potential impact on regulations from other governmental bodies. This category includes the burden of identifying and resolving Conformity Rule conflicts.

Ozone/PM/RH Regional Groups: States and the EPA coordinate air quality efforts through a number of regional management groups [e.g., the Lake Michigan Ozone Study Group (LMOS), the Ozone Transport Assessment Group (OTAG), and the Grand Canyon Visibility Transport Commission (GCVTC)]. Although the FACA subcommittee has not made final recommendations, the additional burden associated with participating in regional management groups is expected to be low. This category includes the additional burden on State and local government members of new and existing regional ozone/PM groups for managing the new joint NAAQS. For the most part, RH managers do not participate in regional air quality management groups and any new activity in this category will probably be focused on the West. Sources of pollution participate in regional groups through trade associations or on a voluntary basis and their burden has not been included in this analysis. This burden category includes, but is not limited to: meeting attendance, air quality modeling for group purposes, and the production of reports and analyses for the regional group.

Public Hearings: This category includes the additional State burden required to organize, advertise, conduct, and transcribe public hearing information related to the new NAAQS in NA's.

Develop Regional Implementation Plans: Based upon the input of public hearings and regional management groups, States and local ozone, PM, and RH management areas will have to construct air quality management plans which address the broader geographical concerns of these groups. This category includes this burden.

Review / Revise Compliance Plans: Sources in NA's are required to develop plans which describe the steps they will undertake to bring themselves into compliance within required time limits. The change from the current to the selected PM and ozone NAAQS will necessarily change the status of many sources. This category measures the expected additional burden to sources in ozone and PM NA's for creating and revising compliance plans for submission to their State authority, as well as the review and approval of the State for those plans. Because areas in attainment do not create compliance plans, it is assumed the burden of compliance plans for sources in attainment areas is zero.

Development of Source Guidance Documents: This category includes the expected additional burden to States for creating source guidance documents to assist sources of pollution in their efforts to attain the alternative standards.

Monitoring and Reporting: This RIA assumes there will be only a slight change in the ozone monitor network by 2010, and some slight overall increase in monitor related tasks may occur for some States. For PM, the administrative burden and cost of monitors has been discussed under a separate ICR. This category includes the additional administrative burden associated with calibrating and certifying the monitor, and reporting data to Federal, State, and local respondents.

Prepare and Review Progress Reports: Each State must make periodic reports to the Agency on its progress toward reaching attainment of the standard, as well as describe any and all plans in each NA to improve and/or maintain their rate of progress. The States will also need to assess reasonable progress for RH. For their part, States must review and pass on these progress reports as part of their SIP requirements. This category includes the additional burden from these tasks which are expected to occur for NA's and State and local ozone and PM management groups.

Recordkeeping: This category includes changes in record keeping for States and sources of pollution that affect NA's and mandatory Class I Federal areas.

10.2.2.3 Estimating the Burden of Alternative NAAQS

Ranges of burden hours are established for each administrative category which serve as upper and lower bounds to the anticipated additional burden of that task, relative to the current ozone or PM standard. Because the analysis of burden per respondent weights the hours applied for the type of respondents in that category, the average of the upper and lower bounds is used for point estimate discussions. It is assumed that, for each respondent type, the effort required for areas in attainment should be less than that for areas of nonattainment. For example, States will have to re-evaluate their SIP plans to accommodate changes. For areas of nonattainment, these changes could account for some planning and coordination beyond that already required to meet the current NAAQS or a baseline activity. For attainment areas, however, a more cursory review of maintenance plans would probably be sufficient. Tables 10-3 and 10-4 display the set of burden categories expected under each NAAQS.

10.3 OZONE ADMINISTRATIVE BURDEN AND COST

10.3.1 Estimating the Number of Respondents for the Ozone NAAQS

Federal oversight generally refers to only the EPA, and most of the burden categories listed in Tables 10.3 and 10.4 refer to only one respondent. However, several categories may involve oversight by other agencies (e.g., DOT, DOE, Department of Defense). To accommodate multiple Federal agencies, if the description of the appropriate category has a number in parentheses at the end, that number indicates how many Agencies are included in the Federal estimation. For example, the Federal oversight component for "Evaluate Strategies for Conformity" was assigned a burden range of "M", which corresponds to a range of 21 to 40 hours. However, as many as eight Federal agencies could be involved in this process. Consequently, rather than a range of 21 to 40 hours, the Federal burden range for "Evaluate Strategies for Conformity" has an estimated range of 168 to 320 hours. Because this adjustment simplifies the calculations which go into translating per-respondent hours into total burden hours, for analytical purposes, Table 10-1 lists only one Federal respondent.

State oversight includes the 50 States, plus the District of Columbia. This analysis divided States into two subcategories for whether or not it contained an NA. States with both attainment and NA's are counted among those with NA's. As the stringency of the ozone standard increases, more areas become NA's, causing more Federal and non-Federal sources of pollution to fall within them. Likewise, the number of States which provide oversight to NA's must also increase. Table 10.1 displays the expected number of States with and without NA's for each 8- hour alternative ozone standard.

Table 10.1 The Projected Number of Respondents and the Distribution of States for Each Alternative Standard

		0.08 5th Max	0.08 4th Max	0.08 3rd Max
Oversight	Federal Oversight	1	1	1
	State Oversight (NAs)	18	25	29
	State Oversight (Attainment)	33	26	22
Sources of Pollution	Federal Sources (NA's)	52	58	77
	Federal Sources (Attainment)	160	160	140
	Non-Federal Sources (NAs)	5,200	7,300	8,500
	Non-Federal Sources	29,000	27,000	26,000

Federal sources include military installations, sources in Federally-managed permit programs on tribal lands and on the Outer Continental Shelf (OCS), Federal prisons, regional electric power organizations (e.g., the Tennessee Valley Authority), and other Federally-owned or leased buildings and compounds. Federal buildings and compounds generally do not have the type of emissions which would fall under the scope of the selected PM and ozone NAAQS and have been excluded from this analysis. As stated earlier, electrical power sources have been included in the baseline for ozone, but for PM, power generating utilities have been included in the inventory. Few Federal prisons fall under the scope of this NAAQS and have been excluded as well [US EPA 1996(b)]. The tribal and OCS sources also are not included in this analysis, but are expected to be small [US EPA 1997(b)]. Therefore, this Federal source discussion focuses on military installations. Not only do military establishments comprise a large percentage of the Federal sources identified, but they also have unique managerial considerations with respect to conformity and national defense. Table 10.2 displays the distribution of military installations across alternative ozone standards.

Table 10.2 The Distribution of Military Installations for Ozone Standards

	ARMY		NAVY		AIR FORCE		MARINES		TOTAL	
	NA's	Attain	NA's	Attain	NA's	Attain	NA's	Attain	NA's	Attain
0.08 5th	19	44	16	43	11	66	6	9	52	160
0.08 4th	19	44	21	38	12	65	6	9	58	150
0.08 3rd	26	37	31	28	14	63	6	9	77	130

Source: United States Department of Defense, 1996, 1997(a), 1997(b), 1997(c), 1997(d)

Non-Federal sources include industrial point source, mobile source, and area source emissions. A number of State-owned sources of pollution are identified in this analysis. These sources are incorporated into the non-Federal source category under the assumption they would require similar technical services from contractors as would a privately-owned source of pollution. Table 10.1 lists the number of sources which may be affected by each alternative discussed in the RIA. The national estimate for point, area, and mobile sources used to determine the number of sources in attainment areas came from the Agency's part 70 and 71 operating permits analyses [US EPA 1995, 1996(b)] .

10.3.2 Estimating the Per Respondent Burden for the Ozone NAAQS

The burden range assigned to each respondent type for each category represents the expected additional burden beyond what that respondent would have been expending to fully comply with the current standard. For example, the category for "Data Gathering and Assembly" generally refers to States. Federal efforts for the category refer to the maintenance and upkeep of the databases and additional inventories necessary for modeling purposes. These efforts are most likely independent of the actual standards in place, and therefore the Federal oversight burden has been set at zero. However, if new areas are designated nonattainment and additional controls are required for sources within those areas, each State will have to expand its set of model inputs to accommodate these additions. Given the nature of data management and modeling, the average State with NA's will most likely expend between 1 and 4 person-months in fulfilling these needs. In attainment areas, some States will likely gather additional data, and others will likely decide further effort in this area would not be useful. Therefore, on average, attainment area States will most likely expend between 1 and 20 hours in data gathering. Since sources of pollution do not have to model air quality, their burden is set at zero for all areas.

Table 10.3 Per Respondent Ozone Administrative Burden Estimations For One-time Burden Categories

	NA's				ATTAINMENT AREAS			
	Governments		Sources		Governments		Sources	
	Fed *	State	Fed	Non-Fed	Fed *	State	Federal	Non-Fed
Interpret Rule / Identify New Requirements	M	M	L	L	L	L	L	L
Revise SIPS	H	H	Ø	Ø	Ø	Ø	Ø	Ø

Ø Not Applicable (No Burden Hours)

M Moderate Burden (21 to 40 hours)

L Low Burden (1 to 20 hours)

H High Burden (41 to 160 hours)

Table 10.4 Per Respondent Ozone Administrative Burden Estimations for Reoccurring Burden Categories

	NA's				ATTAINMENT AREAS			
	Governments		Sources		Governments		Sources	
	Fed *	State	Fed	Non-Fed	Fed *	State	Federal	Non-Fed
Evaluate / Improve Inventories (2)	L**	M	Ø	Ø	L**	L	Ø	Ø
Data Gathering and Assembly	Ø	H	Ø	Ø	Ø	L	Ø	Ø
Run Model	L**	M	Ø	Ø	M**	L	Ø	Ø
Evaluate and Interpret Modeling Results	M*	M	Ø	Ø	L*	L	Ø	Ø
Identify Alternative Control Strategies	M*	H	Ø	Ø	Ø	Ø	Ø	Ø
Evaluate Strategies for Conformity (8)	M**	M	Ø	Ø	L**	L	Ø	Ø
Participate in Ozone / PM Regional Groups	M*	H	Ø	Ø	L	M	Ø	Ø
Public Hearings	Ø	H	Ø	Ø	Ø	Ø	Ø	Ø
Develop of Management Plans	Ø	M	Ø	Ø	Ø	Ø	Ø	Ø
Review / Revise Compliance Plans	Ø	H	L	L	Ø	Ø	Ø	Ø
Develop Source Guidance Documents	Ø	M	Ø	Ø	Ø	Ø	Ø	Ø
Prepare and Review Progress Reports	Ø	M	L	L	Ø	L	Ø	Ø
Record keeping	Ø	M	L	L	Ø	L	Ø	Ø

KEY:

Ø	Not Applicable (No Burden Hours)	*	Generally, the EPA, but includes other Agencies as well
L	Low Burden (1 to 20 hours) per year	**	Indicates advisory capacity
M	Moderate Burden (21 to 40 hours) per year		
H	High Burden (41 to 160 hours) per year		

There are 34,324 estimated pollution sources in the United States subject to monitoring [US EPA 1995]. These sources form the basis for the non-Federal source discussion of this analysis. Table 10-1 displays the distribution of sources between nonattainment and attainment areas for each alternative ozone standard.

Tables 10.3 and 10.4 display the range of estimated additonal burden expected for all respondents, relative to the NAAQS analytical baseline.

10.3.3 Determining the Marginal Administrative Burden to Respondents

The marginal administrative burden associated with each of the four respondent categories of this analysis is estimated by multiplying the range endpoints for each burden category by the appropriate number of respondents. For example, Table 10-4 estimates the State oversight burden for "Review / Revise Compliance Plans" in NA's to be between 41 and 160 hours. Table 10.1 shows the .08 5th ozone standard has 18 States with predicted NA's. Consequently, the estimated burden for this category ranges between 738 and 2,880 hours, with a point estimate (average) of 1,809 hours. The sum of all burden category estimations for States under the .08 5th standard results in a point estimate burden of about 17,000 hours. This estimate is a part of the State burden in Table 10.5, below.

Table 10.5 The Total Marginal Burden for the .08 5th Ozone Standard to All Respondents - Point Estimate

(in hours)

	Governments		Sources		TOTALS
	Federal	State	Federal	Non-Fed	
One-Time Categories	30	550	270	43,000	**44,000**
Annual Categories	220	16,000	1,600	160,000	**180,000**
TOTALS	**250**	**17,000**	**1,900**	**200,000**	**220,000**

*Numbers may not add to totals due to rounding

Table 10.6 The Total Marginal Burden for the .08 4th Ozone Standard to All Respondents - Point Estimate

(in hours)

	Governments		Sources		TOTALS
	Federal	State	Federal	Non-Fed	
One-Time Categories	30	740	270	43,000	**44,000**
Annual Categoreis	220	24,000	1,800	230,000	**250,000**
TOTALS	**250**	**22,000**	**2,000**	**270,000**	**290,000**

*Numbers may not add to totals due to rounding

Table 10.7 The Total Marginal Burden for the .08 3rd Ozone Standard to All Respondents - Point Estimate

(in hours)

	Governments		**Sources**		**TOTALS**
	Federal	**State**	**Federal**	**Non-Fed**	
One-Time Categories	30	800	270	43,000	**44,000**
Annual Categoreis	200	24,000	2,400	270,000	**290,000**
TOTALS	**230**	**25,000**	**2,700**	**310,000**	**330,000**

*Numbers may not add to totals due to rounding

The marginal administrative burden for the three alternative 8-hour ozone standards, relative to the burden imposed by the current standard, ranges between 28,000 hours for the lower bound estimate of the .08 4th standard and 634,000 hours for the upper bound estimate for the .08 3rd standard. Most of the burden falls to non-Federal sources. The Agency calculated point estimates of 226,000 and 337,000 hours for the .08 5th, and .08 3rd ozone standards, respectively. The estimated marginal administrative burden for the selected ozone standard ranges between 37,000 and 560,000 hours, with a point estimate of 298,000 hours.

An artifact of construction is that Federal governmental burdens and the annualized burdens for sources are the same for all three ozone standards. Federal governmental burdens are based upon only one respondent, as described above in 10.3.1, above. Therefore, the burden in each Federal category remains independent of the standard. For annualized burdens in sources of pollution, no additional burden is estimated to occur for attainment areas with regard to 5 year annualization category, “Revise SIP’s.” Therefore, the aggregation equation for “annualized” burden hours applied to each source type simplifies to the same equation: the number of sources times the 13-year annualization factor.

Table 10.8 shows the average burden for each respondent type under each alternative ozone standard. As with the total estimated burden to Federal oversight, the average Federal burden for oversight does not change across standards because there is only one respondent. State average burdens range from 342 to 486 hours, with the average burden steadily increasing as the number of NA's increases across standards. Sources of pollution have much lower average burdens, primarily because sources do not have many categories of responsibility.

Table 10.8 Respondent Average Burden for Alternative Ozone Standards
(in hours)

	Administration		Sources of Pollution	
Respondent Type (Number)	**Federal (1)**	**State (51)**	**Federal (214)**	**Non-Federal (34,324)**
TOTAL: .08 5th	250	340	9	6
TOTAL: .08 4th	250	430	10	8
TOTAL: .08 3rd	250	490	13	9

10.3.4 Estimating the Cost per Hour for Respondents

Historically, the Agency has considered State and Federal burden costs to be roughly the same, at $34 per hour. However, since 1993, the EPA has undertaken a number of new analyses which indicate a divergence between Federal and State wages. In the Compliance Assurance Monitoring (CAM) Rule [US EPA 1997(a)], EPA calculated State burden costs to be $40 per hour. The State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officers recently analyzed the cost of State Air Grant activities and used a per hour rate of $50. For consistency within its own analyses, $40 per hour is selected as the fully loaded State employee labor rate for this analysis.

Two compensation rates for non-Federal sources of pollution are applied , one for in-house management, the other for contracted experts. Recent analyses in support of the CAM Rule indicates that for many sources, the cost of contracted labor far exceeds these rates. Consequently, source burden costs in this analysis are determined for non-Federal sources as the cost of industrial administration, estimated at $60 per hour (fully loaded) in the CAM Rule RIA [US EPA 1997(a)].

The hourly cost of Federal oversight and Federal sources of pollution is estimated at its historically applied rate of $34 per hour. This is based upon the fully loaded wage of a full time equivalent at a GS-11 step 3, representing the pay rate for a fully qualified analyst operating in the Regions [US EPA 1992, 1995, 1997].

For purposes of this analysis, "fully loaded" means the wage reported includes the pay seen on the employee's pay check, the additional benefits and contributions of the employer, overhead (including office space and equipment, heating, etc.), and an approximation of secretarial and supervisory time applied to the employee. As stated above, the costs in this chapter are in real 1990 dollars to remain consistent with the costs in the remainder of the RIA.

10.3.5 Estimating the Marginal Administrative Cost of the New Ozone NAAQS

To determine the expected additional administrative cost which may occur as the result of a change from the current to a new ozone standard, each of the burden estimates in Tables 10.5, 10.6, and 10.7 are multiplied by the appropriate cost per hour, as discussed in section 10.3.4. Table 10.9 displays the point estimated marginal administrative costs associated with the additional burden which could be imposed by an alternative eight hour ozone NAAQS. As stated above, these estimates are hypothetical, based upon a series of predicted actions and limiting assumptions about what the actual implementation strategy for the new ozone NAAQS may look like. A more accurate approximation of the potential burden and costs of the new joint NAAQS must wait until the Agency's FACA subcommittee has made its recommendations and the part 51 implementation process has been completed.

The marginal administrative cost of the 8-hour ozone standards range between $1.5 million per year for the lower bound estimate for the .08 5th standard and $37.2 million per year for the upper bound estimate for the .08 3rd standard. As with burden estimates, over 98 percent of the costs are incurred by non-Federal sources. The Agency calculated point estimates of $13.2 million and $19.7 million for the .08 5th and .08 3rd ozone standards, respectively. The expected marginal administrative cost to respondents for the selected ozone standard ranges between $2 million and

$32.8 million, with a point estimate of $17.4 million. The large number of non-Federal sources, combined with the high cost per hour for non-Federal compensation, overwhelmed the total cost estimates for all forms of the standard.

Table 10.9 Total Marginal Costs for Alternative Ozone Standards to All Respondents - Point Estimate
(in thousands of $1990)

	Administration		Sources		TOTALS
	Federal	State	Federal	Non-Federal	
.08 5th	$8	$700	$65	$12,000	**$13,000**
.08 4th	$8	$900	$71	$16,000	**$17,000**
.08 3rd	$8	$1,000	$92	$18,000	**$19,000**

Note: Numbers may not add to totals due to rounding

10.4 PARTICULATE MATTER ADMINISTRATIVE BURDEN AND COSTS

10.4.1 Estimating the Administrative Burden and Costs for the $PM_{2.5}$ NAAQS

Table 10.10, below, displays the expected additional administrative burden and costs for the selected $PM_{2.5}$ standard. While $PM_{2.5}$ 15/65 requires a new monitoring system and planning process, its promulgation permits a dis-investment in PM_{10} monitoring [US EPA 1996(a)]. Furthermore, the cost categories listed for the ozone administrative burden, above, also apply to PM; but because $PM_{2.5}$ is a new pollutant, many PM categories must be analyzed separately from their ozone counterparts. For example, there is no model available at this time which simultaneously predicts PM and ozone air quality. To answer questions about PM and ozone interaction requires at least two separate modeling runs. Therefore, given the characteristics listed here, along with the relative size of the administrative costs of the NAAQS in comparison to its control costs, it is assumed the PM NAAQS-associated administrative costs are roughly the same as those associated with the ozone NAAQS. While the burden and cost for each rule may be the same when taken separately, clearly, there are opportunities for synergy to provide cost savings. . These cost savings can best be discussed in the context of a joint NAAQS implementation program. Tables 10.1, 10.2, 10.3, and 10.4 define the expected scope of the $PM_{2.5}$ analysis and the burden associated with each administrative category. The estimated $PM_{2.5}$ additional costs are listed in Table 10.10.

Table 10.10 The Marginal Non-Monitor Related Administrative Burden* and Cost of $PM_{2.5}$ 15/65 To All Respondents - Point Estimate**

*** (in hours per year)**
**** (in thousands of $1990)**

	Administration		Sources		TOTALS
	Federal	State	Federal	Non-Federal	
Administrative Burden	250	22,000	2,000	270,000	**290,000**
Administrative Cost	$8	$880	$71	$16,000	**$17,000**

Note: Numbers may not add to totals due to rounding

10.4.2 $PM_{2.5}$ Monitoring Costs

The Agency assessed the administrative, operations, and maintenance costs for $PM_{2.5}$ monitoring under a separate ICR [US EPA 1996(a)]. The costs in that ICR are included below in Table 10.11, with operations and maintenance costs determined by applying the cost-per-hour estimates described in 10.3.4. While the Agency's $PM_{2.5}$ monitoring ICR does not address a specific form of the standard, the analysis is representative of the expected levels one would expect to find under any of the alternatives described in this RIA.

Table 10.11 The Marginal Monitor Related Administrative Burden* and Cost for $PM_{2.5}$ 15/65 to All Respondents - Point Estimate**

*** (in hours per year)**

**** (in thousands of $1990)**

	Administration		TOTALS
	Federal	State	
Administrative Burden	24,000	490,000	**514,000**
Administrative Cost	$900	$19,000	**$20,000**

Source: US EPA 1996(a)

Note: Numbers may not add to totals due to rounding

10.4.3 Estimating the Total Burden and Costs for $PM_{2.5}$

Table 10.12 displays the total marginal administrative costs associated with the $PM_{2.5}$ 15/65 standard. As w incremental to the PM_{10} analytical baseline, net of any dis-investment in PM_{10} which may occur because of the new

Table 10.12 The Total Marginal Burden and Cost for $PM_{2.5}$ 15/65 to All Respondents - Point Estimate

*** (in hours per year)**

**** (in thousands of $1990)**

	Administration		Sources		TOTALS
	Federal	State	Federal	Non-Federal	
Total Burden	24,000	510,000	2,100	270,000	**800,000**
Total Cost	$890	$20,000	$71	$16,000	**$37,000**

Note: Numbers may not add to totals due to rounding

10.5 RH ADMINISTRATIVE BURDEN AND COSTS

10.5.1 Estimating the Number of Respondents for the RH Proposal

The Agency is proposing a separate RH rule, with its regulatory impact estimated as a part of this RIA. This section addresses the burden and costs of that rule, taking into consideration the following RH characteristics and making the following assumptions:

- To avoid duplication and costs, a high degree of State coordination between PM and RH is assumed. Therefore, this analysis treats RH as incremental to PM.

- PM emission inventories will be needed for RH implementation activities as well. To account for the effects of pollutant transport, PM inventories will be needed Statewide, and will need to include principal PM constituents (sulfate, nitrate, organic carbon, elemental carbon, and soil dust.) Therefore, part of the PM monitoring network may serve as an RH monitoring network as well. This analysis assumes monitors installed for $PM_{2.5}$ will be able to differentiate between particles for RH strategy planning purposes. RH targets apply for mandatory Class I Federal areas and areas identified through monitoring.

- Presently, visibility monitoring occurs in about 70 Class I areas, funded cooperatively by the EPA and Federal land management agencies. New $PM_{2.5}$ monitors can be sited at Class I areas which do not currently have monitoring to serve as "background" or "transport" monitors. In this way, cost savings can be realized through coordination of the visibility and $PM_{2.5}$ networks.

- REMSAD can model changes in PM concentrations and visibility at the same time through application of a post processor to calculate visibility changes in terms of deciviews. Therefore, it is assumed that PM modeling will provide most of the information needed for RH modeling purposes. The marginal burden for RH modeling relative to the burden expected for PM applies to just the application of the post processor.

- There are 156 mandatory Class I Federal areas in 35 States identified for the proposed RH target. The RH rule assumes all States either have a Class I area or contribute to the RH problem in some Class I areas [US EPA 1997(c)]. The scope of this RH analysis includes all 48 contiguous United States and the District of Columbia. Other American lands have been excluded from this analysis for consistency with the remainder of the chapter.[1]

10.5.2 Estimating the Per Respondent Burden for the Proposed Regional Haze Targets

Using the ozone and $PM_{2.5}$ burden assessment methodology in Tables 10.3 and 10.4 as a template, several adjustments are made to accommodate the differences between RH and the two NAAQS pollutants. First, the RH rule requires States to coordinate their planning with FLM's in charge of affected Class I areas. Therefore, a separate burden category is included for "Consultation and Coordination with Federal Land Managers." Next, the RH burden estimates apply primarily to the Federal and State oversight activities. Estimates of additional administrative burden to sources beyond those associated with implementation of the ozone and PM NAAQS are not included for RH in this analysis, because: (1) RH strategies will ultimately be implemented through State SIPs; and (2) there is significant uncertainty associated with estimating the number of sources which may be subject to RH specific strategies and requirements. The assessment in Tables 10.13, 10.14, and 10.15 applies to States and Federal oversight, not to sources of pollution.

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c.f. Code of Federal Regulations Title 40 part 81 section 400.

Table 10.13 Per Respondent Regional Haze Administrative Burden Estimations For One-time Burden Categories

	Federal	State
Interpret / Identify Requirements	M*	M
Add New Monitors	H	D
Adopt New Rules	N	R

N No Burden * Advisory Capacity
M Moderate Burden (21 to 40
R Ratio Burden (27 to 78 hours)
D Data Collection Burden (1,000 to 1,500 hours)

Table 10-14 Per Respondent Regional Haze Administrative Burden Estimations For Three-Year Burden Categories

	Federal	State
Develop / Revise Monitoring Plan	N	H
Review / Revise SIPs	H	H
Revise Monitoring Plan / Strategies	M	M
Add New Monitors	M	M
FLM Consultation	M	M
Public Hearings	L*	H
Progress Reports	N	M
Review / Revise Compliance Plans	N	H

N No Burden * Advisory Capacity
M Moderate Burden (21 to 40
R Ratio Burden (27 to 78 hours)
D Data Collection Burden (1,000 to 1,500 hours)

Table 10-15 Per Respondent Regional Haze Administrative Burden Estimations For Reoccurring Burden Categories

	Federal	States
Evaluate / Improve Inventories	PM	PM
Data Gathering and Assembly	PM	PM
Run Model **	L*	L
Evaluate / Interpret Model Results	M*	M
Identify Control Strategies ***	M*	H
O3 / PM / RH Regional Groups	M	M
Develop Source Guidance Documents	N	M
Monitoring / Reporting	L	M
Recordkeeping	L	M

N No Burden
L Low Burden (1 to 20 hours)
M Moderate Burden (21 to 40 hours)
H High Burden (41 to 160 hours)
PM PM Effort Used for Regional Haze Purposes

* Advisory
** REMSAD Post Processor
*** Primarily in t he West

The estimated range for the "R" burden level is 27 and 78 hours per year. A moderate burden range for RH participation in regional air quality organizations is established, primarily because States currently have a relatively low level of participation in regional groups, except in the West (e.g., the Grand Canyon Commission).

Figure 10.3 Weighted Average Burden Calculation for States for Regional Haze Rule Adoption

$$R_{Low} = \frac{(35 \times 21) + (17 \times 41)}{51}$$

$$R_{High} = \frac{(35 \times 40) + (17 \times 160)}{51}$$

10.5.3 RH Monitoring

The RH rule requires development of monitoring which is "representative" of RH conditions at every mandatory Class I Federal area subject to the rule. Visibility monitoring already occurs in approximately 70 of these areas through a cooperative inter-governmental program, at a cost of approximately $3 million per year. Monitoring in every mandatory Class I Federal area based on current technology would cost roughly $8 million per year for data collection and reporting. The RH proposal requires an assessment of "representative" modeling which is expected to be some level less than full monitoring at every mandatory Class I Federal area. The incremental monitoring cost for the RH program representative network ranges from $2 to $3 million per year, relative to current RH monitoring costs. For the 86 mandatory Class I Federal areas without monitoring, the average burden hours per State range between 1,000 and 1,500 in the first year of monitor installation. These values are included in Table 10.13 as burden range "D." When States re-evaluate their RH plans, the monitoring network in some mandatory Class I Federal areas may need to be adjusted. The expected average State burden for such adjustments would be much less than the original monitoring network installation. The Agency established the 3-year burden range for these adjustments as moderate.

10.5.4 Determining the Marginal Administrative Burden to Respondents

The RH rule's expected annual burden to respondents was calculated by the same means as that for ozone. In other words, the range of hours for each category is summed, annualizing where appropriate, and the total multiplied by 1 (for the total number of Federal respondents) or 51 (for the total number of State respondents). Table 10.16 displays the average burden per respondent and the total burden of the RH rule.

Table 10.16 Respondent Administrative Burden Estimations for Regional Haze - Point Estimate
(in hours per year)

	Burden - Point Estimate	
	Federal	**State**
Burden per Respondent	220	620
Total Burden	220	32,000

10.5.5 Estimating the Marginal Administrative Cost of the Proposed RH Targets

Table 10.17 displays the average administrative cost per respondent and the total administrative cost of the RH rule in real 1990 thousands of dollars.

Table 10.17 Respondent Administrative Cost Estimates for Regional Haze - Point Estimate
(in thousands of $1990 per year)

	Cost - Point Estimate	
	Federal	**State**
Cost per Respondent	$7	$25
Total Cost	$7	$1,100

10.6 UNCERTAINTY

10.6.1 Permitting Considerations

The Operating Permits Rule, codified in 40 CFR part 70, requires all States to develop permit fees at a level sufficient to fully reimburse the State for its administrative outlay for managing its permits program [US EPA 1992, 1995]. Given that much of the burden to States relates to administration of permit related activities (e.g., recordkeeping, monitoring, and modeling), these costs may be passed on to sources in the form of increased permit fees. While this does not change total costs, it redistributes them between respondent types.

10.6.2 Potential Over- and Understatements

Many sources have taken advantage of an EPA voluntary program which allows them to avoid permit requirements if they limit emissions to below major source levels.[1] Synthetic minors and other exempted sources would have no emissions reduction requirements under title V of the Clean Air Act Amendments of 1990. Consequently, the number of affected non-Federal sources may be less than the number of non-Federal sources identified in this chapter.

Conversely, the burden to non-Federal sources may be over- or underestimated because source counts and emissions projections to 2010 may differ from actual sources in many Standard Industrial Code classifications. This RIA's industrial point source and area source components contain information based on the 1985 National Acid Precipitation Assessment Program emission inventory, projected to 1990 based on historical Bureau of Economic Analysis (BEA) earnings and fuel use data. This does not take into account plant shut-down or start-ups, changes in operating

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A source's classification as major or minor depends on their potential to emit, not actual emissions. Consequently, a source may be emitting at a minor source level (generally less than 100 tons per year (tpy), but varies with the severity of the nonattainment problem of the source's location) but have the potential to emit at a major source level if the source were to operate at an increased capacity. Such sources can seek exclusion from regulatory requirements by applying for status as a "synthetic minor" - a voluntarily limit on its emissions (generally by limiting productive capacity) to a level below the major source cut-off [US EPA 1995].

parctices and efficiency, or the installation of controls between 1985 and 1990 [E.H. Pechan 1997]. Furthermore, intrastate economic differences are not captured. Growth in PM_{10} emissions is estimated by applying particle size multipliers to total suspended particles (TSP) emission estimates. Given the dynamic nature of current technology, estimations of future growth based upon past trends may not be entirely appropriate. A common example of the potential for error is the growth rate in the computer industry over the past 20 years.

The PM regional group participation may be understated. Most regional groups focus on Eastern problems, where PM currently has little infrastructure. Assuming only marginal changes from the current levels of activity for PM with respect to the East presumes no relative change in importance for PM, which cannot be supported by the analyses in this RIA.

The category for "Public Hearings" may be underestimated as well, since public hearings can occur for section 105 and 110 grants as well as for SIP purposes.

10.7 TOTAL BURDEN AND COSTS FOR THE JOINT OZONE / PM NAAQS AND RH TARGET

The total burden and cost to all respondents can be found in Table 10-19. The expected marginal administrative costs associated with promulgation of the new ozone and PM NAAQS and the RH rule are about $55 million per year, requiring slightly more than a million additional burden hours from respondents.

Table 10.19 The Total Marginal Burden* and Cost ** [1]
for the Selected Ozone and $PM_{2.5}$ NAAQS
and Regional Haze Target to All Respondents - Point Estimate

*** (In thousands of hours)**
**** (Costs are in millions of $1990)**

	BURDEN	TOTAL COST
Ozone	300	**$17**
$PM_{2.5}$ Monitoring	520	**$20**
$PM_{2.5}$ Other	300	**$17**
RH	32	**$1**
TOTAL	1,200	**$55**

Marginal costs are additional costs beyond those required to meet the current PM_{10} standard.

10.8 REFERENCES

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11.0 ECONOMIC IMPACT ANALYSIS (EIA)

11.1 RESULTS IN BRIEF

This section is not intended to present a full macroeconomic analysis of the impact of new standards on the U.S. economy as a whole. Rather, it is intended to portray potential impacts on various industries. Given the overall size of the U.S. economy and the estimated benefits and costs associated with the new standards, it is reasonable to expect the impact on the economy as a whole will be minor.

Results from analyses summarized in this chapter suggest the potential for a variety of economic impacts resulting from the application of the hypothetical control scenarios to attain the selected ozone and particulate matter (PM) standards, and meet the requirements of the proposed regional haze (RH) target program. For the selected PM standard, some establishments in 86 industries classified at the 3-digit SIC code level have an annual cost to sales percentage of at least 3 percent. For the selected ozone standard, some establishments in 25 industries classified at the 3-digit SIC code level have an annual cost to sales percentage of at least 3 percent. In general, there are a larger number of industries affected and a greater cost impact per industry for the PM-only alternatives compared to the ozone-only alternatives. Which specific industries or which establishments within these industries will actually be affected depends on the control strategy choices of the State and local level and therefore is difficult to predict with assurances of complete accuracy.

A very small proportion of establishments are potentially affected for most of the SIC codes affected by the selected ozone and PM standards and RH target program. For the selected PM standard, the estimated proportion of establishments potentially affected is 2.53 percent of all establishments in affected SIC codes, and 0.82 percent when estimated over establishments in all SIC codes. For the selected ozone standard, the estimated proportion of establishments potentially affected is 0.13 percent of all establishments in affected SIC codes, and 0.05 percent when estimated over establishments in all SIC codes.

Results from an analysis of impacts to the electric power industry indicate that costs in 2010 from implementation of the 60 percent regional SO_2 cap are approximately $2.6 billion; this is 1.30 percent of estimated electric power industry revenues in 2010. Price, closure estimates and employment impacts on this and other directly affected industries indicate the potential for a net gain in employment for industries directly affected by the regional SO_2 cap, but also the potential for closures of existing electric generation units that will likely be replaced by new more efficient electric generation units.

Impacts from an environmental protection industry model indicate that there is potential for a significant increase in revenues to a number of manufacturing industries including part of the air pollution control industry as a result of the changes to the NAAQS standards.

A characterization of small entity impacts predict some potential for negative impacts on small firms in a number of industries. However, these impacts will likely be mitigated by cost pass through to consumers, flexible implementation strategies when designed by the States, and new control technologies.

11.2 INTRODUCTION

This chapter summarizes results of the EIA associated with the alternative standards assessed in this regulatory impact analysis. The chapter provides information regarding the potential economic impacts associated with the hypothetical control strategy cost estimates presented in Chapters 6 , 7, and 8. Economic impacts on affected industries and source categories, consumers, and others are assessed.

The different analyses summarized in this chapter include:

- Screening Analysis. This consists of an annual control cost-to-sales ratio calculated for each industry or source category, as classified by 3-digit SIC code.

- Utility Industry Analysis. The Integrated Planning Model (IPM) is used to generate estimated economic impacts to electric utilities from applying control alternatives.

- Environmental Protection Industry Analysis. Potential pollution control industry impacts are assessed.

- Qualitative Market Impacts Analysis. Market data is employed to assess the potential incidence of control costs to affected industries versus consumers.

- Small Entity Impacts Analysis. Potential impacts on these entities are characterized using available economic and financial data.

The characterization of small entity impacts in this chapter does not represent a Regulatory Flexibility Analysis (RFA) as defined by the Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA). The PM and ozone National Ambient Air Quality Standards (NAAQS) and RH target program themselves do not impose requirements applicable to small entities. Refer to Chapter 2 for more details on why an RFA is not required for this rulemaking.

Economic impact estimates associated with the full attainment cost estimates presented in Chapter 9 are not computed in this analysis since these cost estimates are too speculative as input to economic impact estimation, and do not reflect estimates for selected control measures and potentially affected industries. The economic impacts associated with implementation of the PM and ozone national strategies, attainment of the current PM_{10} and ozone standards, and the proposed RH target program also are not estimated in this analysis.

11.3 KEY CHANGES IN THE ECONOMIC IMPACT ANALYSIS FROM PROPOSAL RIA

This analysis builds on the economic impact analysis included within the December, 1996 RIAs for the PM and ozone NAAQS proposals. Key changes include:

- A qualitative market impact analysis is done using available price elasticities of demand and supply in order to provide information on potential economic impacts to affected consumers and producers.
- The Integrated Planning Model (IPM) is used to estimate economic impacts to the electric power industry from implementation of the 60 percent regional SO_2 cap.
- The Environmental Protection (EP) Industries economic model is used to estimate changes in revenues and employment for industries that provide goods and services for purposes of environmental protection.

11.4 SUMMARY OF AFFECTED INDUSTRIES

The purpose of the profile of affected industries is to summarize various market characteristics of economic sectors potentially affected by revisions to the PM and ozone NAAQS and the new RH rule. An industry profile provides information on economic sectors that may be valuable to the States for examining the impact of implementing the NAAQS and RH program. This information is background material for the screening, qualitative market and governmental entities analyses.

11.4.1 Types of Sources

The selected control measures cover stationary (point and area) and mobile (on-highway and nonroad) sources. These control measures cover both utility and non-utility point sources. The National Particulate Inventory (NPI) is the major source of information on the stationary and mobile sources covered in our analyses.

11.4.2 Stationary Point Sources

Point sources in the NPI are primarily facilities or establishments that emit 100 tons per year or more of one of the criteria air pollutants or precursors of such pollutants. The point source inventory also contains SIC codes for most of the facilities. For each of the incremental control measures, the Emission Reductions and Cost Analysis Model and the AirCost model [for sulfur dioxide (SO_2) costs] are used to identify all of the potentially affected facilities and their SIC codes. Additional information on stationary point sources is contained in the Industry Profile for Review of the NAAQS for PM_{10} (U.S. Environmental Protection Agency, 1996a.)

11.4.3 Area Sources

The area source inventory accounts for stationary source emissions not included in the point source inventory. An area source is generally defined as a source that emits less than 100 tons per year of a criteria pollutant or precursors of such pollutants. In this inventory, the area sources are facilities or establishments that emit less than 100 tons per year of VOC, NOx, PM, SOx, and several PM precursors. They are identified either from the 1987 SIC Manual or from the National Emissions Inventory.

11.4.4 Mobile Sources

11.4.4.1 On-Highway Sources

The four types of on-highway sources are light-duty vehicles, medium-duty vehicles, heavy-duty vehicles, and light-duty trucks. The control measures reduce emissions of VOC and NOx from these vehicles, and include fuel reformulations, new vehicle exhaust emission standards, and an enhanced inspection and maintenance (I/M) program. Additional information on these sources and control measures is available in the Industry Profile for Review of the NAAQS for PM_{10} (U.S. Environmental Protection Agency, 1996a).

11.4.4.2 Nonroad Mobile Sources

Nonroad mobile sources include large compression ignition (diesel) engines, small recreational vehicle spark-ignition (gasoline) engines, and commercial marine vessels. Nonroad mobile source control measures include emission fees for commercial marine vessels, and reformulated gasoline and diesel fuel control measures for nonroad engines (U.S. Environmental Protection Agency, 1997a).

11.4.5 Industry Profile - Economic and Financial Data

Economic data used in estimating the potential economic impacts of implementing control measures associated with the PM and ozone NAAQS and the proposed RH target program follow the categorization established by the Standard Industrial Classification Manual 1987 (U.S. Office of Management and Budget, 1987). The data are reported by 3-digit SIC code, and include: the number of firms and establishments, employment, and sales revenue. The six major sectors are:

- Manufacturing;
- Agriculture, Mining, and Construction;
- Transportation, Communications, and Utilities;
- Wholesale and Retail Trade and Real Estate;
- Services; and
- Public Administration.

Additional information on the profile of affected industries is in section 1.0 of Appendix H.

11.5 SCREENING ANALYSIS

11.5.1 Introduction

Given the large number of SIC codes potentially affected, it is not feasible to develop a detailed economic profile and EIA for each industry potentially affected by one or more control measures employed in the cost analyses. It is possible, however, to conduct a screening analysis. A screening analysis calculates an annual average cost to sales percentage for each affected SIC code. The purpose of a screening analysis is to provide some signals of potential economic impacts, to show where more refined or detailed economic analysis may be warranted, and to eliminate the need for more extensive analysis of certain SIC codes, particularly in cases where the incremental cost impact is likely to be negligible. It does not, however, reflect any assumptions about specific impacts on a given establishment or type of establishment within an SIC code.

Perhaps the most comprehensive source of sales or revenue data is the 1987 Bureau of the Census' Enterprise Statistics (U.S. Department of Commerce, 1991a). This publication provides company, establishment, employment, and sales totals by employment size category (e.g., 101-200 employees) on a 2- and 3-digit SIC code level. Because the Enterprise Statistics data are not available for all potentially affected SIC codes (e.g., agricultural industries), this source was supplemented by other related Census publications (U.S. Department of Commerce, 1992).

Throughout this chapter, the term *establishment* is defined as a single physical location at which business is conducted or where services or industrial operations are performed. It is not necessarily identical to a *firm*, which may consist of one establishment or more. A *firm* is defined as a business consisting of one or more domestic establishments that the reporting firm specified under its ownership or control during the reporting year. *Employment* is defined as all employees (full-time and part-time) as reported on all establishment payrolls. The sales data reported in this chapter are on an establishment, rather than a firm level for two main reasons:

(1) the cost input data are provided on an establishment basis, and (2) establishment-level revenue data are available for more SIC codes than firm-level revenue data.

11.5.2 Methodology

An annual cost to sales percentage screening analysis is conducted to identify those industries or source categories potentially experiencing economic impacts as a result of imposition of the standard alternatives. Results of the screening analysis provide information regarding the potential severity of impacts on establishments in affected SIC codes.

This calculation, specifically, provides an indication of the magnitude of a price change that would have to occur in order for each industry to fully recover its annual control costs. The resulting ratio of cost to sales (revenues) represents the average price increase necessary for firms in the industry to recover the increased cost of environmental controls. If a price change in affected markets resulting from implementation of the standards is greater than the cost to sales percentage for affected establishments, then affected establishments will receive revenue in excess of the annual cost of control. The analysis was conducted at a 3-digit SIC code level because financial data are more often available at that level as compared to others.

In order to conduct the screening analysis, it is necessary to:

- Use the cumulative (i.e., the total) cost estimates for the control strategies used in the cost analysis to calculate annual average costs per source category or industry on an SIC code basis;
- Divide the annual average costs by the number of affected establishments in the SIC code to provide an annual average cost per affected establishment for each affected SIC code;
- Divide the average annual cost per establishment by the average sales or revenue per establishment in potentially affected industries for each affected SIC code;

The result is the annual cost to sales percentage for each affected SIC code.

The number of establishments are estimated differently depending on the type of emission source. For point sources, the number of affected establishments represents the number of unique plants affected by each control measure. For area and mobile sources, U.S. Environmental Protection Agency (EPA) data are obtained on the number of affected establishments by county and SIC code by projecting from State-level data reported in County Business Patterns (U.S. Department of Commerce, 1991b), since it is not possible to calculate the number of unique establishments affected by each area and mobile source control measure. Generally, the number of establishments in counties reported in County Business Patterns that are affected by control measures is used to estimate the number of affected establishments.

National sales data are available by 3-digit SIC code from the Bureau of the Census' Enterprise Statistics and related publications (U.S. Department of Commerce, 1992). Because of the broad scope of the PM and ozone NAAQS and proposed RH target program, average national sales are used. For each potentially affected SIC code, an estimate of national average sales per establishment is prepared and used as the denominator for each average annual cost to sales percentage calculated. The annual cost to sales percentage estimates reflect the cumulative (total) annual control costs associated with one or more control measures imposed on an industry or source category.

11.5.3 Results

Table 11.1 presents a summary of the number of industries with potential impacts for each standard analyzed and for annual cost to sales percentages of at least 0.01, 0.1, 1, 3, and 5 percent (U.S. Environmental Protection Agency, 1997b). The ozone or PM standard with the potential to affect the greatest number of industries is the $PM_{2.5}$ 15/50 standard, which potentially affects 364 3-digit SIC codes. There are potentially 88 3-digit SIC codes with some affected establishments that have annual cost to sales percentages of at least 3 percent for this standard, and 72 with some affected establishments potentially having annual cost to sales percentages of at least 5 percent. For the selected PM standard, there are 361 3-digit SIC codes with some establishments potentially affected. 86 3-digit SIC codes with some potentially affected establishments have annual cost to sales percentages of 3 percent or greater for this standard, and 67 with some potentially affected establishments have annual cost to sales percentages of 5 percent or greater. For the selected ozone standard, there are 260 3-digit SIC codes with some establishments potentially affected. 25 3-digit SIC codes with some affected establishments potentially have annual cost to sales percentages of 3 percent or greater for this standard, and 13 with some potentially affected affected establishments have annual cost to sales percentages of 5 percent or greater. In general, the PM standards potentially affect more industries than the ozone standards, and the control cost impacts are higher for the PM standards.

Results for the sequenced standards are presented in Table H.1 of Appendix H. The results represent sensitivity analyses for examining the economic impacts associated with a PM following ozone analysis and an ozone following PM analysis.   These sensitivity analyses represent an upper bound for economic impacts to affected industries based on preliminary cost data. Although the preliminary cost data used in these sensitivity analyses do not represent the final and most accurate set of cost data, the results of these analyses may provide insight into the magnitude of the annual cost to sales percentages associated with the sequenced standards.

Table 11.1 Summary of the Number of 3 digit SIC Codes with Potential Economic Impacts for Ozone, PM, and Regional Haze Alternatives in the Year 2010 (Expressed as Average Annual Costs to Sales Percentages; Control Costs and Sales Are in 1990$)**

Alternative	Total No. of 3 digit SIC Codes Potentially Affected	3 digit SIC codes affected - 0.01 Percent or greater	3 digit SIC codes affected - 0.10 Percent or greater	3 digit SIC codes affected - 1 Percent or greater	3 digit SIC codes affected - 3 Percent or greater	3 digit SIC codes affected - 5 Percent or greater
Ozone .08, 5th	261	225	175	57	24	11
Ozone .08, 4th*	260	226	174	59	25	13
Ozone .08, 3rd	263	232	182	64	28	14
$PM_{2.5}$ 16/65 (98th percentile)	358	195	167	101	71	50
$PM_{2.5}$ 15/65* (98th percentile)	361	198	172	119	86	67
$PM_{2.5}$ 15/50 (98th percentile)	364	208	179	120	88	72

* Represents alternatives that are the selected standards.

** For ozone, the proportion of establishments that are potentially affected ranges from 0.10 to 0.16 percent as a percentage of establishments in affected SIC codes across the three standards analyzed; for PM, the proportion of establishments that are potentially affected ranges from 1.51 to 2.57 percent as a percentage of establishments in affected SIC codes across the three standards analyzed.

A very small proportion of establishments are potentially affected for most of the SIC codes affected by the new ozone and PM standards and RH target program. For the ozone standards, the proportion of establishments potentially affected ranges from 0.10 to 0.16 percent of all establishments in affected SIC codes across the standards. For the PM standards, the proportion of establishments potentially affected ranges from 1.51 to 2.57 percent in affected SIC codes across the standards. When measured against establishments in all SIC codes, the proportion of establishments potentially affected ranges from 0.04 to 0.06 percent for the ozone standards, and 0.49 to 0.86 percent for the PM standards. Estimates of the proportion of potentially affected establishments for each ozone and PM standard analyzed are listed in Table H.2 of Appendix H.

The screening analysis indicates that many SIC codes may be impacted by the implementation of the selected measures, but many of the SIC codes affected may experience cost-to-sales percentages below 1 percent and have fewer than 1 percent of their establishments potentially affected. Based *only* on these ratios, and given that most establishments in these SIC codes are not potentially affected, impacts on most of the affected industries may not be substantial for the standards analyzed.

11.5.4 Limitations, Caveats, and Potential Biases

There are a number of assumptions and limitations to the screening analyses. They include:

- Assumptions and limitations specific to the cost inputs limiting the screening analyses include:

    - Detailed cost estimates are not prepared for each emissions source;

    - The analysis is not conducted at the firm level, the proper level for the analysis, since control cost data is only available at the establishment level;

    - Cost estimates are prepared at the average establishment level. The costs can not be estimated for establishments at the economic margin;

- Cost estimates are developed using information available through 1996; recent and future developments in technological innovation for pollution control through the 2010 analysis year could result in costs that are significantly lower than those utilized for this analysis.

- The average cost per plant shown for individual SIC codes affected by the area source fuel combustion and surface coating control measures does not differ because information is not available to identify specific costs for individual industries;

- Revenue (or sales) data used in these analyses represent national averages by industry. Average annual cost-to-sales percentages do not predict impacts on specific establishments;

- Because area and mobile sources are not individually inventoried, the actual number of establishments affected by these control measures is unknown. Generally, the number of establishments in affected counties that are reported in County Business Patterns (U.S. Department of Commerce, 1991b) is used to estimate the number of affected establishments;

- The lack of available input data preclude use of a general equilibrium model;

- Because of difficulties encountered in attempting to identify SIC codes for approximately 900 facilities in Oregon's point source inventory, these point sources are not included in the analysis;

11.6 UTILITY INDUSTRY IMPACTS

11.6.1 Introduction

The IPM (U.S. Environmental Protection Agency, 1996b) estimates cost impacts of regulatory control measures on the electric power industry (SIC 491). IPM also provides inputs to a separate spreadsheet model that estimates changes in employment to directly affected industries. It has been used to estimate cost impacts for various ozone precursor control strategies for the Ozone Transport Assessment Group (OTAG).

Electric power industry impacts assessed are potential price increases in electricity, closures of electric generation units, and employment shifts associated with control measures selected as part of efforts to control SO_2 emissions 60 percent beyond that required to meet Title IV. That program is known as the 60 percent regional SO_2 cap.

11.6.2 Estimation of Electricity Price Increases

Electricity prices vary for each sector--residential, commercial, industrial, and transportation. The weighted average price for all of these sectors is reported as the average national electricity price in any year. In the past, these prices were largely derived from a cost-of-service pricing of power. State public service commissions set prices based on the costs for utilities to provide electricity and their need for a fair return on their investments to provide power.

In a competitive environment, pricing practices will be affected by the value of electricity to the customer, availability of alternatives, and supply availability in various areas of the country. Although it is clear that the electric power industry will want to pass on pollution control costs to consumers, how that may be done for different electric customers is unclear. As a simple way of considering potential average price increases resulting from this rulemaking, the annual incremental compliance costs of the 60 percent regional SO_2 cap are calculated as a percentage of the projected revenues or sales of the electric utilities in 2010. The methodology used here is similar to that employed in the screening analysis. Table 11.2 shows the cost to revenue percentage estimate. The incremental compliance costs for the electric power industry are estimated to be 1.3 percent of their projected revenues. Whether the electric utilities can fully recover these costs through an average price increase of this size will ultimately depend on the way the pricing of electric power is actually conducted by state utility commissions, the demand elasticities for different electricity demand sectors (residential, commerical, industrial), and the supply elasticities for newly competitive utility firms after deregulation occurs.

Table 11.2. Incremental Pollution Control Costs[a] for the Electric Power Industry in 2010 as a Percent of Forecasted Revenues

Forecast of Electricity Sales	3,590,763 million Kwh
Average Cost	6.4 cents/Kwh
Estimated Electricity Sales Revenues	$209.88 billion
Incremental Pollution Control Costs	$2.60 billion
Pollution Control Costs as a Percent of Revenues	1.30 percent

Note: Costs and Sales are in 1990$.

The estimate of electricity revenues shown in Table 11.2 is developed by multiplying the forecasted sales for electric power to consumers in 2010 from the IPM by the average electricity price in 2010 forecasted in the Energy Information Administration's Annual Energy Outlook 1997, December 1996. Notably, this forecasted price by the Energy Information Administration only accounts for a part of the changes that are likely to occur through deregulation of the electric power industry. It is generally believed that electricity prices will fall as a result of deregulation. Therefore, the resulting estimate of future electricity revenues is likely to overstate the revenue that the industry will collect in 2010.

11.6.3 Closure of Electric Generation Units

The IPM considers which generation units are not economically efficient to operate in the future and retires them during the model run. The IPM reports the generation capacity that it closes during each simulation. The difference in closed generation capacity between the baseline for the revised NAAQS and the 60 percent regional SO_2 cap is the electric generation capacity that is estimated by the model to stop generating electricity due to implementation of the revised PM NAAQS. Closures that may occur in the baseline are not part of these estimates. In

[a] As defined above in Section 1.

addition, these estimates only consider existing electric generation units whose costs may be fully depreciated at the time of closure.

Table H.3 in Appendix H provides a comparison of IPM model forecasts for operation (in terms of Gigawatt-hours), annual costs, and annual air emissions from the electric power industry for the baseline and for additional pollution controls selected as part of implementation of the 60 percent regional SO_2 cap. Results show that there is approximately the same electric generation capacity expected under the 60 percent regional SO_2 cap as compared to the baseline in the year 2010. This forecast is due to a predicted increase in combined-cycle natural gas unit capacity that is expected to offset a predicted decrease in coal steam and oil/gas steam generation capacity. Environmental gains result as new combined-cycle units are much more energy efficient than existing coal-fired and oil/gas steam units and produce less NOx and negligible amounts of SOx during their operation. These results do not predict changes in capacity for specific units.

11.6.4 Employment Changes

Employment changes that may occur due to the implementation of the 60 percent regional SO_2 cap are estimated. Implementation of the 60 percent SO_2 cap may lead to job losses in certain sectors and increases in others. To develop a general sense of the size of these employment shifts, a simple model is constructed to assess directly affected major sectors where there may be employment changes. Potential secondary or indirect impacts are not examined.

The analysis considers the following areas where impacts may directly occur:

- Closure of electric generation units;
- Changes in the mix of newly built electric generation capacity -- the building of new combustion turbines and combined-cycle units and the repowering of oil/gas steam and coal-fired units to combined-cycle natural gas units;

- Changes and additions to pollution control equipment installed and operated to control NOx and SOx emissions;
- Changes in coal demand, which affects the coal mining industry and transporters of coal, especially the railroads;
- Changes in natural gas demand, which affects the production, transmission, and distribution of natural gas.

Table H.4 of Appendix H shows results of EPA's analysis of the direct employment changes that may occur in 2010 as a result of the 60 percent regional SO_2 cap. A net increase in employment of 6,140 jobs overall is expected for the directly affected sectors listed above. Changes in employment in the sectors reported include potential employment changes in 2010 that may occur from providing fuels at different demand levels in 2010, as well as installation and operation of electric generation units and pollution control equipment. Results also include changes in employment that occur in operating the new mix of generation units, and pollution control equipment that is added at power plants before 2010 (but does not include employment changes associated with the installation of that equipment in earlier years).

Table H.5 of Appendix H provides details on the employment changes predicted to occur in the coal mining industry in the Eastern and Western regions of the U.S. due to changes in coal demand. Results from this table show there is a net decrease in jobs predicted for the coal mining industry alone, with reduction in jobs in the West offsetting an increase in jobs in that industry in the East. The predicted increases in Eastern coal mining employment result from the addition of scrubbers to many coal-fired electric generation units in the East to comply with the 60 percent regional SO_2 cap. Power plants that add scrubbers are expected to switch from Western to Eastern coals since Eastern coals are less expensive and can be used economically with scrubbers that remove 95 percent of sulfur from the relatively high sulfur content Eastern coal. Western coal mining industry employment losses are due to two factors: 1) the switch to Eastern coals by some coal-fired electric generation units and 2) the increased use of natural gas over coal in the electric power industry in the Eastern U.S. as a response to the 60 percent regional SO_2 cap.

11.6.5 Uncertainties, Limitations, and Potential Biases

There are several uncertainties, limitations, and potential biases inherent in these price, closures and employment change estimates. They include:

- The employment impact model does not take into account secondary or indirect employment impacts;
- The employment impact model relies on inputs of future coal use, natural gas demand, and capacity expansions and closures from IPM. Uncertainty exists associated with each of these inputs;
- The employment impact model does not consider the employment changes from the construction of new capacity (or losses from not constructing it) and only considers operating aspects of new capacity. There is no data readily available on labor inputs to construction of new electric generation capacity.

11.7 ENVIRONMENTAL PROTECTION ACTIVITIES

Even though an industry may bear a regulatory burden, the economic impact may be offset if other industries use its product in pollution control activities. For example, the potential direct economic impact associated with implementation of the ozone and PM NAAQS on the electric utility industry is likely to be negative. However, electricity is required to operate pollution control equipment used in other industries, and the electric utility industry will receive revenues from additional operation of pollution control equipment associated with the implementation of the ozone and PM NAAQS. Another example is that of the construction industry sector. The construction industry sector may experience negative economic impacts from compliance with the new NAAQS. However, the results of the environmental protection (EP) industry model show that the services of the construction industry sector may be in strong demand due to the capital expenditures required in other industries serviced by the construction sector as a result of the new NAAQS. Also, an additional source of revenue for the construction industry sector is from increased pollution control spending by governmental agencies associated with implementation of the new NAAQS. As a consequence, the net economic impact to the construction industry sector could be positive. Similar comparisons can be made for other industries that the new ozone and PM NAAQS may potentially affect.

Results from a supplemental analysis using the Environmental Protection Activities Model (EP) are shown in Table H.6 of Appendix H. This analysis examines the potential revenues to affected industries associated with a sequenced standard (PM 15/50 followed by ozone .08, 3rd max.). This analysis is conducted using a preliminary set of control cost data and thus results are also preliminary. These results represent an upper bound estimate of impacts to affected industries since these results are based on the PM 15/50 and ozone .08, 3rd max. standards which are more stringent than the selected PM and ozone standards. Despite these limitations, results from this analysis may provide insight into the magnitude and/or direction of the revenues for industries affected by implementation of the ozone and PM NAAQS. For a more detailed discussion of the EP model and results from this assessment, see section 2.0 in Appendix H.

It is important to characterize the relationship of the analysis described above to the other analyses presented in this RIA. The revenues that are projected by this analysis reflect the fact that each purchase for pollution control has a buyer and seller. While a dollar spent by the purchaser of a control device or service is a cost, it is also revenue for the seller. This should not be confused with social cost which enters into a benefit-cost analysis. It is another element of the distributional analysis which focusses on the impacts of the costs incurred in meeting regulatory requirements. Revenue gain to the seller should not be confused with profit. In the long run in a competitive market, revenues for the good or service being sold will be offset by the costs of producing the good or service.

11.8 QUALITATIVE MARKET IMPACTS ASSESSMENT

11.8.1 Introduction

The control costs estimated for each standard in the hypothetical control strategy analysis represent estimates of the direct cost impact to establishments, but these estimates do not account for pass-through of costs to consumers or cost reductions due to other market adjustments. Depending on certain market characteristics, the proportion of incremental production costs that a firm can pass on to its consumers can vary widely. This qualitative market impact assessment provides an indication of the level of costs that may be passed through to consumers, thus providing an estimate of how the control costs associated with the control alternatives may be distributed between producers and consumers.

11.8.2 Methodology

The steps of the qualitative market impact analysis methodology are as follows (U.S. Environmental Protection Agency, 1997c):

(1) Select industries meeting the criteria of: a) annual cost to sales ratios for potentially affected establishments of at least 1 percent, and b) having 1 percent or more of their establishments impacted for the proposed ozone and $PM_{2.5}$ alternatives (ozone .08, 3rd and the $PM_{2.5}$ 15/50) into the qualitative market analysis. The choice of these selection criteria is meant to focus the qualitative market analysis on those industries predicted in this analysis to have possible cost impacts and enough establishments potentially affected to warrant attention for additional economic impact assessment.

The criteria listed in step (1) focus on selecting industries with a high likelihood of a price increase if the hypothetical control scenarios used in the control strategy analyses are directly adopted by the States. Fewer affected facilities coupled with high costs to sales percentages increases the likelihood of reduced profitability and closures because, all other things being equal, cost pass through is less feasible for affected facilities if they constitute a small percentage of the overall market.

(2) Convert the annual cost to sales percentage for potentially affected establishments to an annual cost to sales percentage for all establishments. The conversion is accomplished by multiplying the estimate of the proportion of affected establishments in each industry by the annual cost to sales percentages estimated for these affected establishments. The resulting product is used as a proxy for the relative cost per output in each industry (as classified by 3-digit SIC code), a value that is used in quantitative market analyses to determine equilibrium price and production.

(3) Obtain estimated own-price elasticities of demand and supply for each of the industries that meet the screening criteria. These elasticities should be long-run estimates since the analysis estimates economic impacts for the year 2010.

(4) Compare the control cost to sales percentage for all establishments calculated in step (1) with the available demand and supply elasticities collected in step (3) and the percentage of affected establishments within an affected industry to qualitatively assess the likelihood of cost passthrough and the relative impact of control measure costs on directly affected industries.

Estimates of price elasticities of demand and supply are needed to assess cost pass through. The price elasticity of demand is a measure of the responsiveness of product demand to a change in price of a product. Likewise, the price elasticity of supply is a measure of the responsiveness of supply of a product to a change in its price.

Elasticity estimates are used when they are available to provide an indication of how much of the control costs borne directly by firms in affected industries can be passed on to consumers. For example, pollution control costs shift supply curves upward. If demand for products from affected producers is inelastic (i.e., the price elasticity of demand is less than 1), then there will be a large price increase that allows a large cost pass through to consumers. If demand for products from affected producers is elastic (i.e., the price elasticity of demand is greater than 1), then price increases will not be as large resulting in a small pass through of costs. The smaller the price elasticity of demand, the greater the level of pass through to consumers, and vice versa, all other things being equal. The higher the price elasticity of supply, the greater the level of potential passthrough to consumers and therefore the lower the incidence of cost on producers, and vice versa, all other things being equal. If the supply curve is completely flat (i.e., the price elasticity of supply is very large), then there will be full cost pass through regardless of the size of the price elasticity of demand.

It should be noted that most of the products from industries directly affected by the selected control measures are intermediate products to the output of end-use products.

Use of other elasticities, such as cross-price elasticities and elasticities of substitution, is not possible due to the lack of available data.

11.8.3 Results

The results of this analysis are based on the relative lack of ability of producers to pass through costs to consumers. Thus, the higher the estimated incidence of control costs to producers compared to consumers, the higher the estimated impact.

For the limited sample of industries that have the needed data, there are some industries that have a relatively low potential ability to pass through increased control costs associated with the new NAAQS. Since this RIA is based on a hypothetical implementation scenario, the impacts may not occur. However, the information in Table H.7 through H.13 of Appendix H may be very useful as States design the actual implementation strategies to attain the NAAQS.

11.8.4 Uncertainties, Limitations, and Potential Biases

There are a number of uncertainties, limitations, and potential biases within this qualitative market analysis. They include:

- The distribution of costs is assumed to result in an average cost for a marginal establishment. This can lead to an under- or overestimate of cost and economic impacts;
- The assumption of all things being equal that underlies these elasticity estimates is weak. The control measures analyzed in this instance are applied across many different industries. There are many different changes in markets, including those for substitutes and compliments to products affected, occurring simultaneously. Most of these elasticity estimates are based on the assumption that the industry being regulated and its consumers are the only parts of the economy affected;
- Many of the estimates are over 20 years old. Most are not derived from rigorous statistical analyses. Changes in consumers' tastes and preferences over time may mean these estimates are no longer reliable indicators of consumers' behavior with regard to changes in prices;
- Elasticities are assumed to be constant across product prices and levels of output for a given 3-digit SIC code;
- Many of these elasticities are estimated assuming perfect competition in a single national/international market. For some industry sectors, however, markets may be regional. If this is the case, each region will be affected by the cost changes of establishments in that region and not by all establishments in the national/international market. Relative market impacts will therefore vary across regions depending on the locations of affected establishments.

11.9 SMALL ENTITY IMPACTS

11.9.1 Introduction

As explained in the preamble to the final rulemaking and in Chapter 2 of this RIA, the ozone and PM NAAQS and RH program will not impose any regulatory requirements on small entities. Any such requirements would arise from subsequent State regulatory actions. As a result, EPA is not required to conduct a Regulatory Flexibility Analysis under the Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act (RFA/SBREFA).

Nonetheless, EPA has conducted a more limited analysis of the potential impact on small entities of possible State strategies for implementing any new or revised NAAQS in order to provide relevant information to the States as they prepare implementation strategies. The results of this analysis are presented below.

11.9.2 Methodology for Characterization of Potential Impacts

Small entity impacts are characterized as follows (U.S. Environmental Protection Agency, 1997c):

1) Once the annual cost to sales percentages are computed in the screening analysis described above in section 11.5, revenue data for small firms and revenue data for all firms is collected for those affected industries that have an annual cost to sales percentage of 1 percent or greater for the selected PM standard ($PM_{2.5}$ 15/65) The percentage of revenues from small firms in an affected industries having cost to sales percentages of 1 percent or greater is then computed. Conforming to Agency practices, small firms are defined according to the Small Business Administration (SBA) definitions (U.S. Environmental Protection Agency, 1997d). Definitions based on annual revenues, number of employees, or production capacity, and the SBA definitions are listed in Table H.13 of Appendix H. This data, along with estimates of the percentage of establishments potentially affected, are presented for industries affected for the selected PM standard.

2) Strategies to mitigate potential small entity impacts are then presented. Many of these have been implemented in various areas in the U.S.

11.9.3 Results

Table H.14 in Appendix H contains data on the 119 industries classified by 3-digit SIC codes affected by the PM 15/65 standard with an annual cost to sales percentage of 1.0 percent or above. This data provides some indication of the proportion of establishments in an affected industry that potentially may be impacted, and the likelihood of significant small business impacts in affected industries. This information may be of value to the States as they develop implementation strategies to attain the new ozone and PM NAAQS.

11.9.4 Uncertainties, Limitations, and Potential Biases

- It is not possible to differentiate costs for small establishments from large establishments for those establishments affected by area and mobile source control measures. Therefore, this small entity impact characterization assumes the same percentage magnitude of direct impact from area and mobile source control measures on affected smaller firms in an industry as affected larger firms.

- It is necessary to aggregate small firm revenue data at the 2-digit SIC code level rather than at the 3-digit SIC code level for some industries to derive a small business revenue estimate at the 3-digit SIC code level. This is due to a lack of small firm revenue data for the affected 3-digit SIC codes inside these 2-digit SIC codes. This occurs in 8 2-digit SIC codes.

11.9.5 Mitigation of Small Entity Impacts

Control measures employed in the cost analyses provide estimates of average incremental costs, not marginal costs. Except in the case of some point source control measures, these average costs do not take into account differences in production capacity (or scale effects). So the same cost of control is applied to each affected entity in a source category, regardless of its size or other important factors. Many sources in the emission inventory may qualify as small entities under the SBA size standards, though this information is not available in the emissions inventory used for this analysis. In order to meet the ozone standard, it is possible that States may require sources to apply traditional pollution control technology or retrofit existing traditional pollution control technology. Since add-on controls can be capital-intensive, the capital recovery or the fixed component of the annual cost may be a high percentage of the total annual pollution control cost. Small entities, all other factors being equal, generally have less capital available for purchase of add-on pollution control technology than large entities. In addition, the control cost per unit of production for small entities will likely be higher than for large entities due to economies of scale. Thus, control measures requiring the use of add-on control technology may cause small entities affected by State rules to experience disproportionate economic impacts compared to large entities if no strategies to mitigate potential small entity impacts are available for implementation by States.

The analysis of the potential economic impacts of the selected control measures indicates that some small entities may be adversely impacted by implementation of the new NAAQS and RH target program. Actual impacts will depend on which strategies States decide to use to achieve needed reductions in emissions. However, potential impacts can be lessened and sometimes avoided through the use of flexible implementation strategies. Consequently, EPA is encouraging States to exercise regulatory flexibility for small entities when developing strategies to meet the standards adopted today.

While some States may need to turn to small businesses for emission reductions, small businesses will likely be among the last sources States will choose to control. States may consider controls on small businesses only if such businesses are a significant part of an area’s nonattainment problem and attainment cannot be reached through application of all available cost-effective measures to major sources. To the extent States consider controlling small businesses, EPA believes there are many ways States can mitigate the potential adverse impacts those businesses might experience. For example, States could choose to exempt or apply less stringent requirements to small businesses. Examples of such exemptions can be seen in existing EPA air-toxic standards for the printing, hazardous waste, and pharmaceutical industries. In these rules, EPA exempted small facilities or facilities with relatively low air emissions, or reduced the recordkeeping and monitoring burdens for affected facilities. States could also extend the effective date for control requirements for small businesses to 2010 or later.

Reductions needed earlier before the effective date would be obtained from other sources, perhaps using the Clean Air Investment Fund approach described below or through the use of innovative technologies. In addition, applying the most cost-effective control technologies first would tend to exclude small sources which often are not very cost-effective to control. States could also choose to apply control requirements to other businesses first, before requiring them for small businesses.

"Clean Air Investment Funds," described in greater detail in Chapter 9.5.1 above, could be established to enable small businesses to purchase emission credits. Sources facing costs greater than a certain amount (e.g., $10,000 per ton) would have the option to contribute the amount of the cut-off to the Fund, rather than install expensive emission controls. The Fund could then

purchase needed reductions from more cost-effective sources. As described in Chapter 9.2 above, States may need to rely on existing and emerging technologies to attain the standards. If a state cannot demonstrate that it will attain the standard based on all reasonably available controls, examples of which are included in Chapters 5 and 9, the State may rely on innovative technologies as the basis for the remainder needed to reach attainment. EPA believes where States can provide the appropriate assurances that such innovative technologies will be available to be implemented in sufficient time for the area to attain the standard, EPA may accept a submittal similar to the type identified in CAA section 182(e)(5).

The EPA and States also will continue to provide compliance assistance to small businesses through compliance assistance centers and issuance of compliance guidelines designed specifically for small businesses.

Some small businesses are likely to benefit from the NAAQS implementation strategies. Many suppliers of air pollution control technologies which control ozone and fine particulate precursor emissions are small businesses who will likely benefit from implementation of the new standards.

Small businesses also may benefit from these implementation strategies if the increase in their product prices resulting from costs associated with implementation strategies exceed the increase in their costs per unit of production.

11.10 GOVERNMENTAL ENTITIES ANALYSIS

11.10.1 Introduction

This governmental entities assessment, along with the administrative costs assessment in Chapter 10, is not an unfunded mandates analysis (see Chapter 2), since the PM and ozone NAAQS and the RH target program do not impose requirements upon governmental entities. This section provides an illustration of the potential impacts of the control measures used in the cost analysis on affected government entities.

11.10.2 Results

Federal establishments potentially affected by PM or ozone control measures include military installations, sources in Federally managed permit programs on Tribal lands and on the Outer Continental Shelf (OCS), Federal prisons, regional electric power organizations (e.g., the Tennessee Valley Authority (TVA)), and other Federally owned or leased buildings and compounds. Federal buildings and compounds generally do not produce the type of emissions which would fall under the scope of the selected standards. As described in Chapter 4 above, electrical power sources are included in the baseline for the control cost analysis. These sources are not part of this chapter’s definition of ozone sources, but power generating utilities are included in the emissions inventory. Few Federal prisons fall under the scope of these NAAQS. The number of Tribal and OCS potentially affected are also small. Thus, most of the Federal sources potentially affected are military installations.

Non-Federal sources or establishments include industrial point source, mobile source, and area source emissions. A number of State-owned establishments are identified in the hypothetical control strategy analysis. These sources are incorporated in the non-Federal source category under the assumption they would require similar technical services from contractors as would a privately owned source of pollution.

Control measures identified as affecting Federal, State, and county-owned establishments include point, area, and mobile source measures. A list of these control measures is in Table H.15 of Appendix H.   There is some potential for PM area and mobile source control measures to impact country governments and other governmental entities, while there is little potential for ozone precursor control to impact governmental entities. The actual number of governmental entities affected by PM and ozone area and mobile source measures is unknown, since area and mobile sources are not identified by individual source in the emissions inventories.

11.10.5 Uncertainties, Limitations and Potential Biases

The limitations of the governmental entities assessment include:

- The actual number of governmental entities affected by ozone precursor and PM area and mobile source measures is unknown, since area and mobile sources are not identified by source in the emissions inventories.

11.11 ENVIRONMENTAL JUSTICE

Executive Order 12898 (2/16/94), "Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations," requires that each Federal agency make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minorities and low-income populations (Federal Register, 1994).

Since the actual distribution of economic impacts from these standards will depend on the specific implementation strategies employed by States, it is not possible to rigorously assess environmental justice concerns in this analysis. It is anticipated, however, that the costs associated with these standards will likely be spread widely across various industries and many consumers nationwide; whereas, the benefits from these standards will likely be concentrated in urban areas with high concentrations of minority and low-income populations.

11.12 REFERENCES

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12.0 BENEFITS OF NAAQS AND REGIONAL HAZE

12.1 RESULTS IN BRIEF

Partial attainment of the selected particulate matter (PM) National Ambient Air Quality Standards (NAAQS) is expected to yield national annual monetized benefits (health and welfare) of approximately $19 billion to $104 billion. Partial attainment of the selected ozone NAAQS is expected to yield national annual monetized benefits (health and welfare) of approximately $0.4 billion to $2.1 billion. In addition, the benefits associated with the proposed regional haze (RH) rule are estimated to be either, zero, on the assumption that no controls beyond those needed for the NAAQS are imposed, a range of $1.3 to $3.2 billion, if all areas adopted a target of 1 deciview in 15 years, or, $1.7 to $5.7 billion for 1 deciview in 10 years. To the extent that these estimates fail to quantify many benefit categories, such as damage to ecosystems, damage to vegetation in national parks, damage to ornamental plants, damage to materials (e.g., consumer cleaning cost savings), and acid sulfate deposition, these understate actual benefits. The health and welfare benefits categories examined in this analysis and the methodology used to estimate the monetized benefits are presented below. Estimates of full attainment, though less certain than estimates for partial attainment, include a plausible range of benefits of $20 to $110 billion for $PM_{2.5}$ and a plausible range of benefits for 0.08 4th max of $1.5 to $8.5 billion.

12.2 INTRODUCTION

This chapter presents the benefits methodology and results for the PM and ozone NAAQS and a proposed RH rule. In addition, this chapter also presents the methodology and results associated with visibility improvements due to a proposed RH rule. The analysis estimates the potential human health and welfare (all benefits categories except human health) benefits associated with the PM, ozone, and RH rules. The emissions and air quality changes presented in Chapters 6, 7, and 8 are used as inputs to this benefits analysis. The following sections in this chapter include:

- The economic concept of benefits;
- The methodology for estimating post-control air quality changes;
- The methodology for estimating human health effects and the economic value associated with those effects;
- The methodology for estimating welfare effects and the economic value associated with those effects, where feasible;
- The health and welfare benefits associated with alternative PM, ozone, and RH rules;
- A discussion of potential benefit categories that are not quantifiable due to data limitations;
- A list of analytical uncertainties, limitations, and biases;

12.3 UPDATES AND REFINEMENTS

The methodology for estimating health and welfare benefits associated with the PM and ozone NAAQS builds upon previous work conducted for the December 1996 PM and ozone draft regulatory impact analyses (RIAs). This analysis retains the majority of the concentration-response relationships used in the previous RIAs. However, a number of prominent revisions to the previous draft RIAs are made. Major updates and refinements include:

- Expansion of the plausible range of benefits by attempting to quantify several areas of uncertainty that were discussed qualitatively in the preamble and RIA to the proposed rules, through the adoption of a range of plausible assumptions for several key parameters in the analysis;
- Refined estimates of the high end of the plausible range of ozone-induced mortality through a meta-analysis of recently published studies;
- Consideration of PM-related benefits attributable to emission reductions associated with control strategies implemented to meet ozone NAAQS alternatives. These benefits are referred to as ancillary PM benefits;
- The estimation of ozone-related benefits in counties outside of defined ozone nonattainment areas;

- The concept of downwind transport areas is incorporated into the post-control ozone air quality;
- Refined estimates of willingness-to-pay values for benefits categories such as chronic bronchitis and visibility;
- Incorporation of a life-years extended approach to estimate and value premature PM mortality;
- Updated economic information for the agricultural models;
- The estimation of additional benefits categories such as: reduced nitrogen deposition in sensitive estuaries, toxics reductions attributable to ozone controls, commercial forest protection in the western U.S., and visibility improvements in national parks;
- A sensitivity analysis on the air quality rollback procedure employed to simulate post-control ozone air quality;
- The application of the PM source-receptor matrix to post-control emissions on a nation-wide basis (rather than modeling region basis) to estimate PM post-control air quality. This step accounts for pollutant transport between 6 PM modeling regions.

12.4 OVERVIEW OF THE BENEFITS ANALYSIS METHODOLOGY

12.4.1 Introduction

The Clean Air Act requires EPA to set NAAQS and to regulate regional haze in order to provide benefits to society by enhancing (improving and protecting) human health and welfare. This chapter provides information on the types and levels of social benefits anticipated from the proposed rulemaking. This information includes: (1) background information on benefits assessment, describing benefits categories and issues in benefits estimation; (2) qualitative descriptions of the types of benefits associated with alternative standards; (3) quantitative estimates of benefits categories for which concentration-response information is available; and (4) monetized estimates of benefits categories for which economic valuation data are available.

12.4.2 Benefits Categories Applicable to the Regulation

To conduct a benefits analysis, the types or categories of benefits that apply need to be defined. Figure 12.1 provides an example of the types of benefits potentially observed as a result of changes in air quality. The types of benefits identified in both the health and welfare categories can generally be classified as *use benefits* or *non-use benefits.*

Use benefits are the values associated with an individual's desire to avoid his or her own exposure to an environmental risk. Use benefits categories can embody both direct and indirect uses of affected ambient air. The direct use category embraces both consumptive and nonconsumptive activities. In most applications to air pollution scenarios, the most prominent use benefits categories are those related to human health risk reductions, effects on crops and plant life, visibility, and materials damage.

Non-use (intrinsic) benefits are values an individual may have for lowering air pollution concentrations or the level of risk unrelated to his or her own exposure. Improved environmental quality can be valued by individuals apart from any past, present, or anticipated future use of the resource in question. Such nonuse values may be of a highly significant magnitude; however, the benefit value to assign to these motivations often is a matter of considerable debate. While human uses of a resource can be observed directly and valued with a range of technical economic techniques, nonuse values must be ascertained through indirect methods, such as asking survey respondents to reveal their values.

Non-use values may be related to the desire to know that a clean environment be available for the use of others now and in the future, or may be related to the desire to know that the

Figure 12.1 Examples of Potential Benefits of Air Quality Improvements

USE BENEFITS	EXAMPLES
Direct	*Human Health Risk Reductions (e.g., less incidences of coughing) *Increased Crop Yields
Indirect	*Non-Consumptive Use (e.g., improved visibility for recreational activities)
Option Value	*Risk Premium for Uncertain Future Demand *Risk Premium for Uncertain Future Supply (e.g., treating as insurance, the protection of a forest just in case a new use for a forest product will be discovered in the future)
Aesthetic	*Residing, working, traveling, and/or owning property in reduced smog locations
NON-USE BENEFITS	
Bequest	*Intergenerational Equity (e.g., an older generation wanting a younger generation to inherit a protected environment)
Existence	*Stewardship/Preservation/Altruistic Values (e.g., an individual wanting to protect a forest even if he knows that he will never use the forest) *Ecological Benefits

resource is being preserved for its own sake, regardless of human use. The component of non-use value that is related to the use of the resource by others in the future is referred to as the bequest value. This value is typically thought of as altruistic in nature. For example, the value that an individual places on reducing the general population's risk of PM and/or ozone exposure either now or in the future is referred to as the bequest value. Another potential component of non-use value is the value that is related to preservation of the resource for its own sake, even if there is no human use of the resource. This component of non-use value is sometimes referred to as existence value. An example of an existence value is the value placed on the ecological benefits of protecting areas known as wetlands because they play a crucial role in our ecological system, even if the wetlands themselves are not directly used by humans.

The majority of health and welfare benefits categories presented in this analysis can be classified as direct use benefits. These benefits are discussed in greater detail compared to other benefits categories presented in Figure 12.1 because more scientific and economic information has been gathered for the direct use benefits category. For example, scientific studies have been conducted to discern the relationship between ozone exposure and subsequent effects on specific health risks and agricultural commodities. In addition, economic valuation of these benefits can be accomplished because a market exists for some categories (making it possible to collect supply, demand, and price information) or contingent valuation studies have been conducted for categories that people are familiar with (such as willingness-to-pay surveys for non-market commodities).

Detailed scientific and economic information is not as readily available for the remainder of the benefits categories listed in Figure 12.1. Information pertaining to indirect use, option value, aesthetic, bequest, and existence benefits is often more difficult to collect. For example, lowering ambient ozone concentrations in an area is expected to reduce physical damage to ornamental plants in the area. A homeowner living in the affected area with ornamental plants in his yard is expected to benefit from the reduced damage to his plants, with his plants possibly exhibiting an improved appearance or experiencing an extended life. Although scientific information can help identify the benefits category of decreased damage to urban ornamentals, lack of more detailed scientific and economic information (e.g., concentration-response relationships for urban ornamentals and values associated with specific types of injuries and mitigation) prevent quantification of this benefits category.

Another problem related to lack of information is the difficulty in identifying all benefits categories that might result from environmental regulation and in valuing those benefits that are identified. A cost analysis is expected to provide a more comprehensive estimate of the cost of an environmental regulation because technical information is available for identifying the technologies that would be necessary to achieve the desired pollution reduction. In addition, market or economic information is available for the many components of a cost analysis (e.g., energy prices, pollution control equipment, etc.). A similar situation typically does not exist for estimating the benefits of environmental regulation. The nature of this problem is due to the non-market characteristic of many benefits categories. Since many pollution effects (e.g., adverse health or agricultural effects) traditionally have not been traded as market commodities, economists and analysts cannot look to changes in market prices and quantities to estimate the value of these effects. This lack of observable markets may lead to the omission of significant benefits categories from an environmental benefits discussion.

The inability to quantify the majority of the benefits categories listed in Figure 12.1 as well as the possible omission of relevant environmental benefits categories may lead the quantified benefits presented in this report to be underestimated relative to total benefits. It is not possible to estimate the magnitude of this underestimate.

Tables 12.1 and 12.2 present the quantifiable and unquantifiable human health and welfare effects associated with exposure to PM, ozone, and RH. Note that since the pollutants contributing to RH formation are similar to those contributing to particulate formation, the health and welfare categories associated with PM are also associated with RH.

Table 12.1 PM and RH Benefits Categories

	PM Health and Welfare Benefit Categories	
	Unquantified Benefit Categories	**Quantified Benefit Categories (incidences reduced and/or dollars)**
Health Categories	Changes in pulmonary function Morphological changes Altered host defense mechanisms Cancer Other chronic respiratory disease Infant Mortality Mercury Emission Reductions	Mortality (acute and long-term) Hospital admissions for: all respiratory illnesses congestive heart failure ischemic heart disease Acute and chronic bronchitis Lower, upper, and acute respiratory symptoms Respiratory activity days Minor respiratory activity days Shortness of breath Moderate or worse asthma Work loss days
Welfare Categories	Materials damage (other than consumer cleaning cost savings) Damage to ecosystems (e.g., acid sulfate deposition) Nitrates in drinking water Brown Clouds	Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters

* There may be orders of magnitude differences in the size of these benefit categories.

Table 12.2 Ozone Benefits Categories

	Ozone Health and Welfare Benefit Categories	
	Unquantified Health Benefit Categories	**Quantified Benefit Categories (in terms of incidences reduced or dollars)**
Health Categories	Airway responsiveness Pulmonary inflammation Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage Chronic respiratory damage/ Premature aging of lungs	Coughs Pain upon deep inhalation Mortality Hospital admissions for: all respiratory illnesses pneumonia chronic obstructive pulmonary disease (COPD) Acute respiratory symptoms Restricted activity days Lower respiratory symptoms Self-reported asthma attacks Cancer from air toxics Change in lung function
Welfare Categories	Ecosystem and vegetation effects in Class I areas (e.g., national parks) Damage to urban ornamentals (e.g., grass, flowers, shrubs, and trees in urban areas) Reduced yields of tree seedlings and non-commercial forests Damage to ecosystems Materials damage (other than consumer cleaning cost savings) Nitrates in drinking water Brown Clouds	Commodity crops Fruit and vegetable crops Commercial forests Consumer Cleaning Cost Savings Visibility Nitrogen deposition in estuarine and coastal waters Worker productivity

* See footnote to Table 12.1 on page 12-8.

12.4.3 Economic Benefits

The general term “benefits” refers to any and all outcomes of the regulation that are considered positive; that is, that contribute to an enhanced level of social welfare. The economist’s meaning of “benefits” refers to the dollar value associated with all the expected positive impacts of the regulation; that is, all regulatory outcomes that lead to higher social welfare. If the benefits are associated with market goods and services, the monetary value of the benefits is approximated by the sum of the predicted changes in “consumer (and producer surplus.” These “surplus” measures are standard and widely accepted terms of applied welfare economics, and reflect the degree of well-being enjoyed by people given different levels of goods and prices. If the benefits are non-market benefits (such as the risk reductions associated with environmental quality improvements), however, the other methods of examining changes in relevant markets must be used. In contrast to market goods, non-market goods such as environmental quality improvements are public goods, whose benefits are shared by many people. The total value of such a good is the sum of the dollar amounts that all those who benefit are willing to pay.

This conceptual economic foundation raises several relevant issues and potential limitations for the benefits analysis of the regulation. First, the standard economic approach to estimating environmental benefits is anthropocentric -- all benefits values arise from how environmental changes are perceived and valued by people in present-day values. Thus, all near-term as well as temporally distant future physical outcomes associated with reduced pollutant loadings need to be predicted and then translated into the framework of present-day human activities and concerns. Second, as noted above, it may not be possible to quantify the value of all benefits resulting from environmental quality improvements.

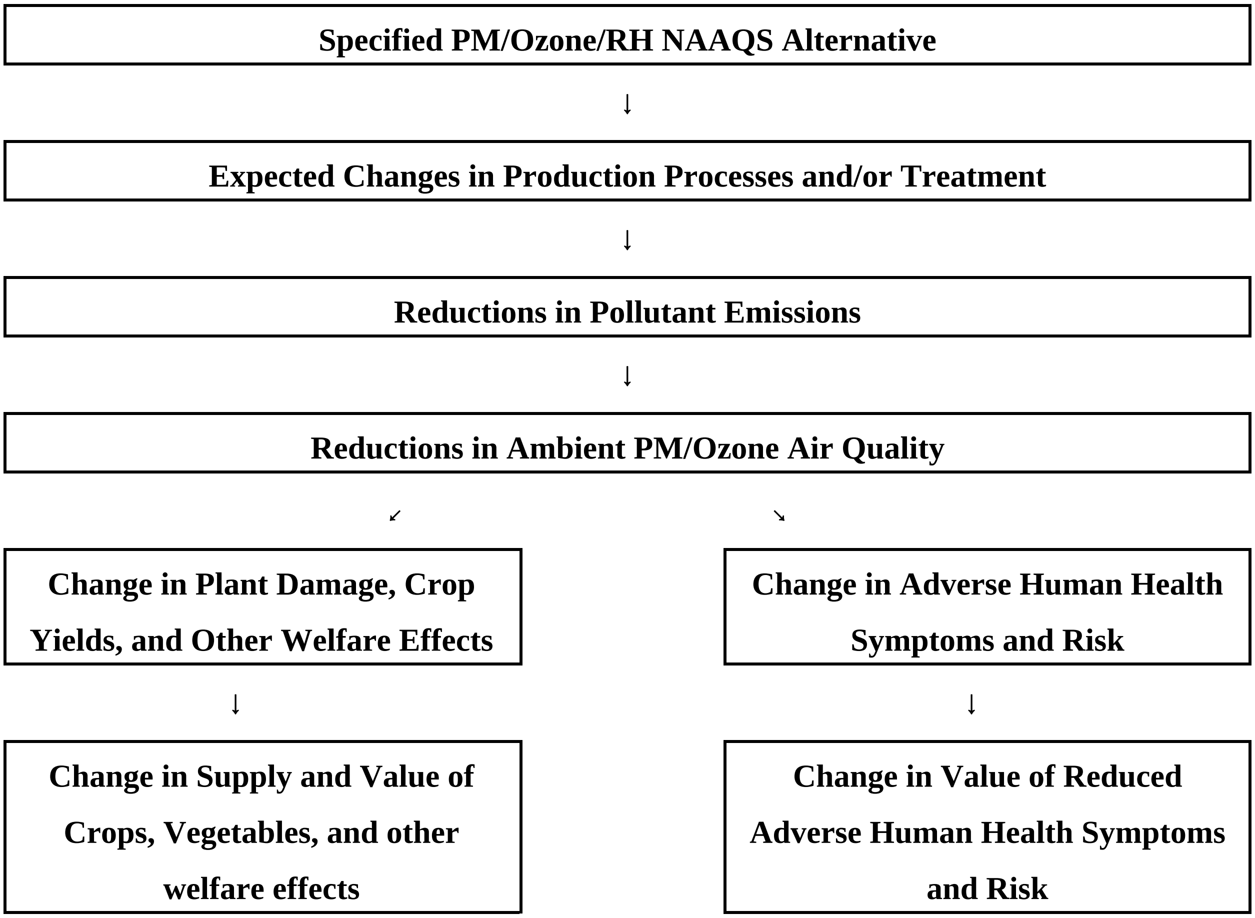
12.4.4 Linking the Regulation to Beneficial Outcomes

Conducting a benefits analysis for anticipated changes in air emissions is a challenging exercise. Assessing the benefits of a regulatory action requires a chain of events to be specified and understood. As shown in Figure 12.2, which illustrates the causality for air quality related benefits, these relationships span the spectrum of: (1) institutional relationships and policy-making; (2) the technical feasibility of pollution abatement; (3) the physical-chemical properties of air pollutants and their consequent linkages to biologic/ecologic responses in the environment, and (4) human responses and values associated with these changes.

The first two steps of Figure 12.2 reflect the institutional and technical aspects of implementing the regulation (the improved process changes or pollutant abatement). The benefits analyses presented in this document begin at the step of estimating reductions in ambient ozone concentrations. The estimated changes in ambient PM or ozone concentrations are directly linked to the estimated changes in precursor pollutant emission reductions through the use of either a source-receptor matrix (see chapter 4) or an air quality rollback procedure given the predicted 2010 baseline air quality. Chapter 4 of this report presents the methodology used to estimate baseline ambient PM and ozone air quality in the year 2010.

This RIA presents two scenarios for analyzing reductions in ambient PM and ozone air quality. The first, referred to as the partial attainment scenario, is intended to reflect residual nonattainment information as presented in the partial attainment cost analysis. For each area identified as not having sufficient control measures to allow it to attain a particular standard, the post-control air quality estimated for each area is intended to reflect the degree of residual nonattainment for that area. The health and welfare benefits estimated for this partial attainment scenario represent the identifiable benefits expected to result from the application of control measures as identified in the partial attainment cost analysis. The second scenario, referred to as the full attainment scenario, relies on the assumption that all areas will be able to attain any PM

Figure 12.2 Example Methodology of a Benefits Analysis



or ozone NAAQS being evaluated. The health and welfare benefits presented under this scenario represent the identifiable benefits that should accrue if all areas in the United States could comply with the standard being analyzed. Note that the benefits presented for the full attainment scenario will always exceed the benefits presented for the partial attainment scenario since the partial attainment scenario accounts for residual nonattainment. Chapter 4 presents a discussion of the models used to estimate baseline PM and ozone air quality.

Other information necessary for the analysis are the physical and chemical parameters and the consequent improvement in the environment (e.g., concentration-response data). Finally, the analysis reaches the stage at which anthropocentric benefits concepts begin to apply, such as reductions in human health risk and improvements in crop yields. These final steps reflect the focal point of the benefits analyses, and are defined by the benefits categories described above. Below, relevant benefits categories are described qualitatively, and where possible, quantitatively.

12.4.5 Plausible Range of Monetized Benefits

As discussed throughout this RIA, there are many sources of uncertainty in estimating both the costs and the benefits of complex regulatory programs such as those that will be required to implement the ozone and PM NAAQS. These include uncertainties about the effects of emissions reductions on air quality, uncertainties about the effects of changes in air quality on health and welfare endpoints of concern, and uncertainties about the economic valuation of these endpoints. For this reason, this RIA has adopted the approach of presenting a “plausible range” of monetized benefits that reflects these uncertainties by selecting alternative values for each of several key assumptions. Taken together, these alternative sets of assumptions define a “high end” and a “low end” estimate for the benefits that have been monetized in this analysis.

In choosing alternative assumptions, EPA has attempted to be responsive to the many comments received on the RIAs that accompanied the proposed rules. As a result, the ranges of benefits presented here are substantially wider than the ranges that were presented in the RIAs for the proposed rules. It should be emphasized, however, that the high and low ends of the plausible range are not the same as upper and lower bounds. For many of the quantitative assumptions involved in the analysis, arguments could be made for an even higher or lower choice, which could lead to an even greater spread between the high end and low end estimates. The analysis attempts to present a plausible range of monetized benefits for the categorizes that have been analyzed. It should also be noted, as discussed in greater detail above, that a number of benefits categories have not been monetized, because of both conceptual and technical difficulties in doing so. These benefits are in addition to the plausible range of monetized benefits considered here.

The uncertainties that have been incorporated into the analysis are noted throughout the discussion of the methodology that follows. However, a few key assumptions, which have a substantial impact on the analysis and which together account for most of the differences between the high and low end estimates are note here.

For PM, one significant source of uncertainty is the possible existence of a threshold concentration below which no adverse health effects occur. As noted in the preamble to the rule, the epidemiological evidence for effects above the level chosen for the annual standard is substantially stronger than the evidence for effects below that level. As noted in the preamble, although the possibility of effects at lower annual concentrations cannot be excluded, the evidence for that possibility is highly uncertain and the likelihood of significant health risk, if any, becomes smaller as concentrations approach background. Consequently, in constructing the high and low end benefits estimates, the following alternative assumptions were used. The high end estimate assumes that health benefits from reductions in $PM_{2.5}$ occur all the way down to background levels for chronic bronchitis and 12 $\mu g/m^3$ mean for long-term mortality. The low end estimate assumes that health benefits occur from $PM_{2.5}$ reductions only down to the level of the standard, or 15 $\mu g/m^3$ for all endpoints. Based on the risk assessment for mortality, approximately 60 percent of mortalities are estimated to occur above 15 $\mu g/m^3$; that adjustment is applied to all PM health benefits for the low end estimate.

There is also substantial uncertainty about the extent of reduced mortality that may be associated with ozone reductions. A number of studies documenting a possible relationship between ozone and premature mortality are newly available, but these studies were not available at the time of the CASAC review of the Criteria Document and Staff Paper, and thus were not reviewed by CASAC and were not used in establishing the basis for the new 8-hour standard. The high end estimate for ozone benefits is based on a meta analysis (discussed in more detail below) of nine of the more complete of these recent epidemiological studies, while the low end estimate assumes no mortality benefits from ozone reductions.

Furthermore, in the RIAs for the proposed rules, benefits that result from reductions in fine particles were attributed only to the PM standard, and benefits that result from reductions in ozone were attributed only to the ozone standard. In fact, however, NOx is a major precursor of both pollutants, so that control measures that reduce NOx emissions may lead to significant reductions in both ozone and fine partculates. It follows that even in the absence of an ozone standard, there would be some ozone benefits from a fine PM standard, and conversely, there would be some PM benefits from an ozone standard even in the absence of a $PM_{2.5}$ standard. There is thus some ambiguity about where to assign benefits that result from control measures that contribute to the attainment of both standards. To account for this ambiguity, the high end benefits estimate for ozone attributes to the ozone standard ("ancillary" PM benefits), while the low end estimate for ozone does not include these ancillary benefits.

Finally, there is substantial disagreement about the appropriate method for valuing reductions in risk of premature mortality. The RIAs for the proposed rule used a value per statistical life saved (VSL) of $4.8 million. This represents an intermediate value from a variety of estimates that appear in the economics literature. It is a value that EPA has frequently used in RIAs for other rules. However, it has been pointed out that a substantial fraction of the premature deaths "avoided" by reductions in fine PM may represent life shortening by as little as a few days or weeks among individuals already suffering from severe respiratory or cardiopulmonary disease. Further, the average age of individuals who die from causes associated with fine PM is significantly higher, and the age specific life expectancy correspondingly lower, than the average age and life-expectancy of individuals used in the studies from which estimates of VSL were derived.

An alternative approach to valuing reductions in premature mortality that addresses these concerns is to estimate total life years extended, rather than premature deaths avoided, and multiply the result by the value of a statistical life-year extended (VSLY). This approach attempts to estimate not only how many premature deaths are avoided, but by how long these deaths are postponed. It is consistent with, but less refined than, the approach recommended in 1993 by the U.S. Public Health Service Panel on Cost-Effectiveness in Health and Medicine, which is the incorporation of morbidity and mortality consequences into a single measure quality adjusted life years (Haddix, et. al., 1996). This alternative approach then assigns a value to each life-year extended, rather than to each death postponed. In this analysis, the high-end estimate for mortality benefits used the VSL approach, with a value of $4.8 million per statistical life saved, while the low-end estimate uses the VSLY approach. While there is currently little quantitative evidence regarding the extent of life shortening reflected in the short term mortality studies, concerns have been raised that a significant fraction of this mortality may reflect life shortening by only a few days or weeks. In contrast, the CAA Section 812 Study notes that the life expectancy of 65-74 year olds, among whom much of the PM-related mortality occurs, is 14 years. This figure does not account for the possibility that much of the premature mortality may occur among individuals who are already suffering from serious respiratory or cardiopulmonary disease. Consequently, in constructing the low-end estimate, the assumption is made that two-thirds of the PM-related mortality reductions estimated from short-term studies represent life shortening of no more than a few weeks, while one-third represents life shortening of 14 years. The resulting estimate of life years extended monetizes the life years lost estimate value of $120,000 per year. This represents the midpoint value from the range of published estimates (Tolley et. al., 1994, p.313).

12.4.6 Comparison of RIA to NAAQS Risk Assessment

The process of proposing and promulgating a revised NAAQS requires the Agency to conduct a series of analyses, two of which examine the health and welfare implications of revising the NAAQS. The first of these analyses is the risk assessment and exposure analyses, summarized in the PM and ozone Staff Papers and supplemental analyses, which are part of the scientific rationale for these health-based standards. (U.S. EPA, 1996c, 1996d) The second is the benefits analysis included in this RIA. In general, this RIA adopts the basic methods employed in the exposure analyses and risk assessment but attempts to expand the scope of the exposure analyses and risk assessment in an effort to identify and quantify all potential benefits categories.

To the extent possible, this health benefits analysis is methodologically consistent with analyses conducted for the PM and Ozone Staff Papers; however, this RIA's health benefits analysis differs from the exposure analyses and risk assessment in five ways.

1. This updated benefits analysis includes a number of health and welfare endpoints that were not included in the risk assessments. The two analyses are different because they serve different purposes: the risk assessment is used to provide a scientific basis for revising the current NAAQS while the purpose of this benefits analysis is to identify all potential health and environmental benefits associated with alternative NAAQS levels. Therefore, this benefits analysis must provide discussions or estimates of all health and environmental effects believed to be associated with exposure to ozone and PM. In addition to expanding the types of endpoints that are included in the analysis, this analysis estimates PM-related benefits attributable to emission reductions associated with control strategies implemented to meet the ozone NAAQS alternatives. These benefits are referred to as ancillary PM benefits associated with the ozone NAAQS. All health and welfare endpoints that are listed for the PM benefits analysis are also estimated for the ozone NAAQS analysis if ozone control strategies reduce NOx emissions, which also have an effect on PM air quality. The ancillary PM benefits occur mostly in areas that

have PM concentrations below the 15 μg/m^3 threshold assumed in the low-end estimate. Areas that have concentrations above 15 μg/m^3 would be out of attainment for $PM_{2.5}$, and it is not clear how to "divide up" the PM benefits between the ozone and PM standards for these areas. Therefore, the PM ancillary benefits are not included in the low-end estimate.

2. This benefits analysis expands the geographical scope of the exposure analyses and risk assessment. The PM and ozone benefits are estimated for the continental U.S. (referred to as a national analysis) as opposed to the risk assessment's limited number of 2 cities for PM and 9 urban areas for ozone. In addition, the PM and ozone benefits are estimated for a full calendar year as opposed to the ozone risk assessments limitation to the ozone season (the PM risk assessment however, was also estimated for a full year). The scope of the benefits analysis is expanded because the NAAQS are nationally applicable rules and control strategies implemented to reduce emissions are typically operated all year.

3. The exposure analyses and risk assessments use population and air quality data from relatively current years (1990 to 1993) to estimate risk reductions. In contrast, this benefits analysis estimates health and welfare effects for projected populations and ambient PM and ozone reductions in the year 2010. The year 2010 is an appropriate time period of analysis for this RIA because the purpose of this analysis is to identify potential benefits and costs associated with the standards when they are implemented. The year 2010 is believed to be a representative year for the purposes of this RIA.

4. The risk and exposure analyses employs a proportional air quality rollback procedure for both the PM and ozone NAAQS (with alternative rollback procedures as sensitivity analyses for ozone). This benefits analysis employs the same proportional air quality rollback procedure for the PM full attainment analysis (an air quality model is used to estimate partial attainment PM concentrations) but applies a hybrid version of the proportional rollback procedure, called quadratic rollback, to simulate post-control ozone

air quality. The quadratic procedure is used for the ozone analysis because the scope of the benefits analysis, especially the time over which benefits are calculated (full year rather than ozone season only), is more broad compared to the ozone risk and exposure assessment. In response to public comments on the ozone exposure analyses and risk assessment, EPA has conducted sensitivity analyses using alternative air quality rollback procedures; including the quadratic rollback employed in this RIA. EPA believes the quadratic rollback procedure generally is more reflective of how ozone levels decreased for many geographic areas and thus, is more suitable for use in a national analysis for a full year. See section 12.6 for a more detailed explanation of the characteristics of the rollback procedures.

5. A significant difference between this benefits analysis and the PM and ozone risk and exposure assessment is the inclusion of the ozone-induced mortality category in the high-end estimate for this analysis. The inclusion of this category creates a significant difference in the benefits results because of the number of avoided mortality cases predicted in new epidemiological assessments and the monetary estimate used to value these avoided cases. A short discussion of the ozone mortality issue is presented here due to this significant difference between this benefits analysis and the risk and exposure assessment.

A number of community epidemiology studies have suggested a possible association of ozone with mortality. The ozone criteria document review of the literature concluded that although an association between high ozone levels and mortality has been suggested, the strength of any such association remained unclear (U.S. EPA, 1996a). However, although early studies of this issue are flawed (e.g., due to poor control for confounders), a significant number of new studies (21 peer-reviewed studies, 12 since CASAC closure) have been published recently that provides more support for an association between ozone exposure and mortality. Although this benefits analysis uses data from these new studies to quantitatively estimate the relationship between ozone exposure and mortality for the high-end estimate, it is important to distinguish the role of this benefits analysis in comparison to the NAAQS risk and exposure assessment.

Results generated by the NAAQS exposure analyses and risk assessment are directly used to determine the appropriate level at which to set a criteria pollutant standard such that public health is protected with "an adequate margin of safety." The exposure analyses and risk assessment use only studies that have been reviewed by the Clean Air Science Advisory Committee (CASAC). The purpose of this benefits analysis is to identify and quantify, to the extent possible, all potential benefits categories that might result from implementation of the revised standards.

The additional ozone mortality studies provide increasing evidence of associations between ozone exposure and daily mortality. While many of these studies show an association between ozone exposure and mortality, studies over longer time periods, which collect and use more data, show stronger statistical significance compared to studies conducted over relatively shorter time frames. See the Benefits Technical Support Document (TSD) (U.S. EPA, 1997a) for a more complete description of the ozone mortality meta-analysis. Because significant uncertainty still exists in the estimation of ozone-induced mortality, this category of benefits is included in the high-end estimate but excluded from the low-end estimate.

12.5 SCOPE OF ANALYSIS

The goal of this analysis is to estimate national-level benefits associated with the revised PM and ozone standards as well as the regional haze program for the year 2010. As was previously explained in this RIA, baseline PM air quality data are reported in two ways: an annual distribution and a daily distribution. Baseline hourly ozone air quality data are generated for the entire year in 2010. Both PM and ozone air quality are projected at their respective existing monitor sites. The monitor-site air quality data are then used to interpolate PM and ozone air quality for all unmonitored counties in the continental U.S. Post-control air quality is then estimated (using either the source-receptor matrix or the air quality rollback procedure) for each of the baseline air quality values. The air quality rollback procedure is applied to the appropriate baseline air quality values for the entire year.

This benefits chapter presents national-level summary results associated with the NAAQS and RH alternatives analyzed in this report. However, readers interested in smaller units of aggregation (e.g., each of the six PM regions or each of the ozone nonattainment areas) can refer to the Benefits TSD.

12.6 ESTIMATION OF POST-CONTROL AIR QUALITY

12.6.1 Introduction

The discussion accompanying Figure 12.2 explains that the starting point for this benefits analysis is the estimation of reductions in ambient concentrations of PM and Ozone. Previous chapters in this analysis have provided information on the development of baseline emissions and air quality as well as the estimation of emission reductions and costs associated with implementation of the various NAAQS alternatives. This chapter continues the analysis by converting the estimated emission reductions into decreased ambient PM and ozone concentrations. The air quality change is defined by two scenarios: (1) Partial Attainment (to reflect air quality improvement expected given the adoption, where needed, of reasonably cost-effective emissions controls for which adequate cost-effectiveness data exist, and (2) Full Attainment (to reflect the potential benefits if all areas are able to meet the standards).

12.6.2 Derivation of Annual Distribution of Daily PM Concentrations

As described in Chapter 4, baseline PM air quality predicted by the source-receptor matrix is used as input to the benefits analysis. Because the annual distribution of daily PM concentrations cannot be predicted by the model, they must be derived from other predicted information. A reasonable functional form for county-specific air quality distributions can be assumed, based on an examination of PM distributions in recent years for which actual data exist. Once a functional form is chosen, all that is unknown about a given county-specific distribution are the values of its parameters. The model-predicted statistics, the annual mean and the 98th or 99th percentile daily maximum, can then be used to estimate these parameters, for each county-specific distribution, completing the estimate of the county-specific distribution of daily PM concentrations in the year 2010. For the baseline PM_{10} alternative, the fourth highest daily maximum value is used. For the selected PM_{10} alternative, the 99th percentile daily maximum value is used. For the $PM_{2.5}$ alternatives, the 3-year average 98th percentile daily maximum value is used. Daily PM concentrations are then generated from this estimated distribution.

To determine the most reasonable annual distributional form for the daily PM concentrations in each county in the United States for the year 2010, PM data for recent years in each of four locations (Philadelphia, PA; St. Louis, MO; Provo, UT; and El Paso, TX) were fit to a number of distributions (including, but not limited to, the lognormal, the beta and the gamma distributions). The gamma distribution was chosen because it generally provided the best fit. The above procedure was carried out for each county in the national analysis, generating 365 daily PM_{10} and 365 daily $PM_{2.5}$ concentrations for each county in the analysis. The procedure used to estimate the two parameters of the gamma distribution and to then generate a year's worth of daily PM concentrations from the fully specified distribution is described in detail in the Benefits TSD (U.S. EPA, 1997a).

12.6.3 Partial Attainment Air Quality Estimation

The partial attainment benefits scenario is assessed to account for the presence of residual nonattainment for both PM and ozone (as described in Chapters 6,7, and 8). Under the partial attainment scenario, the goal is to approximate post-control air quality related to emission reductions achieved by the specific control measures identified in the cost analysis. The reader should keep in mind that even under this partial attainment scenario, there are some areas that the cost analysis estimates will be able to fully attain either the PM and/or the ozone standards. The difference between the full and partial attainment scenarios is that for the partial attainment scenario, under each alternative NAAQS evaluated, a number of areas are identified as residual nonattainment areas, where insufficient control measures are identified to simulate full attainment. Given that the goal of the partial attainment benefits scenario is to link projected emission reductions, costs, and the resulting air quality improvements, the benefits results presented under the partial attainment scenario should be viewed as the results most comparable to the partial attainment cost estimates presented in Chapters 6, 7, and 8.

As described in chapter 4 and chapter 6, the source-receptor matrix and PM cost optimization model are is used to estimate least-cost reductions of primary PM and PM precursors to attain alternative PM standards. Ambient PM concentrations are expected to be affected by both the type of emissions reduced [i.e., nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOC), PM_{10}, $PM_{2.5}$, or ammonia] and the location of the emission reductions. Note that since NOx and VOC are precursor emissions for both PM and ozone, the source-receptor matrix can be used to estimate ambient particulate reductions expected to result from controls imposed under both the PM and the ozone NAAQS. Once control measures are identified in the control strategy/cost analysis, post-control emissions are input to the source-receptor model to predict nationwide post-control PM air quality. This step is conducted to account for pollutant transport between the 6 modeling regions delineated in chapter 6.

The estimation of ambient ozone concentration reductions is more problematic compared to the PM procedure described above. Lack of a national ozone air chemistry model precludes creating a direct link between the imposition of pollution control strategies (as identified in the cost analysis) and the resulting ambient ozone concentration. Rather, this analysis relies on an air quality adjustment procedure (referred to as quadratic rollback) to reduce hourly baseline ozone concentrations. This approach uses a quadratic formula such that relatively higher ozone concentrations get reduced by a greater percentage than relatively lower ozone concentrations . The partial attainment air quality rollback procedure is intended to reflect the degree of nonattainment for each residual nonattainment area.

For each ozone standard analyzed, the cost analysis attempts to identify control strategies that will enable each nonattainment area to achieve its targeted emission reductions. Two outcomes are possible within the analysis: (1) emission reduction targets are achieved or (2) controls likely to be imposed do not fully achieve the emission reduction targets by 2010. Starting with the first example, if an area initially classified as nonattainment is projected to be able to meet its targeted emission reductions, that area is classified as an initial nonattainment area that, with the implementation of additional control strategies, will be able to attain the standard. Under this example, the design value for the nonattainment area (i.e., the recorded monitor value that causes the area to be classified as a nonattainment areas) is reduced by X percent to comply with the standard. All other monitor values within the nonattainment area are also reduced by some smaller percentage compared to X, as determined by the quadratic equation. Also, under this attainment case, the rounding convention of .005 parts per million (ppm) is employed in the air quality rollback procedure. For example, if the standard under evaluation is an 8-hour, .08 ppm standard, the quadratic rollback procedure is employed to reduce the design value ozone concentration to a value of .084 ppm.

The partial attainment scenario also contains a number of areas that belong in the second category. Since the area cannot be deemed to be able to attain the standard within the study period, the air quality rollback procedure must be modified to reflect the presence of residual nonattainment. Relevant information that is known for each nonattainment area includes: (1) the design value causing the area to be classified as nonattainment; (2) the targeted VOC and NOx emission reductions believed to be necessary to enable the area to comply with the standard being analyzed; and (3) the total VOC and NOx emission reductions thought to be possible given identifiable control measures. Using the above information along with an assumption of linearity between emission reductions and ambient ozone concentrations, it is possible to employ the quadratic rollback procedure to approximate partial attainment air quality. Targeted VOC and NOx emission reductions are summed. Achieved NOx and VOC emission reductions are treated equally. A ratio of total achieved to targeted emission reductions is then calculated. This ratio provides the degree of partial attainment that is then applied to the air quality rollback of the design value to meet a particular ozone standard. For example, if an area is estimated to be able to only achieve 50 percent of its targeted emission reductions, then the 50 percent value is used to reduce the design value to only 50 percent towards attainment of the standard (where 100 percent implies full attainment because the emission reductions targets are fully met). Downwind transport areas as described in chapter 4 are also rolled back the same amount as their upwind nonattainment areas. Once these partial attainment rollbacks are complete, the centroid model (see section 4.5.4) is re-run to provide nationwide post-control ozone air quality.

12.6.4 Full Attainment Air Quality Estimation

Because full attainment of the alternative NAAQS nationwide will require use of new technologies whose costs cannot yet be assessed accurately, full attainment of each alternative is simulated by changing the distribution of daily PM or ozone concentrations. The methods described below for adjusting baseline air quality to simulate full attainment apply to both the PM and ozone benefits analyses. The procedure used to adjust both the PM and ozone air quality is referred to as the air quality rollback procedure.

In the absence of historical $PM_{2.5}$ air quality monitoring data, it may be reasonable to simulate full attainment of the PM alternatives by employing a proportional rollback procedure (i.e., by decreasing the appropriate baseline PM and ozone concentrations on all days by the same percentage). An assessment of the plausibility of estimating full attainment air quality by using a proportional (also referred to as linear) rollback procedure is presented in the PM risk assessment (Johnson, 1997). The assessment examines historic changes in $PM_{2.5}$ and concludes that the proportional rollback procedure is a good approximation for the historical decrease in PM levels.

As with the ozone partial attainment scenario, the quadratic air quality rollback procedure is employed to simulate full attainment of the ozone alternatives because historical monitoring data indicates that lower ozone concentrations may decrease by a smaller proportion compared to higher ozone concentrations when control strategies are implemented.

For the PM NAAQS, the full attainment benefits analysis begins where the partial attainment analysis ended. Under the PM full attainment benefits analysis, the proportional rollback procedure is employed to simulate full attainment in the residual nonattainment areas (i.e., by decreasing the appropriate baseline PM concentrations on all days by the same percentage). The PM percent reduction is determined by the controlling standard. For example, suppose both an annual and a daily PM 2.5 standard are proposed. Suppose P_a is the percent reduction required to attain the annual standard (i.e., the percent reduction of daily PM necessary to get the annual average at the monitor with the highest annual average down to the standard). Suppose P_d is the percent reduction required to attain the daily standard with one exceedance (i.e., the percent reduction of daily PM necessary to get the second-highest monitor-day down to the daily standard). If P_d is greater than P_a, then all daily average PM concentrations are reduced by P_d percent. If P_a is greater than P_d, then all daily average PM concentrations are reduced by P_a percent. A rounding convention is also employed in the rollback procedure. Using the proposed $PM_{2.5}$ standard of 15/50 $\mu g/m^3$ as an example, the annual value is reduced to a value of 15.04 $\mu g/m^3$ while the daily value would be reduced to a value of 50.4 $\mu g/m^3$.

For ozone, the process is slightly simpler since there is only one standard to attain at any given time. For example, the design value for a nonattainment area (i.e., the recorded monitor value that causes the area to be classified as a nonattainment area) is reduced by X percent to comply with the standard. Accordingly, the quadratic air quality rollback procedure employed in the ozone partial attainment scenario is also employed in the full attainment scenario. The only difference between the two scenarios is that the ozone full attainment scenario always reduces each nonattainment area's design value to exactly the level of the evaluated standard. The full attainment scenario adheres to the same rounding convention of .005 ppm.

12.6.5 Air Quality Background Levels and Benefits Thresholds

The term background air quality refers to pollution caused by natural sources (as opposed to those caused by anthropogenic sources) and is defined as the distribution of air quality that would be observed in the U.S. in the absence of anthropogenic emissions of PM, VOC, NOx, and SOx in North America. For example, volcanoes emit sulfate precursors and trees emit VOC (i.e., terpenes), which each contribute to PM and ozone formation, respectively.

The health benefits estimation for PM uses two alternative assumptions about benefits from reductions below the level of the standard. The high-end estimate assumes benefits from fine particulate reductions down to 12 $\mu g/m^3$ mean for mortality due to long-term exposure and reductions down to background levels for chronic bronchitis. The PM Staff Paper provides background values for PM_{10} versus $PM_{2.5}$ and west versus east (U.S. EPA, 1996d). Midpoint background values for PM_{10} are estimated at 6 $\mu g/m^3$ for the west and 8 $\mu g/m^3$ for the east. Midpoint background values for $PM_{2.5}$ are estimated at 2.5 $\mu g/m^3$ for the west and 3.5 $\mu g/m^3$ for the east. This analysis uses background PM concentrations for benefits models that do not report a lowest-observed PM concentration or if the reported lowest-observed concentration is below background. For models that report a lowest-observed concentration (the lowest PM concentration at which the concentration-response function is supported) at a higher value than background levels, benefits estimates are only calculated for air quality changes down to the lowest observable level. For example, the Pope et al. study reports a lowest observed annual median $PM_{2.5}$ level as 9 $\mu g/m^3$. Therefore, the concentration-response function is relied upon only down to the 9 $\mu g/m^3$ annual median concentration. The short-term PM-mortality studies generally do not report lowest observed concentrations and are therefore, estimated down to background concentrations. Similarly, most PM-mortality studies do not report lowest-observed levels and are also estimated down to background concentrations. As discussed in the preamble to the rule, benefits from reductions below the standard are significantly more uncertain than those from reductions above the level of the standard. The low-end estimate thus uses a threshold concentration of 15 $\mu g/m^3$, below which further reductions are not assumed to yield additional health benefits. This has the effect of reducing the incidence of estimated health benefits by about 40 percent.

A background level is also imposed on the ozone concentration-response models. A midpoint background value estimated in the ozone Staff Paper is 0.04 ppm (U.S. EPA, 1996c). This analysis accounts for background ozone concentrations by evaluating benefits models only down to the 0.04 level but not below this level. This limitation is placed on models that do not report thresholds or report thresholds below 0.04 ppm. For example, while most ozone-mortality studies report lowest observed ozone concentrations, the concentrations are uniformly lower than 0.04 ppm. Ozone concentration-response functions are therefore, estimated down to background levels. In addition, some clinical studies introduce additional thresholds which are above the assumed background level, in which case, benefits estimates are only calculated for air quality changes down to the reported threshold level.

12.6.6 Ozone Air Quality Rollback Sensitivity Analysis

As mentioned earlier when comparing this benefits analysis to the NAAQS risk and exposure assessment, a point of departure between the two analyses is the air quality rollback procedure applied to ozone data. The risk and exposure assessment applied a proportional air quality rollback procedure to ozone-season air quality values in 9 sample urban areas. In addition, the assessment also conducted several air quality rollback sensitivity analyses, comparing results using a weibull distribution as well as the quadratic rollback procedure.

As noted above, that the quadratic rollback procedure reduces non-peak ozone values (e.g., wintertime ozone values) by a smaller proportion compared to peak ozone values (e.g., ozone concentrations at design-value monitors). The quadratic rollback procedure is deemed to be appropriate for this benefits analysis because the procedure is employed to adjust baseline air quality values for a full calendar year. However, this benefits analysis also conducts a sensitivity analysis using the proportional air quality rollback procedure. In general, the use of a proportional air quality rollback procedure compared to the proportional rollback procedure yields results that are 2 times larger. See the Benefits TSD for more details (U.S. EPA, 1997a). The weibull rollback procedure is data intensive and lack of historical data on a national basis for the analysis year prevents a sensitivity analysis of the weibull rollback procedure to be conducted.

12.7 HUMAN HEALTH BENEFITS

12.7.1 Introduction

Exposure to PM, ozone, and RH can result in a variety of health and welfare effects. The relevant PM, ozone, and RH human health and welfare effects that are quantified (expressed in terms of incidences reduced) and monetized (expressed in terms of dollars) are presented in Tables 12. 1 and 12.2. Note that since the pollutants contributing to RH formation are similar to those contributing to particulate formation, the health and welfare benefits categories associated with PM are also associated with RH. Additionally, note that all health and welfare effects identified for PM and RH in Table 12.1 are also applicable in the high-end estimate to ozone reductions because ozone control strategies may also reduce particulate concentrations through the control of NOx emissions. All categories of benefits listed in Tables 12.1 and 12.2 that are monetized are also quantified. However, some quantified benefits categories are not monetized due to one of two reasons: (1) economic valuation information is not available or (2) a concern about double-counting or an overlapping of effects categories led to a decision to omit a particular benefits category from the aggregation scheme. These issues are discussed in greater detail in Appendix I of this RIA.

For benefits categories listed as unquantified, scientific data are not available for quantifying the relationship between ozone and incidences of each symptom. However, the unquantifiable health benefits categories are listed because evidence in the scientific literature creates a reasonable connection between PM and ozone exposure and these health and welfare effects categories. For example, the collective toxicologic data on chronic exposure to ozone garnered in animal exposure and human population studies provide a biologically plausible basis for considering the possibility that repeated inflammation associated with exposure to ozone over a lifetime may result in sufficient damage to respiratory tissue such that individuals later in life may experience a reduced quality of life. However, such relationships remain highly uncertain due to ambiguities in the data.

The result of having potentially significant gaps in the benefits calculations may lead to an underestimation of the monetized benefits presented in this report. The effect of this potential underestimation is to limit the conclusions that can be reached regarding the monetized benefits and net benefits estimates of each of the PM, ozone, and RH alternative standards.

12.7.2 Health Benefits Methodology

As illustrated in Figure 12.2, the next step in this benefits analysis is to estimate the change in adverse human health effects expected to result from a decrease in ambient PM and/or ozone concentrations. To accomplish this task, a series of scientific studies evaluating the relationship between PM and/or ozone exposure and human health effects are identified. Statistical techniques are employed to estimate quantitative concentration-response relationships between pollution levels and health effects.

A correction has been made from the November Draft RIA in the calculation of the reductions in long-term exposure mortality associated with attainment (or partial attainment) of alternative $PM_{2.5}$ standards. In the previous analysis, changes in long-term $PM_{2.5}$ concentrations in each county were characterized by changes in the annual *mean* concentration for the county. Changes in the incidence of long-term exposure mortality associated with changes in annual mean concentrations were estimated using the concentration-response relationship reported by Pope et al., 1995. However, it appears that Pope et al. estimated the relationship between changes in mortality incidence and changes in the *median*, rather than the *mean*, of daily average concentrations across the year (or across several years). Long-term exposure mortality incidence was re-estimated, based on changes in annual median concentrations rather than annual mean concentrations, for each scenario considered. The reductions in the estimates of monetized benefits associated with long-term exposure mortality reduction due to this correction are generally about 20 percent. The lowest observable value reported in the Pope et al. study is a 9 $\mu g/m^3$ median value. A corresponding mean value is estimated to be approximately 12 $\mu g/m^3$.

Of special interest is the mortality benefits category for both PM and ozone since this category contributes a major portion of the estimated total monetized benefits (except for the low-end estimate for ozone). As explained earlier, the PM concentration-response functions included in this analysis are generally consistent with the PM NAAQS risk and exposure assessment. The studies included in the analyses were reviewed by the CASAC and judged against a set of criteria (e.g., must be published) as detailed in the Benefits TSD (see Appendix J). Also, as explained earlier in this chapter, the relatively newer ozone mortality studies that have been published or accepted by a peer-reviewed journal, but have not yet been through the CASAC or Criteria Document review process. In the absence of this review, this analysis includes in the high-end estimate a detailed assessment of the new ozone mortality studies through a meta-analysis. A subset of 9 ozone mortality studies are chosen for this benefits analysis and are also cross-referenced to the list of PM mortality studies. See Appendix J for details on the studies and the selection criteria.

Of the 9 ozone mortality studies, only two studies providing information for PM-related mortality had not already been included in the PM analysis. One of these studies was conducted in Amsterdam while the other was conducted in Chile. It is believed that the mix of precursor and primary emissions contributing to particulate formation varies widely due to factors such as geography and human and economic activity. It is also believed that the health effects associated with PM exposure are dependent upon the chemical constituents of ambient PM concentrations. For these reasons, one of the criteria used to select studies for inclusion in the PM risk and exposure analysis (and therefore, the PM benefits analysis) is that the studies had to have been conducted in the U.S. or Canada, where the population and human and economic activity patterns are relatively similar. The use of this criterion eliminates the possibility of including data from studies conducted elsewhere, such as Europe or South America. Unlike PM, there are only two precursor emissions for ozone. Although the mix of these pollutants may vary from area to area, the difference of the mix is not believed to cause a significant difference in the type or degree of health effects believed to be associated with ozone exposure (U.S. EPA, 1996b). Therefore, although the ozone mortality meta-analysis includes new studies published since review of the Criteria Document and conducted in areas outside the U.S. or Canada, the scope of the PM mortality analysis is not expanded to include the two new studies.

Tables I.1 and I.2 in Appendix I provide information on the studies this analysis uses to quantify health effects. Table I.1 lists the studies relevant to PM exposure. Since the pollutants contributing to RH formation are similar to those contributing to PM formation, all studies listed for PM exposure are also applicable to the RH benefits analysis. As can be seen from the table, the various health and welfare effects studies have used different air quality indicators for particles. This analysis assesses benefits for both PM_{10} and $PM_{2.5}$. For functions using PM_{10} as an indicator, PM_{10} data for each alternative NAAQS is used. For functions using $PM_{2.5}$ as an indicator, $PM_{2.5}$ data for each alternative NAAQS is used. However, in the case of consumer cleaning cost savings, assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. (See section 12.8.2.5 for more details.)

Table I.2 lists the studies relevant to ozone exposure. The ozone benefits analysis uses data from a combination of clinical studies (where human subjects are exposed to various levels of air pollution in a carefully controlled and monitored laboratory situation) as well as epidemiological studies (where the relationship between ambient exposures to ozone and health effects in the human population are typically studied in a "natural" setting). The portion of the ozone benefits analysis using clinical studies evaluates the concentration-response functions for the total U.S. population as well as two sub-population groups: outdoor children and outdoor workers. These sub-populations are of particular interest because individuals in these sub-populations are believed to experience higher than average exposure to ozone due to the amount of time they spend outdoors as well as the level of physical activity they engage in while outdoors.

Not listed in Table I.2 but also included in the ozone benefits analysis is an additional health category related to toxic air pollutant emission reductions. This category is not listed in Table I.2 because a different methodology is used to estimate the benefits associated with this category. The Benefits TSD provides more information on this methodology (U.S. EPA, 1997a). As explained earlier, reductions in ozone concentrations are achieved by reducing emissions of VOC and NOx. Many of the components of VOC are listed as hazardous air pollutants (HAP) under section 112 of the Clean Air Act (CAA). HAPs, also known as “air toxics,” are associated with a variety of adverse human health effects such as cancer, reproductive and developmental effects, and neurological disorders, as well as adverse ecological effects. This analysis estimates the benefits of reduced exposure to carcinogens potentially resulting from implementation of a revised ozone NAAQS. The analysis focuses on three particular HAP’s expected to account for almost all cancer benefits from reductions of VOC HAP emissions: benzene, 1,3-butadiene, and formaldehyde. Non-cancer human health benefits and ecological benefits resulting from reduced emissions of air toxics are not quantified due to lack of available methods and data.

Other than the air toxics analysis described above, the majority of the models used in both the PM and ozone benefits analysis are epidemiological models. For most concentration-response functions, baseline incidences of health effects are needed for evaluation of the functions. For example, in the case of mortality, county-specific mortality rates were obtained for each county in the United States from the National Center for Health Statistics. Because those studies that estimated concentration-response functions for short-term exposure mortality considered only non-accidental mortality, county-specific baseline mortality rates used in the estimation of PM-related short-term exposure mortality are adjusted to reflect a better estimate of county-specific non-accidental mortality. Each county-specific mortality rate is multiplied by the ratio of national non-accidental mortality to national total mortality. County-specific baseline mortality rates are left unadjusted when applied to long-term exposure mortality functions because the study estimating a concentration-response function for long-term exposure mortality included all mortality cases.

Baseline incidence rates used for the year 2010 baseline are projected using current baseline incidence rates. The extent to which these current rates correspond to projected incidence rates in the year 2010, given either 2010 baseline or post-control PM and/or ozone concentrations, is not known.

This RIA assesses benefits estimates for the year 2010. As explained above, much of the benefits projections are calculated on a county-specific basis. Therefore, county-level population projections must be estimated for the year 2010. This analysis relies on population projections reported by the U.S. Census for the year 2010. However, these projections are available at the State level only. To estimate county-specific 2010 populations, the benefits model distributes the State-level projections to census block groups using the proportion of the 1990 State population accounted for by each block group. Thus, the geographic distribution of each State's population is retained. The population of the continental United States in the year 2010 is projected to be approximately 295.5 million.

12.7.3 Economic Valuation

12.7.3.1 Introduction

The social benefits associated with a change in the environment is the sum of each individual's willingness to pay for (or to avoid) the change. This analysis employs three techniques to value the social benefits resulting from reduced mortality and morbidity due to an environmental change.

One approach is called the "cost of illness" (COI) approach. This approach estimates the value of health improvements as the sum of the direct and indirect costs of illness: the health expenditures made and the loss of labor productivity. An advantage of the cost of illness approach is that economists can rely on observed human behavior. In addition, data are not difficult to collect. This method is commonly accepted by many researchers in the health care industry because it provides estimates for the value of a wide range of health effects. However, the COI approach does not provide a conceptually correct measure of willingness-to-pay (WTP) because it does not account for many factors associated with experiencing or avoiding an adverse health symptom (e.g., the value of discomfort an individual feels when experiencing an adverse health symptom). This analysis uses the COI approach to derive one component of the total value used to monetize the hospital admissions category but enhances that value by attempting to account for other components associated with illness, such as the value of avoiding pain caused by the illness.

The second approach involves conducting a survey and directly asking people what they would be willing to pay for a good, hypothetically assuming (contingent upon) the existence of a market for the good. This method, referred to as contingent valuation (CV), has been applied to a variety of non-market goods, including adverse health symptoms. CV is based on sophisticated survey techniques that may be able to yield valid and reliable WTP values. CV surveys also may address the issues of existence and bequest values because survey responses may include the moral satisfaction of contributing to public goods and charity. Although CV has been increasingly accepted in recent years, its application is controversial. Potential biases in willingness to pay estimates include hypothetical bias, strategic bias, starting point bias, vehicle bias, and information bias.

Finally, the value of a statistical life saved is based on a set of 26 studies, most of which are wage-risk studies. These studies attempt to estimate what workers are willing to pay to reduce their risks of premature mortality by statistical examinations of the wage premiums that are paid for higher risk jobs. The value of a statistical life year extended is based on the results of several studies that attempt to adjust the value of statistical lives saved by the life expectancy of individuals in the studies.

Each of the three methods discussed above is a method to estimate mean willingness to pay for a risk reduction or an adverse health effect avoided. WTP is the maximum amount of money an individual would pay such that the individual would be indifferent between having the good or service and having kept the money.

For both market and non-market goods, WTP values reflect individuals' preferences. Because preferences are likely to vary from one individual to another, WTP values for both market and non-market goods such as improvements in environmental quality are likely to vary from one individual to another. In contrast to market goods, however, non-market goods are public goods whose benefits are shared by many individuals. The individuals who “consume” the environmental quality improvement may have different WTP values for this non-market good. The total social value of the good is the sum of the WTP values of all individuals who consume the good.

If different subgroups of the population have substantially different WTP values for a unit risk reduction and substantially different numbers of units of risk reduction conferred upon them, then estimating the total social benefits by multiplying the population mean WTP value for a unit risk reduction by the predicted number of units of risk reduction could yield a biased result. For example, in the case of PM-induced premature mortality, there is evidence that most of those individuals receiving the benefits of a reduction in the probability of dying in the current year as a result of a reduction in ambient PM concentrations are the elderly. If WTP values for mortality risk improvement among the elderly are substantially different from WTP values for mortality risk improvement among younger individuals, then using the population mean WTP will give a biased result. This issue is addressed in this assessment of PM through the use of a statistical life-year extended approach in the low-end estimate. Unlike PM, there is not enough evidence at this time to assert that ozone mortality is age-dependent.

While the estimation of WTP values for a market good is not a simple matter, the estimation of a WTP value for a non-market good, such as a decrease in the risk of having a particular health problem, is substantially more difficult. Estimation of WTP values for decreases in specific health risks (e.g., WTP to avoid 1 day of coughing or WTP to avoid admission to the hospital for respiratory illness) is further limited by a paucity of information. Appendix I provides a brief description of the derivation of some of the more prominent WTP estimates used in this analysis. A more detailed description of the methodology is provided in the Benefits TSD (U.S. EPA, 1997a).

If exposure to pollution has any cumulative or lagged effects, then a given reduction in pollution concentrations in one year may confer benefits not only in that year, but in future years as well. Because this benefits analysis pertains to a single year only, any benefits achieved in other years are not included in this analysis. On the other hand, benefits even for a single year may not be fully realized until long after the year in which the exposure occurs. In this case it would be appropriate to discount such benefits. Because there is currently inadequate data to determine the lag with which various health benefits are realized, benefits are assumed to occur fully in the same year as exposure.

12.7.3.2 Valuation Estimates

Table 12.3 presents the WTP values available to monetize the reduced adverse health effects presented earlier in this chapter. Each value presented in Table 12.3 represents the point estimate of the monetary value associated with avoiding a unit of a given adverse health effect and is known as a unit dollar value. Although the WTP estimates presented in Table 12.3 are represented as point estimates, this analysis addresses the uncertainty associated with each of the unit dollar values. To further capture the plausible range of monetized values for premature mortality, the low-end estimate values these benefits using a life year extended rather than a lives saved approach. See Appendix I for more information on a sensitivity analysis of uncertainty.

The monetary values used in this analysis are generally consistent with monetary values reported in the Section 812(a) draft report, with the exception of the hospital admissions categories (U.S. EPA, 1997b). The section 812(a) analysis uses the COI approach to derive an economic value for the hospital admissions categories. However, since COI estimates do not measure values associated with pain and suffering (as well as other potential reductions in well-being) resulting from illness, they may significantly understate the true WTP value to avoid illness. For this reason, an adjustment factor is employed to scale the hospital admissions COI estimate upward to reflect a WTP estimate. Following the strategy employed by Chestnut, the hospital admissions COI estimate as reported in the section 812(a) draft report is multiplied by a factor of two. This factor is based on results from three studies providing evidence on COI/WTP ratios for the same study population addressing the same change in an air pollution-related effect. While this adjustment approach is based on limited evidence, the resulting hospital admissions valuation estimate is not clearly biased.

12.7.4 Health Benefits Aggregation Issues

Aggregation refers to the adding together of the monetized benefits associated with different health or welfare endpoints to derive a total monetized benefits attributable to a change in air quality. The dollar benefits from ozone reductions resulting from a specified air quality change is simply the sum of dollar benefits from the reductions in incidence of all non-overlapping health and welfare endpoints with which PM and/or ozone are associated.

Ideally, the effects of air pollution could be divided into mutually exclusive categories that, combined, account for all the effects. Even if health endpoint categories are overlapping, they are mutually exclusive, and can therefore be aggregated, if the populations for which their concentration-response functions are estimated are mutually exclusive. For example, respiratory illnesses among children and respiratory illnesses among adults are mutually exclusive categories. If two endpoints are overlapping, then adding the benefits associated with each endpoint results in double-counting some benefits. Although study-specific point estimates of dollar benefits

Table 12.3 Willingness-to-Pay Estimates (Mean Values)

Health Endpoint	Mean WTP Value per Incident (1990 $)
Mortality Life saved Life year extended	 $4.8 million $120,000
Hospital Admissions: All Respiratory Illnesses, all ages Pneumonia, age ≥ 65 COPD, age ≥ 65 Ischemic Heart Disease, age ≥ 65 Congestive Heart Failure, age ≥ 65 Emergency Visits for Asthma	 $12,700 $13,400 $15,900 $ 20,600 $ 16,600 $9,000
Chronic Bronchitis	$260,000
Upper Respiratory Symptoms	$19
Lower Respiratory Symptoms	$12
Acute Bronchitis	$45
Acute Respiratory Symptoms (any of 19)	$18
Asthma	$32
Shortness of Breath	$5.30
Sinusitis and Hay Fever	not monetized
Work Loss Days	$83
Restricted Activity Days (RAD) Minor RAD Respiratory RAD	 $38 not monetized
Worker Productivity	$1 per worker per 10% change in ozone
Visibility: residential recreational	$14 per unit decrease in deciview per household Range of $7.30 to $11 per unit decrease in deciview per household (see U.S. EPA, 1997a)
Household Soiling Damage	$2.50 per household per μg/m^3

*See the Benefits TSD for citations (U.S. EPA, 1997a).

associated with specific, possibly overlapping endpoints are reported separately in the technical supporting documentation to this RIA, the total benefits estimates presented in this chapter requires that only benefits from non-overlapping endpoints be included in the total calculation.

Appendix I provides a summarized description of the aggregation procedure used in this RIA. In general, four non-overlapping broad categories of health and welfare endpoints are included in the estimation of total dollar benefits in this analysis: (1) mortality, (2) hospital admissions, (3) respiratory symptoms/illnesses not requiring hospital admissions, and (4) welfare endpoints.

12.7.5 National Health Benefits Results

National health benefits estimates for PM and ozone are presented in Tables 12.4 through 12.10. Tables 12.4 and 12.5 present incidence and monetized results, respectively, for alternative
$PM_{2.5}$ standards. Tables 12.6 and 12.7 present benefits results for the selected PM_{10} standard. Tables 12.8 and 12.9 present incidence and monetized results, respectively, for alternative ozone standards. These results represent partial attainment of each alternative. PM benefits estimates are presented incremental from partial attainment of the current ozone and PM NAAQS. Ozone benefits estimates are presented incremental from partial attainment of the current ozone NAAQS, for the high-end estimate, and incremental from partial attainment of the current ozone and new PM NAAQS for the low-end estimate. Benefits estimates associated with the current standards are presented in Appendix C.

All health effects models are evaluated using baseline 2010 air quality and post-control or post-rollback air quality. Results produced by the benefits model represent the reduction in the number of incidences given imposition of a particular PM or ozone NAAQS upon the 2010 air quality baseline. These results are then monetized using WTP estimates.

Table 12.4 PM: National Annual Health Incidence Reductions[a]
Estimates are incremental to the current ozone and PM NAAQS: (year = 2010)

ENDPOINT[b]		Partial Attainment Scenario		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ (μg/m^3)	**16**	**15**	**15**
	Daily $PM_{2.5}$ (μg/m^3)	**65**	**65**	**50**
***1. Mortality[c]: short-term exposure**		4,900	3,300 - 15,600	5,700
long-term exposure		14,000		15,900
***2. Chronic Bronchitis**		56,000	45,000 - 75,000	80,000
Hospital Admissions:				
*3. all respiratory (all ages)		5,100	3,600 - 5,700	6,000
all resp. (ages 65+)		6,400	4,800 - 8,000	8,600
pneumonia (ages 65+)		2,300	1,800 - 2,900	3,100
COPD (ages 65+)		2,000	1,200 - 2,400	2,600
*4. congestive heart failure		1,700	1,200 - 2,100	2,300
*5. ischemic heart disease		1,900	1,200 - 2,400	2,600
***6. Acute Bronchitis**		17,700	12,000 - 20,000	21,000
***7. Lower Respiratory Symptoms**		265,000	179,000 - 299,000	320,000
***8. Upper Respiratory Symptoms**		45,000	36,000 - 60,000	65,000
shortness of breath		93,000	80,000 - 134,000	137,000
asthma attacks		349,000	235,000 - 392,000	416,000
***9. Work Loss Days**		2,799,000	1,900,000 - 3,148,000	3,313,000
***10. Minor Restricted Activity Days (MRADs)**		23,244,000	15,697,000 - 26,128,000	27,499,000

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.5 PM : National Annual Monetized Health Benefits[a]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.) and PM NAAQS (50 μg/m³ annual; 150 μg/m³ daily)
(billions of 1990 $; year = 2010)

		Partial Attainment Scenario High-endEst.		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**16**	**15**	**15**
ENDPOINT[b]	**Daily $PM_{2.5}$ ($\mu g/m^3$)**	**65**	**65**	**50**
***Mortality[c]: short-term exposure long-term exposure**		$23.4 $67.0	$1.8 - $75.1	$27.5 $76.3
***Chronic Bronchitis**		$14.6	$11.7 - $19.4	$20.9
Hospital Admissions: *all respiratory (all ages) all resp. (ages 65+) pneumonia (ages 65+) COPD (ages 65+) *congestive heart failure *ischemic heart disease		 $0.064 $0.080 $0.036 $0.031 $0.028 $0.039	 $0.042 - $0.072 $0.060 - $0.100 $0.030 - $0.046 $0.024 - $0.038 $0.030 - $0.035 $0.030 - $0.049	 $0.076 $0.108 $0.049 $0.041 $0.038 $0.053
***Acute Bronchitis**		$0.001	$0.001 - $0.001	$0.001
***Lower Respiratory Symptoms** ***Upper Respiratory Symptoms** shortness of breath asthma attacks		$0.003 $0.001 $0.000 $0.011	$0.002 - $0.004 $0.001 - $0.001 $0.000 - $0.001 $0.008 - $0.013	$0.004 $0.001 $0.001 $0.015
***Work Loss Days**		$0.232	$0.156- $0.261	$0.275
***Minor Restricted Activity Days (MRADs)**		$0.892	$0.600 - $1.000	$1.100
TOTAL MONETIZED BENEFITS using short-term PM mortality using long-term PM mortality		 $39 $83	 $14.5 - $96.1	 $50 $99

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.6 Proposed PM_{10} Standard (50/150 $\mu g/m^3$) 99th Percentile National Annual Health Incidence Reductions[a]

Estimates are incremental to the current ozone and PM NAAQS: (year = 2010)

ENDPOINT[b]		Partial Attainment Scenario
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**50**
	Daily $PM_{2.5}$ ($\mu g/m^3$)	**150**
***1. Mortality[c]: short-term exposure**		360
long-term exposure		340
***2. Chronic Bronchitis**		6,800
Hospital Admissions:		
*3. all respiratory (all ages)		190
all resp. (ages 65+)		470
pneumonia (ages 65+)		170
COPD (ages 65+)		140
*4. congestive heart failure		130
*5. ischemic heart disease		140
***6. Acute Bronchitis**		1,100
***7. Lower Respiratory Symptoms**		10,400
***8. Upper Respiratory Symptoms**		5,300
shortness of breath		18,300
asthma attacks		8,800
***9. Work Loss Days**		106,000
***10. Minor Restricted Activity Days (MRADs)**		879,000

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.7 Proposed PM_{10} Standard (50/150 $\mu g/m^3$) 99th Percentile National Annual Monetized Health Benefits Incidence Reductions[a]

Estimates are incremental to the current ozone (0.12 ppm, 1-hr.)
(billions of 1990 $;year = 2010)

ENDPOINT[b]		**Partial Attainment Scenario High-end Est.**
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**50**
	Daily $PM_{2.5}$ ($\mu g/m^3$)	**150**
***1. Mortality[c]: short-term exposure**		$1.7
long-term exposure		$1.6
***2. Chronic Bronchitis**		$1.8
Hospital Admissions:		
*3. all respiratory (all ages)		$0.002
all resp. (ages 65+)		$0.006
pneumonia (ages 65+)		$0.003
COPD (ages 65+)		$0.002
*4. congestive heart failure		$0.002
*5. ischemic heart disease		$0.003
***6. Acute Bronchitis**		$0
***7. Lower Respiratory Symptoms**		$0
***8. Upper Respiratory Symptoms**		$0
shortness of breath		$0
asthma attacks		$0
***9. Work Loss Days**		$0.009
***10. Minor Restricted Activity Days (MRADs)**		$0.034
TOTAL MONETIZED BENEFITS		
using long term mortality		$3.4
using short term mortality		$3.5

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.8 Ozone : National Annual Health Incidence Reductions[a]

Estimates are incremental to the current ozone NAAQS
(year = 2010)

ENDPOINT[b]	Partial Attainment Scenario		
	0.08 5th Max High-end Est.	**0.08 4th Max Low- to High-end Est.**	**0.08 3rd Max High-endEst.**
Ozone Health:			
***1. Mortality**	80	0 - 80	120
Hospital Admissions			
*2. all respiratory (all ages)	280	300 - 300	420
all respiratory (ages 65+)	2,300	2,330 - 2,330	1,570
pneumonia (ages 65+)	860	870 - 870	600
COPD (ages 65+)	260	260 - 260	200
emer. dept. visits for asthma	120	130 - 130	180
***3. Acute Respiratory Symptoms** (any of 19)	28,510	29,840 - 29,840	42,070
asthma attacks	60	60 - 60	90
MRADs	620	650 - 650	920
***4. Mortality from air toxics**	1	1 - 1	2
Ancillary PM Health:			
***1. Mortality[c]: short-term exp.**	60	0 - 80	110
long-term exposure	180	0 - 250	340
***2. Chronic Bronchitis**	400	0 - 530	690
Hospital Admissions:			
*3. all respiratory (all ages)	70	0 - 90	120
all resp. (ages 65+)	50	0 - 60	80
pneumonia (ages 65+)	20	0 - 20	30
COPD (ages 65+)	10	0 - 20	20
*4. congestive heart failure	10	0 - 20	20
*5. ischemic heart disease	10	0 - 20	20
***6. Acute Bronchitis**	290	0 - 400	530
***7. Lower Respiratory Symptoms**	3,510	0 - 4,670	6,190
***8. Upper Respiratory Symptoms**	320	0 - 430	570
shortness of breath	800	0 - 1,220	1,660
asthma attacks	4,210	0 - 5,510	7,200
***9. Work Loss Days**	38,700	0 - 50,440	66,160
***10. Minor Restricted Activity Days (MRADs)**	322,460	0 - 420,300	551,300

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] PM mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.9 Ozone : National Annual Monetized Health Benefits Estimates[a]
Estimates are incremental to the current ozone NAAQS (0.12 ppm, 1-hour)
(billions of 1990 $; year = 2010)

ENDPOINT[b]	Partial Attainment Scenario		
	0.08 5th Max High-end Est.	**0.08 4th Max Low- to High-end Est.**	**0.08 3rd Max High-end Est.**
Ozone Health:			
***1. Mortality**	$0.370	$0.000 - $0.380	$0.570
Hospital Admissions			
*2. all respiratory (all ages)	$0.004	$0.004 - $0.004	$0.006
all resp. (ages 65+)	$0.029	$0.029 - $0.029	$0
pneumonia (ages 65+)	$0.014	$0.014 - $0.014	$0.010
COPD (ages 65+)	$0.004	$0.004 - $0.004	$0.003
emer. dept. visits for asthma	$0.001	$0.001 - $0.001	$0.002
***3. Acute Respiratory Symptoms** (any of 19)	$0.001	$0.001 - $0.001	$0.001
asthma attacks	$0	$0 - $0	$0
MRADs	$0	$0 - $0	$0
***4. Mortality from air toxics**	$0.003	$0.006- $0.006	$0.011
Ancillary PM Health:			
***1. Mortality[c]: short-term exp.**	$0.300	$0 - $0.400	$0.520
long-term exposure	$0.870	$0 - $1.210	$1.640
***2. Chronic Bronchitis**	$0.110	$0 - $0.140	$0.180
Hospital Admissions:			
*3. all respiratory (all ages)	$0.001	$0 - $0.001	$0.001
all resp. (ages 65+)	$0.001	$0 - $0.001	$0.001
pneumonia (ages 65+)	$0	$0 - $0	$0
COPD (ages 65+)	$0	$0 - $0	$0
*4. congestive heart failure	$0	$0 - $0	$0
*5. ischemic heart disease	$0	$0 - $0	$0
***6. Acute Bronchitis**	$0	$0 - $0	$0
***7. Lower Respiratory Symptoms**	$0	$0 - $0	$0
***8. Upper Respiratory Symptoms**	$0	$0 - $0	$0
shortness of breath	$0	$0 - $0	$0
asthma attacks	$0	$0 - $0	$0
***9. Work Loss Days**	$0.003	$0 - $0.004	$0.005
***10. Minor Restricted Activity Days (MRADs)**	$0.012	$0 - $0.016	$0.020
TOTAL MONETIZED BENEFITS			
using short-term PM mortality	$0.790	$0.056	$1.300
using long-term PM mortality	$1.400	$1.785	$2.400

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with an * are aggregated into total benefits estimates

[c] PM mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Table 12.10 RH : National Annual Monetized Health Benefits[a]
Estimates are incremental to the selected PM and ozone standards
(billions of 1990 $; year = 2010)

ENDPOINT[b]	1.0 deciview improvement in 15 years (0.67 deciview target)		1.0 deciview improvement in 10 years (1.0 deciview target)	
	Incidence Reductions Low- to High-end Est.	**Monetized Benefits Low- to High-end Est.**	**Incidence Reductions Low- High-end Est.**	**Monetized Benefits Low- to High-end Est.**
***Mortality[c]**	120 - 200	$0.060-$0.950	360 - 600	$0.130 - $2.900
***Chronic Bronchitis**	2,600 - 4,400	$660 - $1,100	3,500 - 5,900	$0.900 - $1.500
Hospital Admissions:				
*all respiratory (all ages)	140 - 230	$0.002 - $0.003	250 - 420	$0.003 - $0.005
all resp. (ages 65+)	290 - 490	$0.004 - $0.006	420 - 700	$0.005 - $0.009
pneumonia (ages 65+)	110 - 180	$0.002 - $0.003	150 - 250	$0.002 - $0.004
COPD (ages 65+)	90 -150	$0.001- $0.002	130 - 220	$0.002 - $0.003
*congestive heart failure	80 - 130	$0.001- $0.002	110 - 190	$0.002 - $0.003
*ischemic heart disease	80 - 140	$$0.002 - 0.003	130 - 210	$0.002 - $0.004
***Acute Bronchitis**	310 - 510	$0 - $0	530 - 880	$0 - $0
***Lower Respiratory Symptoms**	7,800 - 13,000	$0.000 - $0.000	14,000 - 23,000	$0.000 - $0.000
***Upper Respiratory Symptoms**	2,400 - 4,000	$0.000 - $0.000	3,100 - 5,200	$0.000 - $0.000
shortness of breath	1,600 - 2,700	$0.000 - $0.000	4,000 - 6,600	$0.000 - $0.000
asthma attacks	11,000 - 17,800	$0.001 - $0.001	20,000 - 33,000	$0.001 - $0.001
***Work Loss Days**	74,000 - 124,000	$0.006 - $0.010	140,000 - 230,000	$0.011 - $0.019
***Minor Restricted Activity Days (MRADs)**	620,000 - 1,032,000	$0.024 - $0.040	1,150,000 - 1,912,400	$0.044 - $0.073
TOTAL MONETIZED BENEFITS	N/A	$0.760 - $2.100	N/A	$1.100 - $4.500

[a] numbers may not completely agree due to rounding

[b] only endpoints denoted with a * are aggregated into total benefits estimates

[c] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

Tables 12.4 and 12.5 present national annual health incidence reductions and the associated monetized benefits associated with partial attainment of the alternative $PM_{2.5}$ standards. Based on these results, partial attainment of the selected $PM_{2.5}$ would result in decreasing premature mortality within the range of 3,300 to 16,000 cases (depending on whether short-term exposure or long-term exposure mortality is included and on whether a threshold at 15 $\mu g/m^3$ or effects down to background are assumed). The selected standard would also be expected to reduce the development of chronic bronchitis by approximately 45,000 to 75,000 cases and hospital admissions for all respiratory illnesses by approximately 3,600 to 6,000 cases. Total annual monetized health benefits estimates associated with the selected standard are expected to be approximately $14.5 billion when the estimate is based on the low-end assumptions and $96 billion when the estimate is based on the high-end assumptions. These estimates are incremental to partial attainment of the current PM and ozone NAAQS. Incremental from the current standard in the year 2010, population estimates associated with people living in predicted $PM_{2.5}$ nonattainment counties are approximately: 23.6 million for the 16/65 standard; 45.5 million for the 15/65 standard; 52.0 million for the 15/50 standard.

Tables 12.6 and 12.7 present benefits results associated with the selected PM_{10} standard. Based on these results, partial attainment of the selected PM_{10} standard is expected to decrease premature mortality by approximately 350 cases, hospital admissions for all respiratory illness by approximately 200 cases and chronic bronchitis cases by approximately 7,000 cases. Total annual monetized health estimates associated with the selected standard are expected to be approximately $3.4 billion to $3.5 billion.

Tables 12.8 and 12.9 present national annual health incidence reductions and the associated monetized benefits associated with partial attainment of the alternative ozone standards. Note that ozone benefits include ancillary PM benefits for the high end estimate. Based on these results, partial attainment of the selected ozone standard is expected to decrease premature mortality by approximately 160-330 cases, hospital admissions due to all respiratory illnesses by approximately 300, and acute respiratory symptoms by approximately 30,000 cases. Total annual monetized benefits associated with the selected standard are expected to be approximately $0.1 billion for the low-end estimate and $2.1 billion for the high-end estimate.

Incremental from the current standard in the year 2010, population estimates associated with people living in predicted ozone nonattainment areas are approximately: 30.6 million people for the 0.08 5th max., 40.2 million people for the 0.08 4th max., and 62.2 million people for the 0.08 3rd max. standard.

Table 12.10 presents national annual health incidence reductions and monetized benefits estimates associated with the RH targets. Health benefits can be estimated for a RH target because the control strategies (described in chapter 8) implemented to reduce RH also reduce particulate concentrations. This commonality between the control strategies for the two different programs allows the benefits analysis to estimate health as well as visibility benefits attributable to the RH target. The RH benefits estimates are calculated incremental from partial attainment of both the selected PM and selected ozone standards. The method for estimating visibility changes is presented in chapter 8. As explained in chapter 8, the analytical baseline understates the visibility progress achieved by CAA-mandated controls and implementation of a new ozone standard over the period 2000 to 2010. Additionally, the RH benefits are affected by the inability to model full attainment of the selected $PM_{2.5}$ standard as well as the degree to which some Class I area counties reach background air quality conditions. Given this analytical baseline, benefits are calculated using air quality changes incremental from partial attainment of the selected $PM_{2.5}$ standard. Under a visibility target of 0.67 equivalent to a 1 deciview improvement in the haziest days over 15 years, premature mortality is expected to decrease by approximately 120 - 200 cases; the development of chronic bronchitis cases is expected to be reduced by 2,600 - 4,400 cases; and hospital admissions for all respiratory illnesses is expected to decrease by 140 - 230 cases. Total annual monetized health benefits estimates associated with the 0.67 visibility target is expected to be as much as $0.8 to $2.1 billion. Under a visibility target of 1.0 equivalent to a 1 deciview improvement in the haziest days over 10 years, premature mortality is expected to decrease by approximately 360 - 600 cases; the development of chronic bronchitis cases is expected to be reduced by 3,500 - 5,900 cases; and hospital admissions for all respiratory illnesses is expected to decrease by 250 - 420 cases. Total annual monetized health benefits estimates associated with the 1.0 deciview visibility target is estimated to be as much as $1.1 - $4.5 billion.

The monetized health benefits estimates presented in this section are likely to be underestimates of the total health benefits associated with these standards due to a number of data and modeling limitations. See section 12.10 for a discussion of these limitations.

12.8 WELFARE EFFECTS

12.8.1 Introduction

The term "welfare benefits" encompasses all benefits categories other than human health effects. This section presents the welfare benefits methodology and results associated with reductions in ambient PM and ozone. These results include the economic benefits associated with reductions in the yield of some ozone-sensitive important commercial crops and forests and reduction of nitrogen deposition in estuarine and coastal waters for alternative standards. Adequate data are currently available to assess economic benefits for the commodity crops studied in the National Crop Loss Assessment Network (NCLAN) project (discussed in section VII-D.2 of the U.S. EPA Staff Paper for Ozone, June 1996) and for fruits and vegetables grown in California. Data are also available to estimate potential reductions in yield of some important ozone-sensitive commercial forest species nationwide, and to calculate nitrogen deposition avoided in estuaries, visibility improvements, consumer cleaning cost savings, and enhanced worker productivity.

12.8.2 Welfare Benefits Methodology

A number of models are used to estimate the welfare benefits presented in this analysis. This section briefly describes the welfare benefits categories and the methods employed to estimate the economic benefits associated with them.

12.8.2.1 <u>Commodity Crops</u>

The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using a revised and updated (Mathtech, 1994; Mathtech, 1995; U.S. EPA 1997a) Regional Model Farm (RMF) agricultural benefits model. The RMF is an agricultural benefits model for commodity crops that account for about 75 percent of all U.S. sales of agricultural crops (Mathtech, 1994). The results of the model are extrapolated to account for all commodity crops nationwide. A rough approximation of a national estimate can be calculated by proportionally scaling the monetized estimates to the entire market. It is recognized, however, that factors such as the sensitivity to ozone of crops not formally analyzed, regional air quality, and regional economics introduce considerable uncertainty to any approach that develops a national estimate. The RMF explicitly incorporates exposure-response functions into microeconomic models of agricultural producer behavior. The model uses the theory of applied welfare economics to value changes in ambient ozone concentrations brought about by particular policy actions such as attaining ambient air quality standards.

The measure of benefits calculated by the model is the net change in consumers' and producers' surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of alternative standards. Using the baseline and post-control equilibriums, the model calculates the change in net consumers' and producers' surplus on a crop-by-crop basis. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with the policy scenario. Although the model calculates benefits under three alternative welfare measures (perfect competition, price supports, and modified agricultural policy), results presented here are based on the "perfect competition" measure to reflect recent changes in agricultural subsidy programs. Under the recently revised 1996 Farm Act, most eligible farmers have enrolled in the program to phase out government crop price supports for the RMF-relevant crops: wheat, corn, sorghum, and cotton.

For the purpose of this analysis, the six most economically significant crops are analyzed: corn, cotton, peanuts, sorghum, soybean, and winter wheat. The model employs biological exposure-response information derived from controlled experiments conducted by the National

Crop Loss Assessment Network (NCLAN) (Lee et al., 1996). Four main areas of the RMF have been updated to reflect the 1996 Farm Act and USDA data projections to 2005 (the year farthest into the future for which projections are available) These four areas are: yield per acre, acres harvested, production costs, and model farms. Documentation outlining the 2005 update is provided in U.S. EPA, 1997a.

The benefits from the RMF commodity crops range from for partial attainment of the .08 ppm, 4th max. standard are $11 million. See Table 12.15.

12.8.2.2 Fruit and Vegetable Crops

There are currently no national-level economic models that incorporate fruits and vegetables, although more comprehensive modeling efforts are underway. A regional model, the California Agricultural Resources Model (CARM), has been developed and used by the California Air Resources Board. This model is used in this analysis to calculate the benefits of reducing ambient ozone on sensitive crops grown in California (Abt, 1995a). Among these sensitive crops are the economically important fruits and vegetables endemic to California and other states with similar climate, such as Florida and Texas. The crops included in the CARM analysis are: almonds, apricots, avocados, cantaloupes, broccoli, citrus, grapes, plums, tomatoes, and dry beans. In 1990, California crops accounted for almost 50 percent of the U.S. fruit and vegetable production. Results of the model are extrapolated to include 100 percent of the crops. The results of the model are extrapolated to account for fruits and vegetables grown nationwide. A rough approximation of a national estimate can be calculated by proportionally scaling the monetized estimates to the entire market. It is recognized, however, that factors such as the sensitivity to ozone of crops not formally analyzed, regional air quality, and regional economics introduce considerable uncertainty to any approach that develops a national estimate.

The California Air Resources Model (CARM) is a nonlinear optimization model of California agricultural practices which assumes that producers maximize farm profit subject to land, water, and other agronomic constraints. The model maximizes total economic surplus and predicts producers' shifts in acreage planted to different crops due to changing market conditions or resources. The version of the CARM used for this analysis is calibrated to 1990 production and price data. Similar to RMF, the CARM production and price data will be updated using USDA projections to 2005 (Abt, 1997). Although this update is not completed yet, the CARM results have been extrapolated to reflect estimates for the year 2005.

The benefits from the CARM fruits and vegetables for partial attainment of the .08 ppm, 4th max. standard are $23 million. See Table 12.15.

12.8.2.3 Commercial Forests

Any attempt to estimate economic benefits for commercial forests associated with attaining alternative ozone standards is constrained by a lack of exposure-response functions for the commercially important mature trees. Although exposure-response functions have been developed for seedlings for a number of important tree species, these seedling functions cannot be extrapolated to mature trees based on current knowledge. Recognizing this limitation, a study (Pye, 1988 and deSteiger & Pye, 1990) involving expert judgment about the effect of ozone levels on percent growth change is used to develop estimates of ozone-related economic losses for commercial forest products.

An analysis by Mathtech in conjunction with the USDA Forest Service (Mathtech, 1997) of forestry sector benefits describes quantitatively the effect of ozone on tree growth and the demand and supply characteristics of the timber market. The analysis employs baseline and post control ozone data equivalent to, and consistent with, the data used for the RMF and CARM models. The estimates do not include possible non-market benefits such as aesthetic effects. Forest aesthetics is discussed qualitatively later in this chapter.

The economic value of yield changes for commercial forests was estimated using the 1993 timber assessment market model (TAMM). TAMM is a U.S. Forest Service (Adams and Haynes, 1996) spatial model of the solidwood and timber inventory elements of the U.S. forest products sector. The model provides projections of timber markets by geographic region and wood type through the year 2040. Nine regions covering the continental U.S. are included in the analysis. While the Pye *et al*. and deSteiger, Pye *et al.* studies present estimates of O_3 damage to forest growth rates for a variety of wood types by region, they present no damage estimates for western hardwoods. As a result, the forestry sector benefit estimates exclude the potential benefits of improved growth rates for western hardwoods. However, hardwoods account for only about 11 percent of total western growing stocks. TAMM simulates the effects of reduced O_3 concentrations on timber markets by changing the annual growth rates of commercial forest growing-stock inventories. The model uses applied welfare economics to value changes in ambient O_3 concentrations. Specifically, TAMM calculates benefits as the net change in consumer and producer surplus from baseline O_3 concentrations to the O_3 concentrations resulting from full or partial attainment of alternative standards.

Table 12.11 presents estimates of the annual benefits to the commercial forestry sector for two ozone scenarios incremental to the current ozone standard: the 0.08 ppm, 3rd max partial attainment and full attainment. These benefits are estimates of the annual payments that society would be willing to pay over the period 2010 through 2040 for higher growth rates in commercial forests.

Because of the long harvesting cycle of commercial forests and the cumulative effects of higher growth rates, the benefits to the future economy will be much larger than the estimates reported in Table 12.11. For example, the .08 ppm 3rd max standard under the full attainment scenario would generate about $370 million in undiscounted economic surplus to the U.S. economy during the year 2040 and result in about $3.69 billion additional forest inventories by 2040. The estimated annualized benefits for this scenario, $65 million, are much lower because of smaller benefits in earlier years (i.e., the 2010 and 2020 decades) and because the higher benefits realized in later years are heavily discounted. Also, the estimates presented in Table 12.11 are slightly conservative based on the interpretation of the Pye 1988 report versus the deSteiger and Pye 1990 article. Another reason for describing the estimates as conservative is the uncertainty that exists about the relationship between carbon assimilation and how assimilated products affect overall tree growth. A complicating factor is the tree aging process, since “the relative amount of photosynthetic to non-photosynthetic tissue changes with age” (Fox, 1995).

Table 12.11 Ozone: Estimated Annual Commercial Forestry Benefits[a] Incremental to the Current Ozone Standard
(millions of 1990 dollars in 2010)

Scenario	Annual Benefits
8-hr, 3rd max, partial attainment	$14
8-hr, 3rd max, full attainment	$65

12.8.2.4 Nitrogen Deposition in Estuarine and Coastal Waters

The December 1996 RIA did not estimate the benefits of reducing the amount of air-borne nitrogen which is entering our nation's estuaries. Excessive amounts of nitrogen entering our estuaries are linked with the outbreak of large algal blooms. The resulting large fish kills cause a decaying, odoriferous situation which can shut down local tourism. Partially in response to public comments which asked for some proof of the assumed size of these unquantified benefit categories, scientists from EPA and NOAA have developed a methodology to measure the potential benefits from the reduction of atmospheric nitrogen in the estuaries of the East Coast of the United States accrued from implementation of the PM and ozone NAAQS (US EPA, 1997c).

The benefits to surrounding communities of reduced nitrogen loadings resulting from various control strategies for atmospheric NOx emissions were calculated for 12 East and Gulf Coast estuaries, and extrapolated to all 43 Eastern U.S. estuaries. See Table 12.12. The 12 Eastern estuaries represent approximately half of the estuarine watershed area in square miles along the East coast. Benefits are estimated using an average, locally-based cost for nitrogen removal from water pollution (US EPA, 1997c). The benefits to the 12 estuaries are estimated at $112 million for partial attainment of the .08 ppm, 4th max. standard. The benefits for the Eastern U.S. are estimated at $193 million for partial attainment of the .08 ppm, 4th max standard. Total Eastern U.S. projections are made by scaling results based on watershed area

[a] annualized benefits computed over the period 2010 through 2040, discounted at a 7 percent annual rate

and NOAA surveys of nitrogen loadings. These benefits are probably below the actual benefits because they do not include: improved recreation, wildlife habitat, commercial fishing, and other public health benefits.

12.8.2.5 Visibility

Visibility effects are measured in terms of changes in deciview, a measure useful for comparing the effects of air quality on visibility across a range of geographic locations. This measure is directly related to two other common visibility measures: visual range (measured in km) and light extinction (measured in km^{-1}). The deciview measure characterizes visibility in terms of perceptible changes in haziness independent of baseline conditions. The visibility improvement is modeled on a county-specific basis. Based on the deciview measure, two types of valuation estimates are applied to the expected visibility changes: residential visibility and recreational visibility.

Table 12.12: Benefits To Estuaries From Reduced Nitrogen Deposition Due To Alternative PM2.5 and 8Hr Ozone NAAQS*

ESTUARY	PM2.5 15/50		0.08 / 4th max		0.08 / 5th max	
	Reductions in Air N Load	**Value ($ million)**	**Reductions in Air N Load** (thous. kg/yr)	**Value** ($ million)	**Reductions in Air N Load** (thous. kg/yr)	**Value** ($ million)
Albemarle/ Pamlico Sound	240	18	120	9	80	6
Cape Cod Bay	100	14	40	6	40	6
Chesapeake Bay	1,220	60	480	23	390	19
Delaware Bay	190	26	120	17	110	15
Delaware Inland Bays	10	1	0	0	0	0
Gardiners Bay	0	0	0	0	0	0
Hudson River/ Raritan Bay	180	25	140	19	120	17
Long Island Sound	180	42	130	30	110	26
Massachusetts Bay	80	11	40	6	40	6
Narragansett Bay	10	1	10	1	0	0
Sarasota Bay	10	1	0	0	0	0
Tampa Bay	0	0	10	2	10	2
TOTAL for the above 12	2,220	200	1,009	112	900	96
TOTAL for Eastern US	3,820	344	1,880	193	1,548	165

* Reductions and valuation incremental to current ozone and PM NAAQS and target the year 2010; ranges reflect partial attainment of alternative standards. Benefits valued at the average cost today of removing nitrogen from point- and non-point- water pollution controls. Numbers may not add up exactly due to rounding. Total Eastern US projections made by scaling results for the listed estuaries based on watershed area and NOAA surveys of nitrogen loadings.

The residential visibility valuation estimate is derived from the results of an extensive visibility study (McClelland et al., 1991). A household WTP value is derived by dividing the value reported in McClelland et al. by the corresponding hypothesized change in deciview, yielding an estimate of $14 per unit change in deciview. This WTP value is applied to all households in any county estimated to experience a change in visibility.

Recreational visibility refers to visibility conditions in national parks (referred to as Class I areas). Chestnut (Chestnut, 1997a) has developed a methodology for estimating the value to the U.S. public of visibility improvements in Class I areas. Based on contingent valuation studies, Chestnut calculates a household WTP for visibility improvements, capturing both use and non-use recreational values, and attempts to account for geographic variations in WTP.

Chestnut divides the recreational areas of the U.S. into three regions: California, Southwest, and Southeast. The regions are developed to capture differences in household WTP values based on proximity to recreational areas. That is, in-region respondents typically place higher value on visibility improvements at a local recreational area than out-of-region respondents. Chestnut reports both in-region WTP and out-of-region WTP for each of the three regions. Chestnut concludes that, for a given region, a substantial proportion of the WTP is attributable to one specific park within the region. This so called "indicator park" is the most well-known and frequently visited park within a particular region. The indicator parks for the three regions are Yosemite for California, the Grand Canyon for the Southwest, and Shenandoah for the Southeast. In accordance with the Chestnut methodology, this analysis calculates out-of-region and in-region benefits for a particular regions for a given change in Class I areas visibility.

In theory, summing benefits out-of-region and benefits in-region would yield the total monetary benefits associated with a given visibility improvement in a particular recreational region, which could then be summed across regions to estimate national benefits. However, as described earlier, this analysis also estimates benefits associated with residential visibility improvements. To reflect the uncertainties raised by the use of CV methodology, the low-end estimate does not included visibility improvements in non-indicator parks.

12.8.2.6 Consumer Cleaning Cost Savings

Welfare benefits also accrue from avoided air pollution damage, both aesthetic and structural, to architectural materials and to culturally important articles. At this time, data limitations preclude the ability to quantify benefits for all materials whose deterioration may be promoted and accelerated by air pollution exposure. However, this analysis addresses one small effect in this category, the soiling of households by particulate matter. Table I.1 documents the function used to associate nationwide PM levels with household WTP to avoid the cleaning costs incurred for each additional $\mu g/m^3$ of PM.

Assumptions regarding the air quality indicator are necessary to evaluate the concentration-response function. For each alternative scenario, the function for household soiling damage, originally derived using total suspended particulates (TSP) as an indicator of PM, is evaluated using the indicator under consideration for that scenario. PM_{10} and $PM_{2.5}$ are both components of TSP. However, it is not clear which components of TSP cause household soiling damage. The Criteria Document cites some evidence that smaller particles may be primarily responsible, in which case these estimates are conservative.

12.8.2.7 Worker Productivity

Crocker and Horst (1981) and U.S. EPA present evidence regarding the inverse relationship between ozone exposure and productivity in exposed citrus workers. This analysis applies the worker productivity relationship (reported as income elasticity with respect to ozone) to workers engaged in strenuous outdoor labor in the U.S. (approximately one percent of the population). Baseline income for these workers is reported as $73 per day. Table I.2 in Appendix I details the concentration response function.

12.8.3 National Welfare Benefits Results

Table 12.13 presents the welfare benefits associated with partial attainment of the alternative $PM_{2.5}$ standards. PM welfare benefits categories that are monetized in this analysis include: consumer cleaning cost savings, improved visibility and decreased nitrogen deposition. Based on the results presented in Table 12.13, total welfare benefits associated with the selected $PM_{2.5}$ standard range from $4.3 to $8.1 billion annually. These results are incremental to partial attainment of the current ozone and PM NAAQS.

Table 12.14 presents national annual welfare benefits estimates associated with the selected PM_{10} standard. Total annual monetized welfare benefits are estimated to be approximately $5 billion.

The welfare benefits associated with partial attainment of the alternative ozone standards are presented in Table 12.15. Monetized ozone welfare benefits categories include increased yields of commodity crops and fruits and vegetables, increased yields in commercial forests, decreased nitrogen deposition, improved visibility, consumer cleaning cost savings, and increased worker productivity. Based on the results presented in Table 12.15, total welfare benefits associated with the selected ozone standard are expected to be approximately $320 million annually. These results are incremental to partial attainment of the current ozone NAAQS.

Table 12.13 PM : National Annual Monetized Welfare Benefits[a]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.) and PM NAAQS (50 μg/m^3 annual; 150 μg/m^3 daily)
(billions of 1990 $; year = 2010)

CATEGORY		Partial Attainment Scenario		
		High-end Est.	**Low- to High-End Est.**	**High-end Est.**
	Annual $PM_{2.5}$ (μg/m^3)	**16**	**15**	**15**
	Daily $PM_{2.5}$ (μg/m^3)	**65**	**65**	**50**
Consumer Cleaning Cost Savings		$0.29	$0.37	$0.40
Visibility		$7.30	$3.96 - $7.80	$8.40
Nitrogen Deposition		N/E	N/E	$0.34
TOTAL MONETIZED BENEFITS		$7.54	$4.26 - $8.10	$9.10

N/E = not estimated

Table 12.14 PM : Proposed PM_{10} Standard (50/150 μg/m^3) 99th Percentile National Annual Monetized Welfare Benefits[b]
Estimates are incremental to the current ozone (0.12 ppm, 1-hr.)
(billions of 1990 $; year = 2010)

CATEGORY		Partial Attainment Scenario High-end Estimate
	Annual $PM_{2.5}$ (μg/m^3)	**50**
	Daily $PM_{2.5}$ (μg/m^3)	**150**
Consumer Cleaning Cost Savings		$0.034
Visibility		$1.62
TOTAL MONETIZED BENEFITS		$1.6

[a] numbers may not completely agree due to rounding

[b] numbers may not completely agree due to rounding

Table 12.15 Ozone : National Annual Welfare Benefits Estimates[a]
Estimates are incremental to the current ozone NAAQS (0.12 ppm, 1-hour)
(billions of 1990 $, year = 2010)

CATEGORY	Partial Attainment Scenario		
	0.08 5th max	**0.08 4th max**	**0.08 3rd max**
Commodity Crops	$0.000	$0.011	$0.029
Fruits and Vegetables Crops	$0.015	$0.023	$0.023
Commercial Forests	N/E	N/E	$0.014
Nitrogen Deposition in Estuarine and Coastal Waters	$0.165	$0.193	$0.301
Consumer Cleaning Cost Savings	$0.002	$0.003	$0.004
Visibility	$0.056	$0.082	$0.102
Worker Productivity	$0.009	$0.009	$0.014
TOTAL MONETIZED BENEFITS	$0.250	$0.320	$0.490

N/E = not estimated

[a] numbers may not completely agree due to rounding

Table 12.16 presents national annual welfare benefits associated with the regional haze targets. These estimates are calculated incremental from partial attainment of both the PM and ozone selected standards. Monetized welfare benefits associated with reducing RH include consumer cleaning cost savings and improved visibility. The method for estimating visibility changes is presented in chapter 8. The same low-end and high-end assumptions are used in the visibility calculations as are used in the ozone and PM NAAQS benefits analyses. As explained in chapter 8, the analytical baseline understates the visibility progress achieved by CAA mandated controls and implementation of a new ozone standard over the period 2000 to 2010. Additionally, the baseline visibility target may be understated due to the inability to model full attainment of the selected $PM_{2.5.}$ Given this analytical baseline, benefits are calculated using air quality changes incremental from partial attainment of the selected $PM_{2.5}$ standard. Under a visibility target of 0.67 equivalent to a 1 deciview improvement in the haziest days over 15 years, economic benefits associated with consumer cleaning cost savings is estimated as $23 million; increased residential visibility is estimated to yield approximately $140 million; and increased visibility in Class I areas is estimated to yield approximately $340 - $850 million annually. Based on these results, total annual welfare benefits associated with the 0.67 deciview visibility target range from approximately $0.5 to $1 billion. Under a visibility target of 1.0 equivalent to a 1 deciview improvement in the haziest days over 10 years, economic benefits associated with consumer cleaning cost savings is estimated as $31 million; increased residential visibility is estimated to yield approximately $200 million; and increased visibility in Class I areas is estimated to yield approximately $370 - $920 million annually. Based on these results, total annual welfare benefits associated with the 1.0 deciview visibility target range from approximately $0.6 to $1.2 billion.

Table 12.16 RH : National Annual Monetized Welfare Benefits[a]
Estimates are incremental to the selected ozone and PM NAAQS
(billions of 1990 $; year = 2010)

CATEGORY	1.0 Deciview Improvement Over 15 Year (0.67 Deciview Target)	1.0 Deciview Improvement Over 10 Years (1.0 Deciview Target)
Consumer Cleaning Cost Savings	$0.023	$0.031
Visibility	$0.480 - $0.990	$0.57 - $1.13
TOTAL MONETIZED WELFARE BENEFITS	$0.50 - $1.01	$0.60 - $1.16

12.9 SUMMARY OF HEALTH AND WELFARE BENEFITS

The purpose of this section is to summarize the health and welfare benefits discussions presented earlier in this chapter. Annual monetized benefits have been presented separately for health and welfare effects. It is now possible to sum these health and welfare benefits to provide a more complete depiction of the total benefits expected to result from the various alternative standards examined in this RIA. The national monetized health and welfare benefits associated with PM, ozone and RH are presented in Tables 12.17 through 12.20.

The monetized benefit results presented in this benefits chapter cover a plausible range of estimates, from a high end to a low end, reflecting some of the uncertainties in this estimation. A Monte Carlo uncertainty analysis of the monetized benefits of attaining the $PM_{2.5}$ 15/65 standard, the PM_{10} 50/150 standard (99th percentile), and the ozone .08, 4th max. standard are presented in Benefits TSD (USEPA 1997a).

The reduction of ambient ozone concentrations is achieved through the control of precursor emissions. These precursor emissions consist of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The cost analysis shows that many control measures employed in the ozone analysis are successful at removing both types of precursor emissions. In addition to

[a] numbers may not completely agree due to rounding

contributing to ozone formation, VOC and NOx react with other air-borne pollutants to form particulates. The PM air quality model, consolidated regional deposition model (CRDM), is used to estimate a quantifiable relationship between the ozone precursor emissions and ambient PM concentrations (i.e., the source-receptor relationship). An analysis of the ozone-related VOC and NOx emission reductions shows that particulate concentrations as estimated by the source-receptor matrix will decrease as a result of implementation of the ozone controls. These PM reductions are used to estimate ancillary PM benefits attributable to ozone control measures.
The PM reductions attributable to implementation of the ozone control measures are then used in conjunction with all PM-related concentration-response functions to estimate total ancillary PM benefits. For example, all PM benefits categories listed as quantifiable in Table 12.1 are also applicable in the ozone benefits analysis because reductions of ozone precursor emissions will also reduce particulate concentrations.

The inclusion of ancillary PM benefits in the estimation of ozone benefits raises the issue of possible overlap between PM and ozone benefits estimation when using when using single-pollutant and co-pollutant models. A discussion of a possible overlap between PM and ozone mortality effects is presented here since mortality is the single largest contributor to total benefits for both PM and ozone reductions.

The PM-mortality relationship is currently more well established than the ozone-mortality relationship, and the magnitude of the PM effect on mortality appears to be significantly larger than that of ozone. To avoid falsely attributing the PM effects on mortality to ozone, therefore, inclusion of PM in the model was a criterion for inclusion of a study in the analysis of ozone and mortality. Most ozone-mortality studies met this criterion. It might be argued that the inclusion criteria for PM-mortality studies should mirror those of ozone-mortality studies, and that PM-mortality studies that did not include ozone in the concentration-response model should be excluded. The situation with PM-mortality studies, however, is not symmetrical to that of ozone-mortality studies. Because evidence of a significant association between ozone and premature mortality is quite recent, most PM-mortality studies have not included ozone in the concentration-response model. Excluding PM-mortality studies that did not include ozone would therefore substantially reduce the database on the relationship between

PM and mortality. Because it appears that the magnitude of the ozone effect on mortality is substantially smaller than that of the PM effect, and because PM and ozone are generally not highly correlated, the omission of ozone from a concentration-response model is likely to have only a very small effect on the estimated PM coefficient. Any potential double counting of benefits from adding the PM-related benefits estimated from models without ozone to the ozone-related benefits is therefore also likely to be quite small. Avoiding that small amount of possible double counting does not seem worth the substantial loss of information on the PM-mortality relationship that would result from restricting the analysis to only those studies with both PM and ozone in the model.

As shown in Table 12.17, total annual monetized health and welfare benefits associated with partial attainment of the selected $PM_{2.5}$ standard range from a high-end estimate of $104 billion to a low-end estimate of $19 billion. Table 12.18 shows that the high-end esitmate of total annual monetized health and welfare benefits associated with partial attainment of the selected PM_{10} standard range from $5.1 to $5.2 billion. Table 12.19 shows that total annual monetized health and welfare benefits associated with partial attainment of the selected ozone standard range from a high-end estimate of $2.1 billion to a low-end estimate of $0.4 billion. Table 12.20 presents total annual health and welfare benefits of alternative regional haze targets.

Table 12.17 PM: Summary of National Annual Monetized Health and Welfare Benefits[a]
Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category[b]		**Partial Attainment Scenario**		
		High-end Est.	**Low- to High-end Est.**	**High-end Est.**
	Annual $PM_{2.5}$ ($\mu g/m^3$)	**16**	**15**	**15**
	Daily $PM_{2.5}$ ($\mu g/m^3$)	**65**	**65**	**50**
Health Benefits		$83	$15 to $96	$99
Welfare Benefits		$7.5	$4.3 to $8.1	$9
TOTAL MONETIZED BENEFITS		$90	$19 to $104	$107

Table 12.18 PM: Selected PM_{10} Standard (50/150 $\mu g/m^3$-- 99th percentile) Summary of National Annual Monetized Health and Welfare Benefits[a]
Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category		**Partial Attainment Scenario High-end Est.**
	Annual PM_{10} ($\mu g/m^3$)	**50**
	Daily PM_{10} ($\mu g/m^3$)	**150**
Health Benefits		$3.4 to $3.5
Welfare Benefits		$1.6
TOTAL MONETIZED BENEFITS		$5.1 to $5.2

[a] numbers may not completely agree due to rounding

Table 12.19 Ozone: Summary of National Annual Monetized Health and Welfare Benefits[a]

Estimates are incremental to the current ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category	Partial Attainment Scenario		
	0.08 5th max High-end Est.	**0.08 4th max Low- to High-end Est.**	**0.08 3rd max High-end Est.**
Health Benefits	$1.4	$0.06 to $1.76	$2.4
Welfare Benefits	$0.25	$0.32 to $0.32	$0.5
TOTAL MONETIZED BENEFITS	$1.6	$0.4 to $2.1	$2.9

Table 12.20 RH: Summary of National Annual Monetized Health and Welfare Benefits[a]

Estimates are incremental to the selected ozone and PM NAAQS
(billions of 1990 $; year = 2010)

Category	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)		1.0 Deciview Goal Over 10 Years (1.0 DeciviewTarget)	
	Low-end Est.	**High-end Est.**	**Low-end Est.**	**High-end Est.**
Health Benefits	$0.8	$2.1	$1.1	$4.5
Welfare Benefits	$0.5	$1.0	$0.6	$1.2
TOTAL MONETIZED BENEFITS	$1.3	$3.2	$1.7	$5.7

[a] numbers may not completely agree due to rounding.

For a visibility target of 0.67 deciview (i.e., 1.0 deciview goal over 15 years), total annual monetized benefits are expected to range from $1.3 billion to $3.2 billion. For a visibility target of 1.0 deciview (i.e., 1.0 deciview goal over 10 years), total annual monetized benefits are expected to range between $1.7 billion and $5.7 billion. The $1.3 billion to $5.7 billion plausible benefits range presented in this analysis may be potentially overstated due to the inability to quantify all visibility improvements prior to implementation of the RH visibility targets. The benefits associated with the RH targets are directly linked to the eventual choices made by States on the reasonable progress targets for the period 2000 to 2010 of this RH analysis. Should the States submit appropriate State implementation plans (SIPs) with reasonable progress target levels set close to those that would be achieved by implementation of the NAAQS and other CAA requirements, then visibility improvements and benefits attributed to the RH program program will be minimal and could be as low as zero.

The monetized benefits presented above are likely to be under-represented for a number of reasons. First, modeling limitations prevent the estimation of ancillary ozone benefits associated with implementing control strategies designed to reduce particulate concentrations. For example, low NOx burners imposed on industrial combustion sources is a control measure selected in the PM cost analysis. In addition to contributing to PM formation, NOx is also an ozone precursor. Therefore, the use of low NOx burners to reduce particulate concentrations would also concurrently reduce ozone concentrations. To the extent that such controls are used in area that would be imposing them anyway to meet the ozone standard, they may provide additional ozone benefits beyond those included in this analysis. There are also reasons to think that the benefits presented here could be overstated. There are likely to be lags associated with the relationship between changes in air quality and changes in mortality (as measured by long-term studies) and on chronic bronchitis. EPA does not know the magnitude of this lag, but if it did, it would discount the benefits appropriately. EPA has not prepared such estimates here.

A second reason for the under-representation of monetized benefits is the inability to model achievment of RH targets. A discussion of the unquantified benefits as well as uncertainties associated with this analysis are presented in the next section.

Not presented in Table 12.17 are full attainment $PM_{2.5}$ benefits. Estimation of full attainment PM benefits is more uncertain than partial attainment estimation because the sources from which additional emissions will be reduced will not be identified until further monitoring and modeling are performed. The PM partial attainment analysis indicates that PM control strategies outside of a violating county are often selected to help the violating county attain the standard. This procedure often causes PM air quality to change across an entire region rather than only in the violating county. However, for benefits analysis purposes, it is not possible to predict PM air quality distribution changes in areas other than the small number of residual nonattainment counties. This procedure is likely to underestimate the benefits associated with full attainment because it does not account for possible air quality changes and the associated population outside of the few remaining residual nonattainment counties. This method of adjusting partial attainment PM air quality to a full attainment scenario will show only a small change between partial and full attainment of the alternative standards. In the residual nonattainment counties only, the air quality is adjusted using the procedure described in section 12.6. Because regionwide PM air quality changes cannot be estimated, full attainment visibility benefits are assumed equal to the partial attainment visibility benefits for this analysis. This is an underestimate of the full attainment visibility benefits expected from full attainment of the selected PM2.5 standard. This procedure results in a high-end estimate of annual full attainment monetized benefits (health and welfare) of approximately $110 billion and a low-end estimate of $20 billion for the 15/65 alternative. These full attainment PM estimates are presented incremental from full attainment of the current ozone and PM NAAQS.

Full attainment ozone benefits are also not presented in the summary table. The ozone full attainment benefits estimation is limited for the same reason as the PM full attainment analysis. For the high-end estimate in the ozone partial attainment analysis, emission reductions achieved by ozone controls are processed by the source-receptor matrix to predict ancillary PM air quality by ozone controls are processed by the source-receptor matrix to predict ancillary PM air quality changes attributable to each ozone alternative. However, full attainment ozone air quality is estimated by using the air quality adjustment procedure as described in section 12.6. The ozone air quality rollback procedure reduces baseline ozone concentrations to the level specified by each alternative ozone standard. However, it is not possible to know how the PM air quality distributions will change given full attainment of the ozone alternatives. It is not possible to adjust PM air quality distributions in the same manner because, in this context, there is no PM standard against which the PM distributions can be evaluated. Given this limitation, the ancillary PM benefits are proportionally scaled from partial to full attainment using the ratio of ozone full attainment to partial attainment benefits. Using this procedure, high-end annual full attainment monetized ozone benefits (health and welfare) are estimated to be approximately $8.5 billion and low-end benefits are estimated to be approximately $1.5 billion for the 0.08 4th max. alternative. These full attainment ozone estimates are presented incremental from full attainment of the current ozone NAAQS.

12.10 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

12.10.1 Introduction

Given incomplete information, this national benefits analysis yields inexact results because associated with any estimate is the issue of uncertainty. Potentially important sources of uncertainty exist and many of these are summarized in Table 12.21. In most cases, there is no apparent bias associated with the uncertainty. For those cases for which the nature of the uncertainty suggests a direction of possible bias, this direction is noted in the table.

Table 12.21 Identified Sources of Uncertainty in Benefits Estimation

1. Post-Control Air Quality Estimation
1.1 CRDM: The degree to which the CRDM reflects post-control PM air quality
1.2 Air Quality Rollback: The degree to which the air quality rollback procedures reflect future air quality distributions
2. Concentration-Response Relationships
2.1 Mean Value of concentration-response functions
2.2 Mean population: How well the mean population (Mβ) approximates that value of β, that if used in all counties, would yield the same results as would be obtained if county-specific βs were used?
2.3 Future-year concentration-response functions: How similar will future-year concentration-response relationships compare to current concentration-response relationships?
2.4 Correct functional form of each concentration-response relationship
2.5 For crops, the application of exposure-response functions from the NCLAN open-top chambers studies extrapolated to 2010 ambient air exposure patterns
2.6 For some fruit and vegetable crops, the use of alternative non-NCLAN exposure-response functions
3. Baseline Incidence Rates
3.1 Non-county-specific incidence rates: Some baseline incidence rates are not county-specific (e.g., those taken from the epidemiological studies) and may not accurately represent the actual county-specific rates
3.2 Future baseline incidence rates: How similar will future baseline incidence rates compare to current baseline incidence rates?
3.3 Population projections: How well will the population projections compare to actual populations in the year 2010?
4. Economic Valuation
4.1 Willingness-to-Pay estimates: The true distribution associated with each WTP value is unknown
4.2 Future WTP estimates: How similar will future WTP estimates compare to current WTP estimates?
4.3 Valuation method: Does valuation based on mortality risk, or extensions to life better reflect WTP?
4.4 Discounting/Lags: Lags between exposure and incidence might affect benefits.
5. Aggregation of Monetized Benefits
5.1 Incomplete information for all benefit categories: Monetized benefit estimation is limited to those health and welfare endpoints for which concentration-response functions and WTP values are estimated
5.2 Possible double counting: Given that the pollutants have similar effects there may be double counting some of the benefits categories

12.10.2 Projected Income Growth

This analysis does not attempt to adjust benefits estimates to reflect expected growth in real income. Economic theory argues, however, that WTP for most goods (such as environmental protection) will increase if real incomes increase. The degree to which WTP may increase for the specific health and welfare benefits provided by the PM, ozone, and RH rules cannot be estimated due to insufficient income elasticity information. Thus, all else equal, the benefit estimates presented in this analysis are likely to be understated.

12.10.3 Unquantifiable Benefits

In considering the monetized benefits estimates, the reader should be aware that many limitations for conducting these analyses are mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many PM and ozone-induced adverse effects. Tables 12.1 and 12.2 lists the categories of benefits that this analysis is able to quantify and those discussed only in a qualitative manner. In general, if it were possible to include the unquantified benefits categories in the total monetized benefits, the benefits estimates presented in this RIA would increase.

The benefits of reductions in a number of ozone- and PM-induced health effects have not been quantified due to the unavailability of concentration-response and/or economic valuation data. These effects include: reduced pulmonary function, morphological changes, altered host defense mechanisms, cancer, other chronic respiratory diseases, infant mortality, airway responsiveness, increased susceptibility to respiratory infection, pulmonary inflammation, acute inflammation and respiratory cell damage, and premature aging of the lungs. Indirectly, SOx emissions controls applied for the purpose of implementing the $PM_{2.5}$ standard are expected to result in considerable reductions of mercury (approximately 16%). Mercury's toxic effects include human neurotoxicity; fish deaths and abnormalities; plant damage (e.g., senescence, reduced growth, decreased chlorophyll content, leaf injury, and root damage); and impaired reproduction, liver damage, kidney damage, and neurotoxicity in birds and other mammals.

In addition to the above non-monetized health benefits, there are a number of non-monetized welfare benefits of PM and ozone controls from reduced adverse effects on vegetation, forests, and other natural ecosystems. The CAA and other statutes, through requirements to protect natural and ecological systems, indicate that these are scarce and highly valued resources. In a recent attempt to estimate the "marginal" value (changes in quantity or quality) of ecosystem services, Costanza *et al*. (1997) state that policy decisions often give little weight to the value of ecosystem services because their value cannot be fully quantified or monetized in commercial market terms. Costanza *et al*. warn that "this neglect may ultimately compromise the sustainability of humans in the biosphere". Lack of comprehensive information, insufficient valuation tools, and significant uncertainties result in understated welfare benefits estimates in this RIA. However, a number of expert biologists, ecologists, and economists (Costanza, 1997) argue that the benefits of protecting natural resources are enormous and increasing as ecosystems become more stressed and scarce in the future. Just the value of the cultural services (i.e., aesthetics, artistic, educational, spiritual and scientific) may be considered infinite by some, albeit in the realm of moral considerations. Additionally, agricultural, forest and ecological scientists (Heck, 1997) believe that vegetation appears to be more sensitive to ozone than humans and consequently, that damage is occurring to vegetation and natural resources at concentrations below the selected ozone NAAQS. Experts also believe that the effect of ozone on plants is both cumulative and long-term. The specific non-monetized benefits from ozone reductions in ambient concentrations would accrue from: decreased foliar injury; averted growth reduction of trees in natural forests; maintained integrity of forest ecosystems (including habitat for native animal species); and the aesthetics and utility of urban ornamentals (e.g., grass, flowers, shrubs and trees). Other welfare categories for which there is incomplete information to estimate the economic value of reduced adverse effects include: existence value of Class I areas (e.g., Grand Canyon National Park); materials damage; reduced sulfate deposition to aquatic and terrestrial ecosystems; and visibility impairment due to "brown clouds" (i.e., distinct brown layers of trapped air pollutants close to the ground).

Infant Mortality

A recent study in the U.S. has found an association between infant mortality and PM_{10} (Woodruff et al., 1997). This conclusion is similar to conclusions in previous studies (Ministry of Public Health, 1954; Bobak et al., 1992; Knobel et al., 1995 and Penna et al., 1991). These last 3 studies were reviewed by the CASAC but not relied on by EPA in standard setting. The most recent study finds that high PM_{10} exposure is associated with increases in total infant mortality. Evaluation by cause of death finds a higher association for respiratory mortality and sudden infant death syndrome for normal birthweight infants. Although the association between PM exposure and increased postneonatal mortality risk is important, this category could not be included in the quantified benefits analysis because the new study was not published at the time the benefits analysis was conducted.

Other Human Health Effects

Human exposure to PM and ozone is known to cause health effects such as: airway responsiveness, increased susceptibility to respiratory infection, acute inflammation and respiratory cell damage, premature aging of the lungs and chronic respiratory damage. An improvement in ambient PM and ozone air quality is expected to reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are known to be PM or ozone-induced, concentration-response data is not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects leads to an underestimation of the monetized benefits presented in this analysis.

Mercury Emission Reductions

Emissions of mercury from human activity are thought to contribute between 40 to 75 percent of the current total annual input of mercury to the atmosphere. This RIA imposes a national SOx strategy for the purpose of implementing the $PM_{2.5}$ alternatives. From the 2010 baseline, the SOx strategy is estimated to reduce 11 tons of mercury, which is approximately a 16 percent reduction.

Once emitted to the atmosphere, mercury can deposit to the earth in different ways and at different rates, depending on its physical and chemical form. The form of mercury emitted influences its atmospheric fate and transport, as do conditions specific to its site of release. The result is that mercury deposition is a local, regional, and global issue. Mercury can be deposited directly to water bodies or can be transported from land by run-off and enter many different types of water bodies. The water bodies contain microorganisms that have the metabolic capability to carry out chemical reactions which bind mercury to methyl groups, producing methylmercury. Methylmercury is the form of mercury to which humans and wildlife are generally exposed, usually from eating fish which have accumulated mercury in their muscle tissue.

Methylmercury is biologically concentrated or bioaccumulated. That is, an animal at a higher position in the foodweb may have mercury concentrations thousands of times higher than an animal at a lower position in the foodweb. The transfer of mercury in the foodweb to progressively higher concentrations in large fish is key to understanding how release of mercury to the atmosphere results in exposure to high concentrations of mercury in fish, and ultimately humans and wildlife which consume fish. Humans are most likely to be exposed to methylmercury through fish consumption, although exposure may occur through other routes as well. In addition, mercury is a known human toxicant which has been associated with occupational exposure and with exposure through consumption of contaminated food. The range of neurotoxic effects can vary from subtle decrements in motor skills and sensory ability to tremors, inability to walk, convulsions, and death. Neurotoxicity can also affect a developing embryo or fetus.

The environmental impacts of mercury on fish include death, reduced reproductive success, impaired growth, and developmental and behavioral abnormalities. Exposure to mercury can also cause adverse effects in plants, birds, and mammals. Effects of mercury on plants include plant senescence, growth inhibition, decreased chlorophyll content, leaf injury, root damage, and inhibited root growth and function. Reproductive effects are the primary concern for avian mercury poisoning and can include liver and kidney damage as well as neurobehavioral effects. Although clear causal links between mercury contamination and population declines in various wildlife species have not been established, mercury may be a contributing factor to population declines of the endangered Florida panther and the common loon.

Current levels of mercury in freshwater fish in the U.S. are such that advisories have been issued in 37 states warning against the consumption of certain amounts and species of fish that are contaminated with mercury. Seven states have statewide advisories. Such widespread contamination is a concern for several reasons including: potential health risk to people who continue to catch and eat fish from these waters; economic losses to tourism, commercial and recreational fisheries; health and economic impacts to people, including subsistence fishers, who can no longer eat fish from these waters.

Urban Ornamentals

Urban ornamentals represent an additional vegetation category likely to experience some degree of effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. Ornamentals used in the urban and suburban landscape include shrubs, trees, grasses, and flowers. The types of economic losses that could potentially result from effects that have been associated with ozone exposure include: 1) reduction in aesthetic services over the realized lifetime of a plant; 2) the loss of aesthetic services resulting from the premature death (or early replacement) of an injured plant; 3) the cost associated with removing the injured plant and replacing it with a new plant; 4) increased soil erosion, 5) increased energy costs from loss of shade in the urban environment; 6) reduced seedling survivability; and 7) any additional costs incurred over the lifetime of the injured plant to mitigate the effects of ozone-induced injury. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals (Abt, 1995b), both by private property owners/tenants and by governmental units responsible for public areas, making this a potentially important welfare effects category. However, 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. While recognizing this limitation, an estimate of ozone-induced damage to ornamentals can be made based on data assessing retail expenditures on environmental horticulture at $23 billion in 1991 (Abt, 1995b). If only half of a percent of public expenditures on ornamentals could be traced to ozone-induced damage avoided with a revised ozone standard, then benefits would amount to $115 million.

Aesthetic Injury to Forests

Ozone is a regionally dispersed air pollutant that has conclusively been shown to cause discernible injury to forest trees (Fox, 1995). One of the welfare benefits expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available documenting that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species. Ozone inhibits photosynthesis and interferes with nutrient uptake, causing a loss in vigor that affects the ability of trees to compete for resources and makes them more susceptible to a variety of stresses (U.S. EPA, 1996a, p. 5-251). Extended or repeated exposures may result in decline and eventual elimination of sensitive species. Ozone concentrations of 0.06 ppm or higher are capable of causing injury to forest ecosystems.

The most notable effects of ozone on forest aesthetics and ecosystem function have been documented in the San Bernardino Mountains in California. Visible ozone-related injury, but not necessarily ecosystem effects, have also been observed in the Sierra Nevada in California, the Appalachian Mountains from Georgia to Maine, the Blue Ridge Mountains in Virginia, the Great Smoky Mountains in North Carolina and Tennessee, and the Green Mountains in Vermont (U.S. EPA, 1996a, pp. 5-250 to 5-251). These are all locations where there is substantial recreation use and where scenic quality of the forests is an important characteristic of the resource. Economic valuation studies of lost aesthetic value of forests attributed to plant injuries caused by ozone are limited to two studies conducted in Southern California (Crocker, 1985; Peterson et al., 1987). Both included contingent valuation surveys that asked respondents what they would be willing to pay for reductions in (or preventions of increases in) visible ozone injuries to plants. Crocker found that individuals are willing to pay a few dollars more per day to gain access to recreation areas with only slight ozone injury instead of areas with moderate to severe injury. Peterson et al. estimated that a one-step change (on a 5 point scale) in visible ozone injury in the San Bernardino and Angeles National Forests would be valued at an aggregate amount of between $27 million and $144 million for all residents of Los Angeles, Orange, and San Bernardino counties. A reassessment of the survey design, in light of current standards for contingent valuation research, suggests that it is plausible that concerns for forest ecosystems and human health could have been embedded into these reported values. The extent of this possible bias is uncertain.

Present analytic tools and resources preclude EPA from quantifying the national benefits of improved forest aesthetics expected to occur from the selected ozone standard. This is due to limitations in our ability to quantify the relationship between ozone concentrations and visible injury, and limited quantitative information about the value to the public of specific changes in visible aesthetic quality of forests. However, there is sufficient supporting evidence in the physical sciences and economic literature to support the finding that the proposed changes to the ozone NAAQS can be expected to reduce injury to forests, and that reductions in these injuries will likely have a significant economic value to the public.

Nitrates in Drinking Water

Nitrates in drinking water are currently regulated by a maximum contaminant level (MCL) of 10 mg/L on the basis of the risk to infants of methemoglobinemia, a condition which adversely affects the blood's oxygen carrying capacity. In an analysis of pre-1991 data, Raucher, et al. (1993) found that approximately 2 million people were consuming public drinking water supplies which exceed the MCL. Supplementing these findings, the National Research Council concluded that 42 percent of the public drinking water users in the U.S. (approximately 105 million people) are either not exposed to nitrates or are exposed to concentrations below 1.3 mg/L (National Research Council, 1995).

In a recent epidemiological study by the National Cancer Institute, a statistically significant relationship between nitrates in drinking water and incidence of non-Hodgkin's lymphoma were reported (Ward, et al., 1996). Though it is generally acknowledged that traditional water pollution sources such as agricultural runoff are mostly responsible for violations of the MCL, other more diffuse sources of nitrate to drinking water supplies, such as that from atmospheric deposition, may also become an important health concern should the cancer link to nitrates be found valid upon further study.

Brown Clouds

NOx emissions, especially gaseous NO_2 and NOx aerosols, can cause a brownish color to appear in the air (U.S. EPA, 1993). In higher elevation western cities where wintertime temperature inversions frequently trap air pollutants in atmospheric layers close to the ground, this can result in distinct brown layers. In Denver, this phenomenon has been named the "brown cloud." In the eastern U.S., a layered look is not as common, but the ubiquitous haze sometimes takes on a brownish hue. To date, economic valuation studies concerning visual air quality have focused primarily on the clarity of the air in terms of being able to see through it, and have not addressed the question of how the color of the haze might be related to aesthetic degradation. It may be reasonable to presume that brown haze is likely to be perceived as dirty air and is more likely to be associated with air pollution in people's minds. It has not, however, been established that the public would have a greater value for reducing brown haze than for a neutral colored haze. Results of economic valuation studies of visibility aesthetics conducted in Denver and in the eastern U.S. (McClelland et al., 1991) are not directly comparable because changes in visibility conditions are not defined in the same units of measure. However, the WTP estimates for improvements in visibility conditions presented in this assessment are based on estimates of changes in clarity of the air (measured as deciview) and do not take into account any change in color that may occur. It is possible that there may be some additional value for reductions in brownish color that may also occur when NOx emissions are reduced.

Other Unquantifiable Benefits Categories

There are other welfare benefits categories for which there is incomplete information to permit a quantitative assessment for this analysis. For some endpoints, gaps exist in the scientific literature or key analytical components and thus do not support an estimation of incidence. In other cases, there is insufficient economic information to allow estimation of the economic value of adverse effects. Potentially significant, but unquantified welfare benefits categories include: existence and user values related to the protection of Class I areas (e.g., Grand Canyon National Park), tree seedlings for more than 10 sensitive species (e.g., black cherry, aspen, ponderosa pine), non-commercial forests, ecosystems, materials damage, and reduced sulfate deposition to aquatic and terrestrial ecosystems. Although scientific and economic data are not available to allow quantification of the effect of ozone in these categories, the expectation is that, if quantified, each of these categories would lead to an increase in the monetized benefits presented in this RIA. For example, the National Acid Precipitation Assessment Program (NAPAP) reports that user values for visibility changes at recreation sites in the east and west are in the range of $1 to $10 per visitor per day. Similarly, estimates of the economic effects of acidic deposition damages on recreational fishing in the Adirondack region of New York range from $1 million to $13 million annually.

Potential Disbenefits

In this discussion of unquantified benefits, a discussion of potential disbenefits must also be mentioned. Several of these disbenefit categories are related to nitrogen deposition while one category is related to the issue of ultraviolet light.

<u>Passive Fertilization</u>

Several disbenefit categories are related to nitrogen deposition. Nutrients deposited on crops from atmospheric sources are often referred to as passive fertilization. Nitrogen is a fundamental nutrient for primary production in both managed and unmanaged ecosystems. Most productive agricultural systems require external sources of nitrogen in order to satisfy nutrient requirements. Nitrogen uptake by crops varies, but typical requirements for wheat and corn are approximately 150 kg/ha/yr and 300 kg/ha/yr, respectively (NAPAP, 1990). These rates compare to estimated rates of passive nitrogen fertilization in the range of 0 to 5.5 kg/ha/yr (NAPAP, 1991). Approximately 75 percent (70 -80 percent) of nitrogen deposition is in the form of nitrates (and thus can be traced to NOx emissions) while most of the remainder is due to ammonia emissions (personal communication with Robin Dennis, NOAA Atmospheric Research Lab, 1997).

Elsewhere in this analysis, it is estimated that a 0.08 3rd max ozone standard would result in NOx emissions reductions of approximately 0.3 million tons/yr for partial attainment or 1.4 million tons/yr for full attainment from a 2010 baseline. These reductions are roughly equivalent to 1 - 6 percent of 1990 emission levels (i.e., the approximate year of the NAPAP deposition estimates).

NOx reductions resulting from a 0.08 3rd max ozone NAAQS could therefore, in theory, increase the nitrogen fertilization requirement for wheat from 0 - 0.03 percent for partial attainment and from 0 - 0.17 percent for full attainment. For corn, the increase would be from 0 - 0.01 percent for partial attainment and from 0 - 0.08 percent for full attainment. However, given the extremely small magnitude of these increases, it is highly unlikely that farmers could detect them and increase their fertilization application accordingly nor even control their nitrogen applications with this degree of precision.

Information on the effects of changes in passive nitrogen deposition on forest lands 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 in could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (U.S. EPA, 1993).

However, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (U.S. 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 Light

A reduction of tropospheric ozone to meet health and welfare-based standards is likely to increase the penetration of ultraviolet light, specifically UV-B, to ground level. UV-B is an issue of concern because depletion of the stratospheric ozone layer (i.e., ozone in the upper atmosphere) due to chlorofluorocarbons and other ozone-depleting chemicals is associated with increased skin cancer and cataract rates. EPA is not currently able to adequately quantify these effects for the purpose of valuing benefits for these standards. If EPA were able to do so it would attempt to quantify these effects.

Other EPA programs exist to address the risks posed by changes in UV-B associated with changes in total column ozone. As presented in the Stratospheric Ozone RIA (U.S. EPA, 1992), stratospheric ozone levels are expected to significantly improve over the next century as the major ozone depleting substances are phased out globally. This expected improvement in stratospheric ozone levels is estimated to reduce the number of nonmelanoma skin cancers (NMSC's) by millions of cases in the U.S. by 2075.

12.11 REFERENCES

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13.0 BENEFIT-COST COMPARISONS

13.1 RESULTS IN BRIEF

Estimated partial attainment (P/A) benefits of implementation of the particulate matter (PM) and ozone NAAQS greatly exceed estimated P/A costs. Estimated combined net P/A benefits (P/A benefits minus P/A costs) for the combined $PM_{2.5}$ 15/65 and ozone 0.08 4th max alternatives range from approximately $10 to $96 billion.

Considered separately, estimated P/A benefits of alternative $PM_{2.5}$ standards far outweigh estimated P/A costs. Estimated quantifiable net P/A benefits of the selected $PM_{2.5}$ 15/65 standard range from $10 to $95 billion. Estimated quantifiable full-attainment (F/A) net benefits range from negative $18 to positive $67 billion. Estimated quantifiable net P/A quantified and monetized benefits of the ozone 0.08 4th max standard range from negative $0.7 to positive $1.0 billion. F/A benefit estimates are somewhat smaller than F/A cost estimates. Quantifiable net benefits for full attainment of the 0.08 4th max. ozone standard are estimated to range from negative $1.1 to negative $8.1 billion.

13.2 INTRODUCTION

This Regulatory Impact Analysis provides cost, economic impact, and benefit estimates potentially useful for evaluating PM, ozone, and RH control alternatives. Benefit-cost analysis provides a systematic framework for assessing and comparing such alternatives. According to economic theory, the efficient alternative maximizes net benefits to society (i.e., social benefits minus social costs). However, both the Agency and the courts have defined the primary National Ambient Air Quality Standards (NAAQS) setting process as a fundamentally health-based decision that specifically is not to be based on cost or other economic considerations. This benefit-cost comparison for the PM and ozone NAAQS, therefore, is intended to generally inform the public about the potential costs and benefits that may result when revisions to the PM and ozone NAAQS are implemented by the States. The benefit-cost comparison for the RH rule, however, may be used to support the decision making process for this program.

13.3 COMPARISONS OF BENEFITS TO COSTS

13.3.1 Separate PM and Ozone NAAQS

13.3.1.1 <u>Results</u>

Tables 13.1 and 13.2 present the estimated P/A benefits, costs, net benefits, and residual nonattainment area (RNA) results for alternative $PM_{2.5}$ NAAQS and ozone NAAQS, respectively.

Full attainment (F/A) cost and benefit estimates of alternative $PM_{2.5}$ and ozone NAAQS are presented in Chapters 9 and 12. Estimated F/A costs of the selected $PM_{2.5}$ 15/65 standard equal $36.7 billion, while estimated F/A benefits range from $19.8 to $109.7 billion. Estimated F/A costs of the ozone 0.08 4th max standard equal $9.6 billion, while estimated F/A benefits range from $1.5 to $8.5 billion.

13.3.1.2 <u>Key Results and Conclusions</u>

- Monetized net benefit estimates are positive and substantial for all three $PM_{2.5}$ alternatives for the P/A scenario. For the selected $PM_{2.5}$ 15/65 standard, estimated net annual P/A benefits range from $10 to $95 billion, depending whether the estimates are based on the low end and high end assumptions.

- Monetized net benefit estimates are ambiguous for the three ozone standards assessed for the P/A scenario. For the selected ozone 0.08 4th max standard, estimated net annual P/A benefits range from negative $0.7 billion to positive $1.0 billion, depending on whether the estimates are based on the low or the high end assumptions. Note that significant categories of nonmonetized benefits are omitted from these estimates.

Table 13.1 Comparison of Annual Benefits and Costs of PM Alternatives in 2010[a,b] (1990$)

$PM_{2.5}$ Alternative ($\mu g/m^3$)	Annual Benefits of Partial Attainment[c] (billion $) (A)	Annual Costs of Partial Attainment (billion $) (B)	Net Benefits of Partial Attainment (billion $) (A - B)	Number of Residual Nonattainment Counties
16/65 (high end estimate)	90	5.5	85	19
15/65 (low end estimate) (high end estimate)	19 - 104	8.6	10 - 95	30
15/50 (high end estimate)	108	9.4	98	41

a All estimates are measured incremental to partial attainment of the current PM_{10} standard (PM_{10} 50/150, 1 expected exceedance per year).

b The results for 16/65 and 15/50 are only for the high end assumptions range. The low end estimates were not calculated for these alternatives.

c Partial attainment benefits based upon post-control air quality as defined in the control cost analysis.

Table 13.2 Comparison of Annual Benefits and Costs of Ozone Alternatives in 2010[a,b] (1990$)

Ozone Alternative (ppm)	Annual Benefits of Partial Attainment (billion $)[c] (A)	Annual Costs of Partial Attainment (billion $) (B)	Net Benefits of Partial Attainment (billion $) (A - B)	Number of Residual Nonattainment Areas
0.08 5th Max (high end estimate)	1.6	0.9	0.7	12
0.08 4th Max (low end estimate) (high end estimate)	0.4 - 2.1	1.1	(0.7) - 1.0	17
0.08 3rd Max (high end estimate)	2.9	1.4	1.5	27

a All estimates are measured incremental to partial attainment of the baseline current ozone standard (0.12ppm , 1 expected exceedance per year).

b The results for .08, 5th and .08, 3rd max. are only for the high end assumptions. The low end estimates were not calculated for these alternatives.

c Partial attainment benefits based upon post-control air quality estimates as defined in the control cost analysis.

13.3.2 Combined PM and Ozone NAAQS

Based on results from sensitivity studies performed for the sequential implementation of a PM and an ozone standard (see Appendix D), the sum of estimated P/A costs and benefits associated with separate PM and ozone standards, regardless of sequence, is likely to exceed the P/A costs and benefits associated with coordinated implementation of both standards, but only by a small percentage. Thus the benefits and costs of coordinated implementation of a $PM_{2.5}$ 15/65 and ozone 0.08 4th max standards can be estimated roughly by summing results from the separate standards analyses.

13.3.3 Regional Haze Rule

13.3.3.1 Results

The estimated benefits and costs associated with achieving a .67 and 1 deciview visibility improvement, incremental to the application of controls to attain the $PM_{2.5}$ 15/65 standard, are presented in Table 13.3.

13.3.3.2 Key Results and Conclusions

- Net monetized benefit estimates are ambiguous for both RH alternatives assessed.

- Actual benefits and costs associated with the proposed RH rule will depend on the reasonable progress target levels included in State Implementation Plans (see Chapter 8).

Table 13-3 Comparison of Annual Monetized Benefits and Costs of RH Alternatives in 2010 (1990$)

RH Alternative Incremental to $PM_{2.5}$ 15/65	**Annual Benefits (billion $)** (A)	**Annual Costs (billion $)** (B)	**Net Benefits (billion $)** (A - B)	**Residual Noncompliant Class I Areas**
1.0 Deciview Improvement Over 15 Year (0.67 Deciview Target)	1.3 - 3.2	2.1	(0.8) - 1.1	17
1.0 Deciview Improvement Over 10 Years (1.0 Deciview Target)	1.7 - 5.7	2.7	(1.0) - 3.0	28

NOTE: The benefits range results are associated with the RH targets and are directly linked to the eventual choices made by States on the reasonable progress targets for the period 2000 to 2010. Should the States submit approvable State implementation plans (SIPs) with reasonable progress target levels set close to those that would be achieved by implementation of the NAAQS and other CAA requirements, then visibility improvements and benefits attributed to the RH program will be minimal and could be as low as zero.

13.4 LIMITATIONS TO THE BENEFIT-COST COMPARISONS

As discussed throughout this document, there are significant analytical uncertainties associated with these benefit-cost assessments. Various emission inventory, air quality modeling, cost, health and welfare effect, and valuation uncertainties and limitations are discussed throughout this analysis. An effort has been made to account for some of these uncertainties through the estimation of a plausible range of monetized benefits as described in chapter 12. Additional limitations specific to the comparison of estimated benefits and costs for the various alternatives include the following:

- Some identified benefit categories associated with PM and ozone reductions could not be quantified or monetized. Nonmonetized benefit categories include changes in pulmonary function, altered host defense mechanisms, and cancer. Thus, this chapter presents a comparison of estimated *monetized* benefits versus estimated total costs.

- The uncertainty associated with the benefit estimates may be greater than the uncertainty associated with the P/A cost estimates. In particular, benefit estimates vary greatly depending on the mortality risk reduction effect and valuation measures employed.

- Full-attainment cost estimates are speculative and should be compared with full-attainment benefit estimates with caution.

- Comparisons of P/A costs and benefits across alternatives examined should be made with caution because of the existence of residual nonattainment (RNA). P/A costs associated with more stringent standards may not increase at an increasing rate because the additional violating counties may have low-cost controls available to attain the more stringent standards. The number of RNA areas, however, increases with the stringency of the standards.

- The cost and benefit estimates presented in this chapter do not account for market reactions to the implementation of these rules. These estimates represent the direct but not the true social benefits and costs (calculated after market adjustments to price and output changes, etc.) associated with alternative standards. Social costs are typically somewhat smaller than direct control costs while social benefits may be greater or less than direct benefits depending on the specific market adjustments and substitutions that occur.

13.5 SUMMARY

Despite numerous limitations and uncertainties, the analysis provided in this document provides a basis for believing that in the reference year 2010 benefits resulting from efforts to meet both new NAAQS are likely to exceed costs. Though uncertainties associated with estimates after the next decade trend toward lower costs, it is not clear today what those out-year costs will be. The history of compliance with the Clean Air Act indicates, however, that a commitment to continue progress today does not require rigid adherence to timelines that, in ten or more years, prove to be impractical.

APPENDIX A

EMISSIONS AND AIR QUALITY

APPENDIX A.1

ESTIMATION OF 1990 EMISSIONS BY MAJOR SECTOR

Industrial Point Sources

The National Particulates Inventory (NPI) defines industrial point sources as those non-utility sources (i.e., boilers and processes) that emit more than 100 tons per year of at least one criteria air pollutant or precursor of such pollutants. Base year emissions are derived from the 1985 National Acid Precipitation Assessment Program (NAPAP) (U.S. EPA, 1989) and projected to 1990 based on Bureau of Economic Analysis (BEA) growth in industrial sector earnings (BEA, 1990). Because PM_{10} and $PM_{2.5}$ emission estimates are not available from the NAPAP files, annual PM_{10} and $PM_{2.5}$ emissions in the NPI are calculated from Total Suspended Particulates (TSP) emissions by applying a Source Classification Code (SCC)-specific particle size distribution factor from the PM calculator program (U.S. EPA, 1994b). Industrial point source emissions for California and Oregon from the Grand CanyonVisibility Transport Commission (GCVTC) are incorporated in the NPI (Radian, 1995).

Utility Sources

Emissions from fossil-fuel fired steam electric generating boilers are developed from 1990 U.S. Department of Energy (DOE, 1991b) fuel use data and emission limits combined with EPA emission factors (U.S. EPA, 1995a). Gas turbine and internal combustion (IC) engine emissions are derived from the 1985 NAPAP inventory (U.S. EPA, 1989) and projected to 1990 using BEA earnings data by industry sector (BEA, 1990).

Non-Road Engines/Vehicles

The non-road engine/vehicle sector includes all transportation sources that are not counted as highway vehicles such as marine vessels, railroads, aircraft, and non-road internal combustion engines and vehicles. EPA's Office of Mobile Sources (OMS) developed a non-road internal combustion engine and vehicle emissions inventory for 27 ozone nonattainment areas (U.S. EPA, 1991b). These area-specific estimates are extrapolated to develop national nonroad emission estimates based on population. For aircraft, railroads, and commercial marine vessels, the 1985 NAPAP inventory (U.S. EPA, 1989) is grown to 1990 using sector-specific BEA growth factors. PM_{10} and $PM_{2.5}$ emissions are estimated by applying particle size multipliers to TSP emissions using the PM calculator program (U.S. EPA, 1994b).

Motor vehicles

Base year motor vehicle emissions are developed by multiplying VMT by pollutant-specific emission factor estimates. The NPI VMT, by county/SCC (i.e., vehicle type/functional roadway class), are based on data from the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) (FHWA, 1992). The HPMS areawide data base contains State-level VMT estimates for rural and small urban areas, as well as separate VMT estimates for each large urban area within a State. VMT estimates for each of these categories are provided by functional roadway class and are converted to county-level estimates segregated by vehicle type and roadway class.

1990 control-specific emission factors for VOC and NOx are generated using the EPA's motor vehicle emission factor model MOBILE5a (U.S.EPA, 1993a). PM_{10}, $PM_{2.5}$, and SO_2 1990 control-specific emission factors are generated using another EPA motor vehicle emission factor model, PART5 (U.S. EPA, 1994c). The 1990 emissions factors are calculated based on historical temperatures, gasoline volatility (RVP) data, and inspection/maintenance (I/M) information. Emissions estimates are calculated at the county/vehicle-type/roadway-type level, accounting for county differences in I/M programs. Additionally, emissions are calculated by month and summed to develop annual emission estimates. Ozone season daily VOC and NOx are calculated based on temporally allocated VMT and maximum ozone season temperatures for nonattainment areas and July temperatures for rest-of-state areas.

Area Sources

Area sources include solvent use and small stationary sources (e.g., dry cleaners, gasoline marketing, and industrial fuel combustion) that emit less than 100 tons per year of at least one criteria air pollutant or preccursor pollutant. These sources are not included in the industrial point source data base. The 1985 NAPAP Inventory (U.S. EPA. 1989) is used as the basis for most area source categories.   BEA historical earnings data (BEA, 1990), population, fuel use data from the State Energy Data System (SEDS) (DOE, 1991a), and other category-specific indicators are used to project the 1985 NAPAP to 1990. SEDS data serve as an indicator of emissions growth for the area source fuel combustion categories and for the gasoline marketing categories. Particle size multipliers are applied to estimate PM_{10} and $PM_{2.5}$ emissions from TSP estimates (U.S. EPA, 1994b).

Solvent emissions are estimated from a national solvent material balance model using solvent data from various marketing surveys (U.S. EPA, 1993b). Emissions are allocated to the county-level based on employment and population data (BOC, 1987; BOC, 1988a; BOC, 1988b).

Prescribed burning emission estimates are based on a 1989 USDA Forest Service Inventory of PM and air toxics (USDA, 1989). This inventory of prescribed burning contains State-level emissions, which are allocated to the county-level using the State-to-county distribution of emissions in the 1985 NAPAP Inventory.

PM_{10} emissions for fugitive dust sources for the NPI are taken from the 1990 National Emission Trends inventory for agricultural tilling, construction activity, paved and unpaved roads (U.S. EPA, 1996d). $PM_{2.5}$ emissions are estimated by applying particle size multipliers to the PM_{10} estimates (U.S. EPA, 1994b). Emissions for beef cattle feedlots are developed specifically for the NPI. Because construction activity emission estimates are provided at the EPA-region level, these estimates are disaggregated to the county-level based on Census of Agriculture data, land use, and construction earnings data (USDA, 1991; BOC, 1987). Paved and unpaved road emissions are estimated using the EPA's OMS PART5 emission factor model (U.S. EPA, 1994c) combined with paved and unpaved road VMT estimates based on FHWA data (FHWA, 1992). PART5 reentrained road dust emission factors depend on the average weight, speed, and number of wheels of the vehicles traveling on paved and unpaved roadways, the silt content of roadway surface material, and precipitation data. The activity factor for calculating reentrained road dust emissions is VMT.

Residential wood combustion emissions estimated for the 1990 National Emission Trends inventory (U.S. EPA, 1993c) are used in Version 3 of the NPI. Residential wood combustion emissions include those from traditional masonry fireplaces, freestanding fireplaces, wood stoves, and furnaces.

Ammonia emissions from livestock feedlots and fertilizers are estimated based on county-level Census of Agriculture data for number of head of livestock raised and amount and type of fertilizer used (BOC, 1992). Emission factors are taken from a study of ammonia emissions conducted in the Netherlands (Asman, 1992; Battye et al., 1994)). Anthropogenic ammonia emissions are believed to be small relative to natural sources of ammonia.

For the States of California and Oregon, 1990 emissions from the GCVTC inventory are incorporated for all area source categories (Radian, 1995). The data for these two States are based on State-compiled inventories that are based on more recent and detailed data than the emissions in the NAPAP inventory.

Biogenics/Natural Sources

Biogenic VOC emissions are developed based on EPA’s Biogenic Emissions Inventory System (BEIS) (Pierce et al, 1990). State-level estimates are disaggregated to the county level based on urban and rural land use. EPA has since developed county-level biogenic emissions using version 2 of BEIS (BEIS2) (Geron, 1994), but these more recent estimates are not used in this analysis.

Emissions of primary PM come from natural sources such as wind erosion and wild fires. PM_{10} emissions from wind erosion are taken from the 1990 National Emission Trends inventory (U.S. EPA, 1996d). $PM_{2.5}$ emissions are estimated by applying particle size multipliers. Wild fire emissions are taken from estimates developed for the GCVTC for the 11 GCVTC States (Radian, 1995). The wildfire data in the GCVTC inventory represent a detailed survey of forest fires in the study area. For non-GCVTC States, emissions are based on the 1985 NAPAP inventory values (U.S.EPA, 1989). Wild fires also contribute to natural source VOC and NOx emissions and, to a much smaller extent, to SO_2 and SOA emissions.

APPENDIX A.2

Base Year 1990 National Emissions Estimates by Source Category

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
UTILITY						
Coal	27.1	6,689.5	15,221.9	268.4	99.2	0.5
Gas/Oil/Other	7.8	679.1	611.9	10.6	5.9	0.2
Internal Combustion	1.9	57.1	30.7	4.1	3.7	0.0
Total	**36.8**	**7,425.7**	**15,864.5**	**283.1**	**108.8**	**0.7**
INDUSTRIAL POINT						
Fuel Comb. Industrial	126.1	1,955.8	2,482.2	221.1	162.0	2.0
Fuel Comb. Other	10.3	103.9	202.4	16.6	8.2	0.1
Chemical & Allied Product Mfg.	1,066.2	275.4	440.1	62.5	42.7	5.0
Metals Processing	72.5	81.0	664.7	137.9	96.3	0.2
Petroleum & Related Industries	238.3	99.9	434.8	28.9	19.5	0.6
Other Industrial Processes	327.0	308.0	393.6	374.3	224.3	6.8
Solvent Utilization	1,126.2	2.5	0.8	2.1	1.8	16.1
Storage & Transport	490.1	2.4	4.6	64.4	26.5	4.1
Waste Disposal & Recycling	9.7	20.7	21.0	8.0	6.7	0.0
Miscellaneous	0.3	0.0	0.0	10.7	1.6	0.0
Total	**3,466.6**	**2,849.7**	**4,644.2**	**926.4**	**589.5**	**34.8**

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
AREA						
Fuel Combustion Industrial	17.8	1,269.7	626.9	29.1	14.8	0.1
Fuel Combustion - Residential Wood	663.1	45.7	6.3	475.4	475.4	28.6
Fuel Combustion Other	22.8	565.5	384.3	35.3	20.4	0.4
Chemical & Allied Product MFG	449.2	0.0	0.0	0.0	1.6	0.9
Petroleum & Related Industries	450.2	19.4	1.4	1.6	22.6	1.1
Other Industrial Processes	84.4	4.3	1.7	34.6	0.0	0.2
Solvent Utilization	4,701.0	0.0	0.0	0.0	0.0	45.1
Storage & Transport	1,220.3	0.0	0.0	0.0	0.0	14.4
Waste Disposal & Recycling	2,154.6	60.0	14.8	218.2	190.7	1.3
Fugitive Dust - Natural Sources	13.8	0.0	0.0	5,184.8	777.7	0.0
Agricultural Production - Crops	78.9	10.4	0.2	7,004.5	1,467.7	0.1
Fugitive Dust - Paved Roads	0.0	0.0	0.0	5,960.7	1,490.2	0.0
Fugitive Dust - Unpaved Roads	0.0	0.0	0.0	12,362.0	1,854.3	0.0
Fugitive Dust - Construction	0.0	0.0	0.0	8,311.4	1,662.3	0.0
Agricultural Production - Livestock	76.1	0.0	0.0	401.7	60.3	0.0
Other Combustion - Wild Fires	234.2	89.1	1.3	243.6	217.0	0.2
Other Combustion - Prescribed Burning	179.5	124.6	4.7	447.1	377.1	0.1
Miscellaneous	0.0	0.0	0.0	8.5	1.9	0.0
Total	**10,345.9**	**2,188.8**	**1,041.5**	**40,718.5**	**8,634.1**	**92.4**

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
NONROAD						
Nonroad Gasoline	1,596.8	176.0	3.2	42.1	35.0	11.7
Nonroad Diesel	185.0	1,438.4	16.7	185.6	170.8	4.4
Aircraft	191.9	139.7	8.0	40.4	28.5	4.5
Marine Vessels	36.0	183.7	147.5	24.2	17.8	1.0
Railroads	44.2	898.0	66.6	44.0	40.5	1.0
Total	**2,053.9**	**2,835.8**	**242.0**	**336.3**	**292.6**	**22.7**
MOTOR VEHICLE						
LDGV	4,207.2	3,406.1	143.0	63.1	38.1	25.7
LDGT1	954.0	775.2	37.6	15.2	9.8	5.8
LDGT2	803.5	557.8	20.5	16.9	11.1	4.9
HDGV	466.9	333.1	10.8	10.6	7.0	3.4
LDDV	11.6	35.9	12.7	8.8	7.8	1.0
LDDT	2.8	7.4	2.8	1.7	1.5	0.0
HDDV	313.9	2,318.4	340.1	238.2	215.7	7.4
MC	50.5	11.6	0.3	0.4	0.2	0.3
Total	**6,810.5**	**7,445.6**	**567.70**	**354.70**	**291.2**	**47.6**

Note: Emission estimates may not sum due to rounding.
1990 fugitive dust emissions have not been adjusted here as described in Section 4.4.2.3.
Air quality impacts from major emitting sectors are not necessarily proportional to their contribution to national emissions estimates. See PM and ozone air quality modeling sections 4.4 and 4.5 and Chapters 6 and 7.

APPENDIX A.3
2010 CAA CONTROL ASSUMPTIONS BY MAJOR SECTOR

Industrial Point Sources

Point source control measures for VOC include RACT, new CTGs and Title III MACT controls (Pechan, 1997a). Title III MACT controls are generally as stringent, or more stringent, than RACT controls and are thus the dominant control option for many source categories. Major stationary source NOx emitters in marginal and above nonattainment areas and in the Northeast Ozone Transport Region (OTR) are required to install RACT-level controls. Given that NOx RACT controls are specified by each state, NOx RACT is modeled using representative RACT levels for each source category. OTAG Level 2 NOx controls and a 0.15 lb NOx/MMBtu cap on fuel combustors of >250 MW are also modeled for these sources in the 37 OTAG States. Rule effectiveness of 95% is assumed for all VOC and NOx control measures.

VOC and NOx emissions reductions in ozone nonattainment areas for the following CAA provisions are not accounted for: (1) offsets for major new source growth and major modifications; (2) Rate of Progress/Reasonable Further Progress (ROP/RFP) requirements; (3) additional VOC and/or NOx reductions needed in nonattainment areas for attainment of the current ozone standard by deadlines determined by nonattainment classification (e.g., serious, severe).

No new CAA-controls are assumed for point source SO_2 emitters, although individual states or nonattainment areas may require additional reductions. Because there are no PM_{10} control measures specifically prescribed by the CAA, PM controls for industrial point sources are assumed equivalent to 1990 levels. Although from a national perspective industrial point source PM_{10} emissions are a small component relative to area source PM_{10} emissions, this assumption could overestimate baseline PM_{10} emissions from individual point sources in some areas.

Utility

The 2010 CAA-control emissions for the utility sector are modeled using the Integrated Planning Model (IPM). Control measure assumptions include Title I and IV requirements. Existing fossil fuel burning units >25 MW and all new fossil fuel units (regardless of size) must comply with the Title IV Acid Rain SO_2 Allowance Trading Program. All new units are modeled as meeting SO_2 New Source Performance Standards (NSPS) for coal-fired units. However, it is assumed that every utility will operate new and existing units to obtain the largest amount of SO_2 reduction possible (i.e., 95%) to minimize allowances that any utility would have to purchase under the Title IV program. NOx RACT requirements are applied for existing sources in the OTR and nonattainment areas, where States have not applied for NOx waivers. Title IV Phase I and II emission limits are modeled as appropriate. Additionally, an OTAG-wide 0.15 lb/MMBtu summertime NOx cap with trading and banking implemented in 2005 is modeled (U.S.EPA, 1997a).

No CAA-mandated controls are assumed for emissions of VOC, PM_{10}, and $PM_{2.5}$ from utilities. However, emissions of these three pollutants are affected by the SO_2 and NOx controls modeled. VOC, PM_{10}, and $PM_{2.5}$ are calculated using boiler-specific heat input and emissions factors. Ammonia slippage is estimated for units where Selective Catalytic Reduction (SCR) is chosen as the control measure in IPM (Pechan, 1997a).

Nonroad Engines/Vehicles

The final rule for heavy duty diesel engines and the proposed Phase I rule for gasoline engines are incorporated in the 2010 CAA emissions scenario. Although Phase II emissions standards for small gasoline engines have not been proposed, emission reduction estimates are used from the California Federal Implementation Plan (FIP). Proposed emissions standards for gasoline and diesel marine engines and locomotives are applied in the 2010 CAA control emissions scenario. There are no CAA-mandated controls modeled for commercial aircraft for the 2010 baseline. Finally, a reformulated gasoline benefit of 3.3 percent is applied to all gasoline-powered engines in estimating 2010 emissions in areas that participate in the Federal reformulated gasoline program (Pechan, 1997a).

Motor Vehicles

The 2010 CAA control emissions also incorporate effects of mobile source controls (Pechan, 1997a). The nationwide emissions impacts from Federal tailpipe and evaporative emissions standards, Phase II Reid Vapor Pressure (RVP) limits for fuel volatility, the Federal Motor Vehicle Control Program (FMVCP) and heavy-duty NOx standard are estimated. The Federal reformulated gasoline program is applied to nine areas required to adopt this program under the CAA plus those areas that have opted into the program. The effects of the Oxygenated Fuel program for all carbon monoxide nonattainment areas are incorporated in the 2010 emissions. Basic I/M, low-enhanced I/M or high-enhanced I/M are applied to nonattainment areas according to requirements laid out in the CAA. National LEV is estimated nationally, with the exception of California where California LEV is applied.

Area Sources

Area source control measures incorporated in the 2010 CAA emissions include direct PM emissions controls in PM nonattainment areas, area source industrial fuel combustion NOx RACT, and VOC controls for: (1) Title I RACT and new CTGs in ozone nonattainment areas; (2) Title I national Stage II vapor recovery, final rules for Treatment, Storage and Disposal Facilities (TSDFs) and Municipal Solid Waste Landfills, and proposed Federal consumer solvent and AIM coatings rules; (3) Title III national MACT standards; and (4) onboard vapor recovery systems in the OTR and ozone nonattainment areas classified as serious and above (Pechan, 1997a). There are no controls for ammonia in the 2010 emissions baseline.

APPENDIX A.4

2010 National Post-CAA Control Emissions Estimates by Source Category

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
UTILITY						
Coal	24.7	3,598.8	9,661.4	249.0	83.8	0.5
Gas/Oil/Other	1.7	72.6	84.2	1.6	1.6	0.0
Internal Combustion	23.5	83.7	0.0	26.0	25.9	0.0
Total	**49.9**	**3,755.1**	**9,745.6**	**276.6**	**111.3**	**0.5**
INDUSTRIAL POINT						
Fuel Comb. Industrial	134.0	1,149.0	3,262.0	275.8	200.0	2.6
Fuel Comb. Other	14.9	76.9	282.9	23.0	11.1	0.1
Chemical & Allied Product Mfg.	542.7	211.1	546.4	74.2	52.0	1.8
Metals Processing	67.0	104.0	857.1	175.1	121.4	0.2
Petroleum & Related Industries	103.4	109.0	489.3	36.0	24.1	0.3
Other Industrial Processes	230.9	284.2	522.6	480.9	293.0	6.4
Solvent Utilization	809.5	3.1	1.0	3.0	2.5	12.0
Storage & Transport	252.7	3.0	6.4	75.9	30.8	1.8
Waste Disposal & Recycling	8.8	17.3	22.0	9.0	7.5	0.0
Miscellaneous	0.6	0.0	0.0	16.9	2.6	0.0
Total	**2,164.5**	**1,957.6**	**5,989.8**	**1,169.9**	**745.1**	**25.2**

Major Sector	**VOC** (1000 tpy)	**NOx** (1000 tpy)	**SO_2** (1000 tpy)	**PM_{10}** (1000 tpy)	**$PM_{2.5}$** (1000 tpy)	**SOA** (1000 tpy)
AREA						
Fuel Combustion Industrial	26.6	1,896.8	948.4	43.8	22.2	0.2
Fuel Combustion - Residential Wood	489.2	55.4	9.2	350.9	350.9	21.1
Fuel Combustion Other	29.0	742.3	532.3	47.4	27.3	0.5
Chemical & Allied Product MFG	270.4	0.0	0.0	0.0	0.0	0.5
Petroleum & Related Industries	202.8	15.0	1.1	1.2	1.2	0.4
Other Industrial Processes	108.0	6.0	2.5	44.2	29.3	0.3
Solvent Utilization	4,701.4	0.0	0.0	0.0	0.0	43.5
Storage & Transport	769.6	0.0	0.0	0.0	0.0	5.4
Waste Disposal & Recycling	513.5	74.5	19.6	261.6	228.1	0.5
Fugitive Dust - Natural Sources	13.8	0.0	0.0	5,184.8	777.7	0.0
Agricultural Production - Crops	127.8	17.0	0.4	10,004.5	2,102.1	0.1
Fugitive Dust - Paved Roads	0.0	0.0	0.0	7,489.0	1,872.3	0.0
Fugitive Dust - Unpaved Roads	0.0	0.0	0.0	12,300.2	1,846.0	0.0
Fugitive Dust - Construction	0.0	0.0	0.0	9,389.7	1,973.3	0.0
Agricultural Production - Livestock	115.3	0.0	0.0	658.4	99.1	0.0
Other Combustion - Wild Fires	234.2	89.1	1.3	243.6	217.0	0.2
Other Combustion - Prescribed Burning	179.5	124.6	4.7	445.0	377.1	0.1
Miscellaneous	0.0	0.0	0.0	16.1	2.6	0.0
Total	**7,781.1**	**3,020.7**	**1,519.5**	**46,480.4**	**9,926.2**	**72.8**

Major Sector	VOC (1000 tpy)	NOx (1000 tpy)	SO_2 (1000 tpy)	PM_{10} (1000 tpy)	$PM_{2.5}$ (1000 tpy)	SOA (1000 tpy)
NONROAD						
Nonroad Gasoline	1,255.9	276.3	4.1	51.6	42.9	9.2
Nonroad Diesel	261.6	935.8	22.4	187.1	172.1	6.2
Aircraft	300.3	249.2	13.8	41.3	29.1	7.1
Marine Vessels	34.4	158.5	142.3	23.3	17.0	1.0
Railroads	35.5	442.8	53.8	33.1	30.4	0.8
Total	**1,887.7**	**2,062.6**	**236.4**	**336.4**	**291.5**	**24.3**
MOTOR VEHICLE						
LDGV	2,263.6	2,402.1	178.0	74.0	42.2	13.8
LDGT1	760.6	783.8	64.0	22.7	13.4	4.6
LDGT2	583.0	631.6	32.6	11.4	6.8	3.6
HDGV	142.2	296.3	14.1	6.6	4.3	1.0
LDDV	0.0	0.0	0.0	0.0	0.0	0.0
LDDT	0.4	1.0	0.1	0.1	0.1	0.0
HDDV	151.8	1,443.0	120.1	88.4	73.9	3.6
MC	44.3	16.5	0.5	0.5	0.3	0.3
Total	**3,945.9**	**5,574.3**	**409.2**	**203.7**	**141.0**	**26.9**

Note: Emission estimates may not sum due to rounding.
1990 fugitive dust emissions have not been adjusted here as described in Section 4.4.2.3.
Air quality impacts from major emitting sectors are not necessarily proportional to their contribution to national emissions estimates. See PM and ozone air quality modeling sections 4.4 and 4.5 and Chapters 6 and 7.

APPENDIX A.5

OZONE REGRESSION EQUATION USED IN ROM EXTRAPOLATION METHODOLOGY

The equations used to predict average expected changes in ozone concentrations between 1990 and 2007 were generated through Ordinary Least Squares (OLS) regression of 1990 ROM basecase ozone concentration predictions and a number of explanatory variables against 2007 ROM predictions for the two emissions scenarios: CAA control and regional control strategy scenarios (MathTech, 1997). ROM results are available for the Eastern U.S. However, air quality concentrations are needed for the entire country to assess national benefits and costs. Through the inclusion of other explanatory variables, the regression equations control for factors that may differ between the east and west and could therefore explain variations in concentration values between 1990 and 2007.

The coefficient for ROM90, the modeled ozone concentration value in 1990, is positive and statistically different from zero in both regression equations. The results for the CAA-control scenario indicate that, all else equal, 2007 hourly ozone concentrations can be expected to decrease percent relative to 1990 hourly ozone concentrations (ROM90 coefficient = 0.90). The results for the regional control strategy scenario suggest that, all else equal, 2007 hourly ozone concentrations can be expected to decrease relative to 1990 hourly ozone concentrations (ROM90 = 0.79).

- Functional form: linear
- Sample selection: A random sample of ROM hourly predicted grid cell ozone concentrations for both 1990 and 2007 were selected using a random number generator
- Model specification: Five additional descriptive variables were included in the regression:
    - MFGPC:growth rate in manufacturing earnings per capita between 1990 and 2007 per county (BEA, 1990)
    - POP07: county population growth rate between 1990 and 2007 (BOC, 1992)

- County ozone nonattainment classification as expressed by 1 of 3 binary variables:
    - SEVR: severe
    - SERS7: serious
    - MAMD: moderate or marginal

Table 1. ROM Extrapolation Methodology: Regression Equation Statistics (Ordinary Least Squares)

INDEPENDENT VARIABLES	DEPENDENT VARIABLES			
	REGIONAL CONTROL STRATEGY (7,484 Observations)		CAA-CONTROL SCENARIO (1,093 Observations)	
	COEFFICIENT	T-STATISTIC	COEFFICIENT	T-STATISTIC
Constant	9.4709	6.362	-1.09765	-0.403
ROM90	0.78766	292.809	0.904335	193.696 *
MFGPC	0.37046	0.506	1.66716	1.306 **
POP07	-2.3576	-2.487	2.47670	1.404 **
SEVR	0.88009	2.941	0.601086	1.255
SERS7	0.39421	1.247	-0.789582	-1.580 **
MAMD	1.3104	7.088	0.258379	0.748
Adjusted R^2		**.92**		**.973**

* Statistically significant at the one percent level
** Statistically significant at the twenty percent level

APPENDIX B

SUMMARY OF CONTROL MEASURES IN THE PM, REGIONAL HAZE, AND OZONE PARTIAL ATTAINMENT ANALYSES

APPENDIX B.1
SUMMARY OF CONTROL MEASURES

This appendix contains a list of control measures used in the ozone, PM, and regional haze analyses. The list is sorted by affected source category and contains information on the pollutants reduced and the annual incremental cost per ton of pollutant reduced. All cost and emission reduction estimates for a given control measure are calculated incremental to controls already in place, or incremental to the next less stringent new control measure. For example, the cost and emission reductions associated with Selective Catalytic Reduction for Ammonia - Oil-Fired Reformers are incremental to application of Low-NOx Burners. The application of some control measures may result in cost savings (i.e., negative average incremental cost per ton values). In these cases, the estimated cost savings are due to the recovery of valuable products or to switching to technologies with lower long-run operating costs. Further, some control measures are assigned a zero incremental cost per ton. These measures involve either a long-run transition to a substitute technology with equivalent capital and operating costs, or behavioral change-inducing public information programs for which cost information could not be found or easily developed.

Some control measures have different cost and effectiveness values depending upon the analysis in which they are used. The baseline from which the control measure's cost and effectiveness is evaluated is slightly different for each analysis. For instance, the ozone analysis contains national application of more stringent Tier 2 light duty gasoline truck standards. The existence of this control measure affects the average incremental cost and effectiveness of any mobile source control measure affecting light duty gasoline trucks. Also, the cost and effectiveness of the PM and regional haze control measures are evaluated incremental to control measures selected to meet the current ozone standard, where the cost and effectiveness of the same controls in the ozone analysis are evaluated incremental to the 2010 CAAA baseline.

TABLE B.1
SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
MOBILE SOURCE CONTROL MEASURES																	
O3INC	mOT5	Highway Veh - HD Diesels	HDDV Retrofit Program	3,078					Y	Y	0	0	0	25,500	25,500	25,501	25,667
PMINC	mOT5	Highway Veh - HD Diesels	HDDV Retrofit Program	3,078					Y	Y	0	0	0	25,500	25,500	25,501	25,667
O3BSE	mOT1	Highway Veh - LD Gas Trucks	Tier 2 Standards	3,020	Y	Y	Y				16,913	4,996	0	0	5,636	35,676	53,544
O3INC	mOT3	Highway Veh - LD Gasoline	High Enhanced I/M	313	Y	Y	Y				1,146	1,348	0	0	440	677	805
O3INC	mOT4	Highway Veh - LD Gasoline	Fleet ILEV	3,078	Y	Y					25,299	0	0	0	7,161	24,191	75,877
PMINC	mOT3	Highway Veh - LD Gasoline	High Enhanced I/M	313	Y	Y	Y				987	1,319	0	0	397	620	805
PMINC	mOT4	Highway Veh - LD Gasoline	Fleet ILEV	3,078	Y	Y					22,457	0	0	0	6,555	20,741	75,826
O3INC	mOT2	Highway Vehicles - Gasoline	Federal Reformulated Gasoline	354	Y	Y	Y		Y	Y	6,726	37,145	0	754,763	3,732	6,363	25,339
O3INC	mOT6	Highway Vehicles - Gasoline	Transportation Control Package	3,078	Y	Y	Y	Y	Y	Y	12,755	10,000	110,390	294,652	4,158	5,697	7,135
PMINC	mOT6	Highway Vehicles - Gasoline	Transportation Control Package	3,078	Y	Y	Y	Y	Y	Y	11,457	10,000	112,543	290,750	3,897	5,394	7,135
allcs	PHDRET	Nonroad Diesel Engines	Heavy Duty Retrofit Program	3,020					Y	Y	0	0	0	9,531	8,286	9,503	14,000
O3INC	VNRFG	Nonroad Gasoline Engines	Federal Reformulated Gasoline	4,158	Y	Y					3,879	0	0	0	200	4,387	27,100
POINT SOURCE CONTROL MEASURES																	
allcs	V0529	Aircraft Surface Coating	Incineration	104	Y	Y					8,937	0	0	0	8,768	8,943	9,047
allcs	n05603	Ammonia - NG-Fired Reformers	Oxygen Trim + Water Injection	1			Y				0	774	0	0	774	774	774
allcs	n05604	Ammonia - NG-Fired Reformers	Selective Catalytic Reduction	34			Y				0	5,354	0	0	5	7,859	22,828
allcs	n05701	Ammonia - Oil-Fired Reformers	Low-NOx Burners	2			Y				0	984	0	0	984	984	984
allcs	n05703	Ammonia - Oil-Fired Reformers	Selective Catalytic Reduction	2			Y				0	5,138	0	0	5,138	5,138	5,138
allcs	V0951	Bakeries	Incineration at Oven Vent	4	Y						1,470	0	0	0	1,470	1,470	1,470
allcs	V0349	Beverage Can Coating	Incineration	422	Y	Y					8,937	0	0	0	7,925	8,935	9,525
allcs	V0321	Carbon Black Manufacture	Flare	38	Y						1,089	0	0	0	892	1,653	7,674
allcs	V0211	Cellulose Acetate Manufacture	Carbon Adsorption	12	Y						998	0	0	0	549	9,470	20,878
allcs	n03301	Cement Manufacturing - Dry	Mid-Kiln Firing	10			Y				0	568	0	0	566	568	568
allcs	n03303	Cement Manufacturing - Dry	SNCR - Urea Based	18			Y				0	1,221	0	0	1,220	1,222	1,233
allcs	n03305	Cement Manufacturing - Dry	Selective Catalytic Reduction	133			Y				0	9,849	0	0	9,756	9,848	9,851
allcs	n03401	Cement Manufacturing - Wet	Mid-Kiln Firing	6			Y				0	516	0	0	516	516	516
allcs	n03403	Cement Manufacturing - Wet	Selective Catalytic Reduction	10			Y				0	4,925	0	0	4,925	4,925	4,926

Note: Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

TABLE B.1
SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	V0541	Charcoal Manufacturing	Incineration	35	Y	Y					1,776	0	0	0	1,776	1,776	1,776
allcs	SCHEM	Chemical Manufacturing	FGD Scrubber	106				Y			0	0	1,627	0	232	7,317	71,688
allcs	P1001	Coal clean.-material handling	Local hood/venturi scrubber	449					Y	Y	0	0	0	1,527	331	8,360	94,156
allcs	P1002	Coal clean.-material handling	Local hood/fabric filter	452					Y	Y	0	0	0	500	17	974	8,456
allcs	P1003	Coal clean.-material handling	Water suppression	71					Y	Y	0	0	0	8,099	6,915	8,184	17,669
allcs	P1701	Coal cleaning - thermal dryers	Venturi scrubber	4					Y	Y	0	0	0	521	512	908	2,092
allcs	P0101	Coke mfg - oven pushing	Partial shed to baghouse	29					Y	Y	0	0	0	29,504	8,605	26,781	45,558
allcs	P0201	Coke sizing & screening - cold	Total enclosure to baghouse	1					Y	Y	0	0	0	4,244	4,244	4,244	4,244
allcs	n05901	Comm/Instit Incinerators	Selective Noncatalytic Redctn	7			Y				0	2,810	0	0	2,799	2,809	2,822
allcs	V1089	Fabric Coating	Incineration	1	Y						8,200	0	0	0	8,200	8,200	8,200
O3INC	n02405	Gas Turbines - Natural Gas	SCR + Steam Injection	72			Y				0	74,638	0	0	34,140	98,407	208,448
PMINC	n02405	Gas Turbines - Natural Gas	SCR + Steam Injection	178			Y				0	73,853	0	0	35,831	568,704	2,728,167
allcs	n02403	Gas Turbines - Natural Gas	Low-NOx Burners	64			Y				0	333	0	0	248	537	5,537
allcs	n02404	Gas Turbines - Natural Gas	SCR + Low-NOx Burners	6			Y				0	14,307	0	0	6,826	28,245	71,887
allcs	n02405	Gas Turbines - Natural Gas	SCR + Steam Injection	481			Y				0	48,132	0	0	668	49,502	466,613
allcs	n02406	Gas Turbines - Natural Gas	SCR + Water Injection	2			Y				0	38,266	0	0	32,795	40,607	48,418
allcs	n02301	Gas Turbines - Oil	Water Injection	1			Y				0	1,275	0	0	1,275	1,275	1,275
allcs	n02302	Gas Turbines - Oil	SCR + Water Injection	55			Y				0	19,311	0	0	17,500	19,717	24,233
allcs	n03104	Glass Manufacturing - Flat	Selective Catalytic Reduction	4			Y				0	1,483	0	0	1,440	17,071	63,833
allcs	n03105	Glass Manufacturing - Flat	Oxy-Firing	21			Y				0	15,121	0	0	10,101	44,568	534,000
allcs	n03005	Glass Mfg - Container	Selective Catalytic Reduction	16			Y				0	2,198	0	0	1,706	2,685	5,332
allcs	n03006	Glass Mfg - Container	Oxy-Firing	112			Y				0	23,797	0	0	15,695	32,302	96,303
allcs	n03206	Glass Mfg - Pressed/Blown	Oxy-Firing	26			Y				0	24,856	0	0	18,028	34,501	101,958
allcs	PGELE	Grain Elevators	Oil Suppression	190					Y	Y	0	0	0	2,413	2,409	2,416	2,424
allcs	n02210	IC Engines- Gas	Low Emission Combustion	1,980			Y				0	151	0	0	38	181	12,919
allcs	n02212	IC Engines- Gas	Nonselective Catalytic Redctn	1,964			Y				0	6,927	0	0	79	24,579	636,422
allcs	n02101	IC Engines- Oil	Ignition Timing Retard	22			Y				0	411	0	0	204	528	561
allcs	n04601	IC Engines - Gas, Diesel, LPG	Ignition Timing Retard	621			Y				0	545	0	0	467	553	800
allcs	n04604	IC Engines - Gas, Diesel, LPG	Selective Catalytic Reduction	622			Y				0	2,110	0	0	1,200	2,093	2,440
allcs	n02104	ICEngines- Oil	Selective Catalytic Reduction	1,310			Y				0	2,162	0	0	1,184	2,126	4,953

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TABLE B.1
SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	SICIX	ICI Boilers	Scrubber	1,626				Y			0	0	2,491	0	166	12,782	1,239,857
allcs	n04401	ICI Boilers - Bagasse	SNCR - Urea Based	41			Y				0	3,337	0	0	1,118	22,700	192,589
allcs	PICIC	ICI Boilers - Coal	Fabric Filter	956					Y	Y	0	0	0	4,190	23	25,505	474,751
allcs	n01401	ICI Boilers - Coal/Cyclone	Selective Noncatalytic Redctn	1			Y				0	1,917	0	0	1,917	1,917	1,917
allcs	n01404	ICI Boilers - Coal/Cyclone	Natural Gas Reburn	1			Y				0	2,975	0	0	2,975	2,975	2,975
allcs	n01201	ICI Boilers - Coal/FBC	SNCR - Urea Based	6			Y				0	1,431	0	0	841	1,920	3,467
allcs	n01301	ICI Boilers - Coal/Stoker	SNCR - Urea Based	29			Y				0	2,129	0	0	466	4,342	12,079
allcs	n01101	ICI Boilers - Coal/Wall	SNCR - Urea Based	9			Y				0	886	0	0	371	2,040	11,188
allcs	n01103	ICI Boilers - Coal/Wall	Low-NOx Burners	29			Y				0	864	0	0	366	3,302	47,897
allcs	n01104	ICI Boilers - Coal/Wall	Selective Catalytic Reduction	314			Y				0	10,272	0	0	115	49,101	1,302,848
allcs	n04201	ICI Boilers - Coke	SNCR - Urea Based	9			Y				0	778	0	0	363	1,154	2,712
allcs	n04203	ICI Boilers - Coke	Low-NOx Burners	8			Y				0	3,338	0	0	2,389	3,198	3,998
allcs	n04204	ICI Boilers - Coke	Selective Catalytic Reduction	9			Y				0	8,439	0	0	4,187	10,957	37,307
allcs	n01601	ICI Boilers - Distillate Oil	Low-NOx Burners	30			Y				0	3,978	0	0	284	4,347	50,742
allcs	n01602	ICI Boilers - Distillate Oil	LNB + Flue Gas Recirculation	34			Y				0	511,234	0	0	4,900	146,330	4,135,550
allcs	n01603	ICI Boilers - Distillate Oil	Selective Catalytic Reduction	492			Y				0	8,125	0	0	85	49,770	10,337,925
allcs	PICIG	ICI Boilers - Gas	Fabric Filter	1,972					Y	Y	0	0	0	13,267	22	68,861	6,996,274
allcs	n04501	ICI Boilers - Liquid Waste	Low-NOx Burners	33			Y				0	257	0	0	8	2,070	14,662
allcs	n04502	ICI Boilers - Liquid Waste	LNB + Flue Gas Recirculation	2			Y				0	9,707	0	0	3,092	9,165	15,237
allcs	n04503	ICI Boilers - Liquid Waste	Selective Catalytic Reduction	33			Y				0	1,167	0	0	151	14,185	116,392
allcs	n04301	ICI Boilers - LPG	Low-NOx Burners	22			Y				0	112	0	0	3	1,974	7,415
allcs	n04302	ICI Boilers - LPG	LNB + Flue Gas Recirculation	2			Y				0	8,911	0	0	7,250	8,318	9,386
allcs	n04303	ICI Boilers - LPG	Selective Catalytic Reduction	22			Y				0	1,496	0	0	184	22,354	116,461
allcs	n02001	ICI Boilers - MSW/Stoker	SNCR - Urea Based	41			Y				0	1,858	0	0	412	6,507	75,410
allcs	n01701	ICI Boilers - Natural Gas	Low-NOx Burners	48			Y				0	41	0	0	0	332	1,405
allcs	n01702	ICI Boilers - Natural Gas	LNB + Flue Gas Recirculation	361			Y				0	10,607	0	0	3,300	10,163	11,333
allcs	n01703	ICI Boilers - Natural Gas	Oxygen Trim + Water Injection	262			Y				0	487	0	0	12	1,199	12,390
allcs	n01704	ICI Boilers - Natural Gas	Selective Catalytic Reduction	4,953			Y				0	8,258	0	0	23	14,496	1,736,467
allcs	PICIO	ICI Boilers - Oil	Fabric Filter	2,530					Y	Y	0	0	0	10,678	375	42,426	7,257,569
allcs	n04101	ICI Boilers - Process Gas	Low-NOx Burners	8			Y				0	376	0	0	243	380	436

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SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	n04103	ICI Boilers - Process Gas	Oxygen Trim + Water Injection	171			Y				0	383	0	0	8	854	10,000
allcs	n04104	ICI Boilers - Process Gas	Selective Catalytic Reduction	750			Y				0	6,416	0	0	10	18,771	656,400
allcs	n01501	ICI Boilers - Residual Oil	Low-NOx Burners	146			Y				0	658	0	0	65	1,298	36,570
allcs	n01502	ICI Boilers - Residual Oil	LNB + Flue Gas Recirculation	4			Y				0	3,520	0	0	1,100	3,213	5,100
allcs	n01503	ICI Boilers - Residual Oil	Selective Catalytic Reduction	2,192			Y				0	3,435	0	0	89	12,175	330,638
allcs	PICIW	ICI Boilers - Wood	Electrostatic Precipitator	767					Y	Y	0	0	0	1,905	81	13,243	688,124
allcs	n01801	ICI Boilers - Wood/Bark/Stoker	SNCR - Urea Based	823			Y				0	1,275	0	0	166	5,942	197,817
allcs	n06001	Industrial Incinerators	Selective Noncatalytic Redctn	45			Y				0	2,809	0	0	2,400	2,791	3,000
allcs	P0301	Iron & steel - casthouses	Total enclosure to baghouse	20					Y	Y	0	0	0	17,062	16,806	17,345	18,805
allcs	P0402	Iron & steel - casthouses	Local hood venting to baghouse	20					Y	Y	0	0	0	8,069	7,472	11,872	28,336
allcs	n03606	Iron & Steel Mills- Annealing	Low-NOx Burners + SCR	20			Y				0	9,677	0	0	9,136	9,672	10,220
allcs	n03502	Iron & Steel Mills- Reheating	Low-NOx Burners	4			Y				0	295	0	0	295	295	295
allcs	n03503	Iron & Steel Mills- Reheating	LNB + Flue Gas Recirculation	44			Y				0	1,326	0	0	1,309	1,331	1,391
allcs	P0501	Iron&steel-hot metal transfer	Movable canopy to baghouse	1					Y	Y	0	0	0	22,699	22,699	22,699	22,699
allcs	P1601	Kraft process	ESP	80					Y	Y	0	0	0	9,347	35	469,630	1,655,816
allcs	P1602	Kraft process	Scrubber	127					Y	Y	0	0	0	10,984	3	59,526	311,949
allcs	P1603	Kraft process	Demister	75					Y	Y	0	0	0	479	83	889	3,464
allcs	V0981	Leather Products	RACT Extended to Other Areas	1	Y	Y					1,538	0	0	0	1,538	1,538	1,538
allcs	n05801	Lime Kilns	Mid-Kiln Firing	28			Y				0	568	0	0	568	568	569
allcs	n05803	Lime Kilns	SNCR - Urea Based	28			Y				0	1,221	0	0	1,220	1,221	1,224
allcs	n05805	Lime Kilns	Selective Catalytic Reduction	140			Y				0	9,849	0	0	9,831	9,849	9,861
allcs	n03901	Medical Waste Incinerators	Selective Noncatalytic Redctn	3			Y				0	12,615	0	0	10,800	12,014	12,630
allcs	P0901	Min. prod. - material handling	Local hood/venturi scrubber	314					Y	Y	0	0	0	1,773	1	24,283	109,298
allcs	P0902	Min. prod. - material handling	Local hood/fabric filter	316					Y	Y	0	0	0	802	118	2,704	9,571
allcs	P0903	Min. prod. - material handling	Water suppression	170					Y	Y	0	0	0	8,162	7,221	8,234	16,347
allcs	P0601	Mineral prod- dryers/furnaces	Venturi scrubber	206				Y	Y	Y	0	0	15,685	2,804	493	23,828	760,680
allcs	P0602	Mineral prod- dryers/furnaces	Fabric filter system	56					Y	Y	0	0	0	1,375	275	3,405	20,749
allcs	P1201	Mineral prod- loading/storage	Water suppression	469					Y	Y	0	0	0	8,025	7,222	8,177	16,770
allcs	P1501	Mineral prod. - vehicle travel	Chemical suppression	82					Y	Y	0	0	0	255	239	253	726
allcs	SMINP	Mineral Products	FGD Scrubber	421				Y			0	0	10,149	0	902	34,663	399,254

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TABLE B.1
SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	n03801	Municipal Waste Combustors	Selective Noncatalytic Redctn	4			Y				0	2,810	0	0	2,810	2,810	2,811
allcs	n02901	Nitric Acid Manufacturing	Extended Absorption	1			Y				0	8,650	0	0	8,650	8,650	8,650
allcs	n02903	Nitric Acid Manufacturing	Nonselective Catalytic Redctn	46			Y				0	11,482	0	0	8,521	10,346	20,669
allcs	P1801	Ore crushing	Fabric filter	1,193					Y	Y	0	0	0	10,923	32	13,259	54,574
allcs	P2001	Ore crushing/grinding	Fabric filter	5					Y	Y	0	0	0	22,149	14,079	22,423	27,803
allcs	P1901	Ore grinding	Fabric filter	734					Y	Y	0	0	0	7,222	79	8,558	66,224
allcs	V0971	Organic Acids Manufacture	RACT Extended to Other Areas	72	Y						1,607	0	0	0	1,538	1,609	1,616
allcs	SPETR	Petroleum Industry	FGD Scrubber	818				Y			0	0	6,745	0	86	35,852	459,256
allcs	P0701	Phosphate rock calcining	Venturi scrubber	5				Y	Y	Y	0	0	569	313	95	132	278
allcs	V0389	Plastic Parts Coating	Incineration	130	Y	Y					8,937	0	0	0	8,893	8,938	8,996
allcs	P0801	Prim. metals-material handling	Local hood/venturi scrubber	175					Y	Y	0	0	0	1,360	306	9,733	45,388
allcs	P0802	Prim. metals-material handling	Local hood/fabric filter	176					Y	Y	0	0	0	535	70	820	4,683
allcs	P0803	Prim. metals-material handling	Water suppression	13					Y	Y	0	0	0	8,127	7,884	8,109	8,673
allcs	SPMET	Primary Metal Production	FGD Scrubber	250				Y			0	0	7,266	0	187	31,971	363,162
allcs	P1301	Primary metals: vehicle travel	Chemical suppression	2					Y	Y	0	0	0	377	372	945	1,517
allcs	V1801	Printing - Letterpress	Carbon Adsorption	21	Y	Y					510	0	0	0	247	994	4,514
allcs	V1821	Printing - Lithographic	New CTG to Other Areas	46	Y	Y					(490)	0	0	0	(544)	(499)	(333)
allcs	n02504	Process Heaters-Distillate Oil	Ultra-low-NOx Burners	45			Y				0	948	0	0	292	1,376	3,067
allcs	n02506	Process Heaters-Distillate Oil	Low-NOx Burners + SNCR	60			Y				0	20,343	0	0	5,335	46,385	234,090
allcs	n02507	Process Heaters-Distillate Oil	Low-NOx Burners + SCR	225			Y				0	29,763	0	0	5,576	39,370	324,800
allcs	n04804	Process Heaters - LPG	Ultra-low-NOx Burners	2			Y				0	774	0	0	774	775	775
allcs	n04807	Process Heaters - LPG	Low-NOx Burners + SCR	2			Y				0	30,933	0	0	30,411	30,683	30,954
allcs	n02704	Process Heaters - Natural Gas	Ultra-low-NOx Burners	145			Y				0	810	0	0	20	1,556	14,157
allcs	n02706	Process Heaters - Natural Gas	Low-NOx Burners + SNCR	3,223			Y				0	15,765	0	0	4,083	30,521	4,140,200
allcs	n02707	Process Heaters - Natural Gas	Low-NOx Burners + SCR	3,275			Y				0	39,833	0	0	4,457	75,958	15,900,750
allcs	n04904	Process Heaters - Other Fuel	Ultra-low-NOx Burners	4			Y				0	531	0	0	463	484	539
allcs	n04907	Process Heaters - Other Fuel	Low-NOx Burners + SCR	4			Y				0	18,437	0	0	17,571	18,148	18,444
allcs	n04704	Process Heaters - Process Gas	Ultra-low-NOx Burners	579			Y				0	604	0	0	337	794	9,736
allcs	n04706	Process Heaters - Process Gas	Low-NOx Burners + SNCR	668			Y				0	13,991	0	0	5,200	27,278	826,133
allcs	n04707	Process Heaters - Process Gas	Low-NOx Burners + SCR	685			Y				0	36,070	0	0	19,332	57,984	1,204,600

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STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	n02604	Process Heaters - Residual Oil	Ultra-low-NOx Burners	1			Y				0	465	0	0	465	465	465
allcs	n02605	Process Heaters - Residual Oil	Low-NOx Burners + SNCR	3			Y				0	16,367	0	0	14,600	16,367	19,900
allcs	n02607	Process Heaters - Residual Oil	Low-NOx Burners + SCR	233			Y				0	18,427	0	0	17,566	18,495	22,650
allcs	SPULP	Pulp and Paper Industry	FGD Scrubber	277				Y			0	0	10,739	0	864	40,584	437,151
allcs	V1701	Service Stations- Stage I	Vapor Balance	3	Y	Y					68	0	0	0	62	88	135
allcs	V0571	SOCMI - Distillation	New CTG level control	64	Y	Y					1,372	0	0	0	817	2,737	8,069
allcs	V0561	SOCMI - Reactor Processes	New CTG level control	67	Y	Y					454	0	0	0	454	454	454
allcs	n05403	Space Heaters - Distillate Oil	Selective Catalytic Reduction	18			Y				0	12,987	0	0	2,826	34,065	251,459
allcs	n05503	Space Heaters - Natural Gas	Oxygen Trim + Water Injection	563			Y				0	774	0	0	717	774	825
allcs	n05504	Space Heaters - Natural Gas	Selective Catalytic Reduction	606			Y				0	8,777	0	0	87	23,748	326,473
allcs	P1401	Surface mining: vehicle travel	Chemical suppression	25					Y	Y	0	0	0	1,106	191	1,825	5,904
allcs	P1101	Surface mining-loading/storage	Water suppression	127					Y	Y	0	0	0	7,712	6,890	7,689	18,025
allcs	V0171	Terephthalic Acid Manufacture	Incineration	2	Y	Y					10,652	0	0	0	930	5,836	10,741
allcs	V0961	Urea Resins - General	RACT Extended to Other Areas	3	Y	Y					1,563	0	0	0	1,509	1,550	1,571
O3INC	n00206	Utility Boiler-Coal/Tangential	Selective Catalytic Reduction	39			Y				0	1,210	0	0	1,036	1,334	2,511
PMINC	n00206	Utility Boiler-Coal/Tangential	Selective Catalytic Reduction	39			Y				0	1,208	0	0	1,036	1,332	2,511
O3INC	n00107	Utility Boiler - Coal/Wall	Selective Catalytic Reduction	45			Y				0	1,066	0	0	889	1,213	2,643
PMINC	n00107	Utility Boiler - Coal/Wall	Selective Catalytic Reduction	45			Y				0	1,066	0	0	889	1,213	2,643
O3INC	n00510	Utility Boiler - Oil-Gas/Wall	Selective Catalytic Reduction	51			Y				0	6,050	0	0	1,088	27,863	193,699
PMINC	n00511	Utility Boiler - Oil-Gas/Wall	Selective Catalytic Reduction	110			Y				0	17,619	0	0	1,088	59,792	140,343
PMINC	PUTILC	Utility Boilers - Coal	Fabric Filter	53					Y	Y	0	0	0	2,695	316	4,298	11,389
PMINC	PUTILG	Utility Boilers - Gas	Fabric Filter	197					Y	Y	0	0	0	313,215	1,651	572,318	2,507,957
allcs	V0281	Vegetable Oil Manufacture	Stripper and Equipment	18	Y						(21)	0	0	0	(145)	804	7,479
allcs	V0531	Whiskey Fermentation - Aging	Carbon Adsorption	16	Y						34	0	0	0	34	34	34
allcs	V0399	Wood Furniture Coating	Incineration	290	Y	Y					8,937	0	0	0	8,855	8,937	8,987
AREA SOURCE CONTROL MEASURES																	
allcs	V2262	Adhesives - Industrial	SCAQMD 1168 (Content Limits)	2,933	Y	Y					2,109	0	0	0	2,022	2,109	2,178
allcs	V2263	Adhesives - Industrial	SC 1168 Am. (Content Limits)	2,780	Y	Y					7,189	0	0	0	4,500	7,178	9,900
allcs	V2483	Aerosols	CARB Tier 2 Stds - Reform.	2,972	Y	Y					293	0	0	0	292	293	295
allcs	Pagbu	Agricultural Burning	Bale Stack/Propane Burning	370					Y	Y	0	0	0	5,252	1,831	3,321	8,164

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					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	Pagtl	Agricultural Tilling	Soil Conservation Plans	2,922					Y	Y	0	0	0	138	133	138	150
allcs	V2202	Architectural Coatings	SCAQMD 1113 (Phase I Limits)	3,078	Y	Y					4,076	0	0	0	3,856	4,127	22,281
allcs	V2462	Autobody Refinishing	CARB BARCT Limits	2,520	Y	Y					4,018	0	0	0	3,896	4,021	4,138
allcs	V2463	Autobody Refinishing	FIP VOC Content + Improved TE	2,520	Y	Y					15,177	0	0	0	15,073	15,176	15,740
allcs	V2712	Bakeries >100,000 lbs brd/day	Incineration	490	Y						1,470	0	0	0	1,469	1,470	1,471
allcs	Pcatf	Beef Cattle Feedlots	Watering	1,290					Y	Y	0	0	0	307	306	307	307
allcs	n10601	Comm/Instit - NG Consumption	Water Heater Replacement	2,964			Y				0	0	0	0	0	0	0
allcs	n10602	Comm/Instit - NG Consumption	Low NOx Water/Space Heater	2,964			Y				0	1,608	0	0	1,527	1,608	1,660
allcs	Pcnst	Construction Activities	Dust Control Plan	2,605					Y	Y	0	0	0	3,600	3,600	3,600	3,600
O3INC	VCONS	Consumer Solvent	CARB Mid-Term Limits	12,162					Y	Y	2,101	0	0	0	1,857	2,101	2,533
allcs	V2721	Cutback Asphalt	Switch to Emulsified Asphalts	2,612	Y	Y					0	0	0	0	0	0	0
allcs	V2222	Ind. Maintenance Coatings	SCAQMD 1113 (Phase I Limits)	2,500	Y	Y					4,083	0	0	0	3,804	4,065	14,732
allcs	n10001	Industrial Coal Combustion	RACT to 50 tpy (LNB)	1,530			Y				0	1,350	0	0	700	1,344	2,000
allcs	n10002	Industrial Coal Combustion	RACT to 25 tpy (LNB)	1,557			Y				0	1,350	0	0	850	1,352	2,200
allcs	n10201	Industrial NG Combustion	RACT to 50 tpy (LNB)	2,383			Y				0	770	0	0	714	771	900
allcs	n10202	Industrial NG Combustion	RACT to 25 tpy (LNB)	2,477			Y				0	770	0	0	650	770	867
allcs	n10101	Industrial Oil Combustion	RACT to 50 tpy (LNB)	2,880			Y				0	905	0	0	500	1,031	1,700
allcs	n10102	Industrial Oil Combustion	RACT to 25 tpy (LNB)	3,084			Y				0	1,010	0	0	100	1,005	2,100
allcs	V2474	Mach/Electr./Railrd Coating	SCAQMD 1107 (Content Limits)	1,192	Y	Y					3,888	0	0	0	2,822	3,930	5,404
allcs	V2519	Marine Surface Coating	Incineration	622	Y	Y					8,937	0	0	0	8,300	8,937	9,160
allcs	V2239	Metal Coil and Can Coating	Incineration	1,702	Y	Y					8,937	0	0	0	8,663	8,939	9,188
allcs	V2454	Metal Furn/Appli/Parts Coating	SCAQMD 1107 (Content Limits)	4,062	Y	Y					4,618	0	0	0	2,547	4,668	9,810
allcs	V2533	Misc Surf Coating- Electronics	SCAQMD 1164 (Add-on/Low-VOC)	1,947	Y	Y					6,795	0	0	0	5,975	6,861	7,300
allcs	V2549	Motor vehicle surface coating	Incineration	1,020	Y	Y					8,937	0	0	0	8,693	8,938	9,246
allcs	V2791	Oil and NG Production Fields	RACT (Equip/Maint) Extended	684	Y	Y					334	0	0	0	300	334	347
allcs	V2662	Open Burning	Advisory Program	4,031	Y		Y				0	0	0	0	0	0	0
allcs	V2329	Open Top/Convey. Degreasing	SCAQMD 1122 (Low-VOC Solvents)	9,820	Y	Y					100	0	0	0	100	100	100
allcs	PP170	Paved Road-Rural Major Coll.	Vacuum Sweeping	2,975					Y	Y	0	0	0	392	180	376	610
allcs	PP150	Paved Road-Rural Minor Art.	Vacuum Sweeping	2,975					Y	Y	0	0	0	348	198	333	479
allcs	PP190	Paved Road-Rural Minor Coll.	Vacuum Sweeping	2,975					Y	Y	0	0	0	491	208	436	707

Note: Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

TABLE B.1
SUMMARY OF CONTROL MEASURES

STRAT Code[a]	MEAS ID[b]	SOURCE CATEGORY	MEASURE NAME	COUNT[c]	Pollutant Reduced						Average Nationwide Cost Per Ton[d] (single pollutant)				Range of Cost Per Ton Incidence[e]		
					VOC	SOA	NOx	SO_2	PM_{10}	$PM_{2.5}$	VOC	NOx	SO_2	PM_{10}	Min.	Avg.	Max.
allcs	PP130	Paved Road-Rural Oth Prin Art.	Vacuum Sweeping	2,975					Y	Y	0	0	0	159	93	156	224
allcs	PP290	Paved Road-Urban Minor Art.	Vacuum Sweeping	2,226					Y	Y	0	0	0	187	100	182	229
allcs	PP250	Paved Road-Urban Oth Freeway	Vacuum Sweeping	1,778					Y	Y	0	0	0	301	112	284	400
allcs	PP270	Paved Road-Urban Oth Prin Art.	Vacuum Sweeping	2,225					Y	Y	0	0	0	287	212	278	350
allcs	PP110	Paved Road - Rural Interstate	Vacuum Sweeping	2,972					Y	Y	0	0	0	1,066	660	1,055	1,432
allcs	PP210	Paved Road - Rural Local	Vacuum Sweeping	2,891					Y	Y	0	0	0	514	262	475	712
allcs	PP310	Paved Road - Urban Collector	Vacuum Sweeping	2,225					Y	Y	0	0	0	248	184	241	342
allcs	PP230	Paved Road - Urban Interstate	Vacuum Sweeping	2,158					Y	Y	0	0	0	650	249	634	1,008
allcs	PP330	Paved Road - Urban Local	Vacuum Sweeping	2,226					Y	Y	0	0	0	846	389	810	1,089
allcs	V2952	Pesticide Application	CA FIP Rule - Reformulation	3,106	Y	Y					9,300	0	0	0	8,067	9,302	11,150
allcs	Ppreb	Prescribed Burning	Increase Fuel Moisture	989					Y	Y	0	0	0	2,618	2,616	2,618	2,633
allcs	n10901	Residential NG Combustion	Water Heater Replacement	3,049			Y				0	0	0	0	0	0	0
allcs	n10902	Residential NG Combustion	Low NOx Water/Space Heater	3,049			Y				0	1,608	0	0	1,550	1,608	1,700
allcs	Presw	Residential Wood Combustion	Education and Advisory Program	3,159	Y	Y			Y	Y	947	0	0	1,320	895	982	4,657
allcs	V2441	Rubber & Plastics Mfg	SCAQMD 1145 (Low-VOC Coatings)	1,540	Y	Y					1,030	0	0	0	1,025	1,030	1,050
allcs	V2833	Serv.Stations- Undergrnd Tanks	P/V Vents + Vapor Balan	2,776	Y	Y					25	0	0	0	20	25	29
allcs	V2803	Service Stations - Stage I	P/V Vents + Vapor Balan	2,685	Y	Y					25	0	0	0	20	25	50
allcs	V2212	Traffic Marking Paints	SCAQMD 1113 (Phase I Limits)	2,958	Y	Y					3,940	0	0	0	3,837	3,941	4,100
allcs	PU270	Unpaved Rd-Urban Oth Prin Art.	Hot Asphalt Paving	218					Y	Y	0	0	0	508	0	421	1,360
allcs	PU170	Unpaved Road-Rural Major Coll.	Chemical Stabilization	1,664					Y	Y	0	0	0	2,348	0	2,995	7,250
allcs	PU150	Unpaved Road-Rural Minor Art.	Chemical Stabilization	93					Y	Y	0	0	0	1,199	784	1,208	2,417
allcs	PU190	Unpaved Road-Rural Minor Coll.	Chemical Stabilization	2,620					Y	Y	0	0	0	2,609	1,403	3,231	6,444
allcs	PU290	Unpaved Road-Urban Minor Art.	Hot Asphalt Paving	1,473					Y	Y	0	0	0	574	0	482	2,267
allcs	PU210	Unpaved Road - Rural Local	Chemical Stabilization	3,018					Y	Y	0	0	0	2,664	1,403	3,170	6,360
allcs	PU310	Unpaved Road - Urban Collector	Hot Asphalt Paving	1,799					Y	Y	0	0	0	566	0	557	1,836
allcs	PU330	Unpaved Road - Urban Local	Hot Asphalt Paving	2,191					Y	Y	0	0	0	548	0	627	1,821
allcs	V2851	Web Offset Lithography	New CTG level control	2,352	Y	Y					(105)	0	0	0	(120)	(105)	(100)

a Strat. Code = Code indicating whether the measure is evaluated incremental to partial attainment of the ozone standards (O3INC), PM standards (PMINC), or both (allcs)
b Meas. ID = Control measure identification code
c COUNT= Potential number of point sources (for points source measures) or counties (for area and mobile source measures) to which the control measure can be applied nationwide. (continued...)

d Average nationwide cost per ton calculated by dividing total nationwide emission reduction for the specified pollutant by the total annual incremental cost of the control measure. All costs are expressed in 1990 dollars.

e Range of cost per ton values derived from the array of cost per ton values for individual applications of each control measure (i.e., the collection of cost per ton values associated with the number of potentially affected sources in the COUNT column. The average cost per ton incidence is calculated as the average of each cost per ton value in the collection of cost per ton values associated with each potentially affected source, and may differ from the average nationwide cost per ton values appearing in the preceding columns. All costs are expressed in 1990 dollars.

APPENDIX B.2

DOCUMENTATION OF CONTROL MEASURES BY SOURCE CATEGORY[1]

Source Category[2]	Control Measure Description	Reference[3]
STATIONARY POINT VOC SOURCES		
Aircraft Surface Coating	Incineration	Pechan, 1994a
Beverage Can Surface Coating	Incineration	Pechan, 1994a
Carbon Black Manufacture	Flare	Pechan, 1989
Cellulose Acetate Manufacture	Carbon Adsorption	Pechan, 1989
Charcoal Manufacturing	Incineration	Pechan, 1989
Commercial Bread Bakeries (>100,000 pounds of bread/day)*	Incineration at Oven Vent	Pechan, 1997
Fabric Coating	Incineration	Pechan, 1994b
Leather Products	RACT for Ozone Nonattainment Areas Extended to Attainment Areas	Pechan, 1994b
Organic Acids Manufacture	RACT for Ozone Nonattainment Areas Extended to Attainment Areas	Pechan, 1994b
Plastic Parts Surface Coating	Incineration	Pechan, 1994a
Printing - Letterpress	Carbon Adsorption	Pechan, 1989
Printing - Lithographic	New CTG Level of Control Extended to Other Areas	Pechan, 1994c
Service Stations- Stage I	Vapor Balance/Submerged Fill	Pechan, 1989
SOCMI - Distillation	New CTG Level of Control	Pechan, 1994c
SOCMI - Reactor Processes	New CTG Level of Control	Pechan, 1994c
Terephthalic Acid Manufacture	Incineration	Pechan, 1989
Urea Resins - General	RACT for Ozone Nonattainment Areas Extended to Attainment Areas	Pechan, 1994b
Vegetable Oil Manufacture	Stripper and Equipment	Pechan, 1989
Whiskey Fermentation - Aging	Carbon Adsorption	Pechan, 1989
Wood Furniture Surface Coating	Incineration	Pechan, 1994c
STATIONARY AREA/NONROAD VOC SOURCES		
Adhesives - Industrial*	VOC Content Limits (Based on SCAQMD's Rule 1168)	Pechan, 1997
Adhesives - Industrial*	VOC Content Limits (Based on SCAQMD's Amendments to Rule 1168)	Pechan, 1997
Aerosol Paints*	Reformulation (Based on CARB Tier 2 Standards)	Pechan, 1997
Architectural Coatings*	Phase I VOC Limits (Based on SCAQMD's Rule 1113)	Pechan, 1997
Autobody Refinishing	CARB BARCT Limits	Pechan, 1994a
Autobody Refinishing	VOC Content Limits + Improved Transfer Efficiency (Based on California Federal Implementation Plan Rule for Ozone Nonattainment Areas)	Pechan, 1994a
Commercial Bread Bakeries (>100,000 pounds of bread/day)*	Incineration	Pechan, 1997
Consumer Products*	CARB Mid-Term Limits	Pechan, 1997
Cutback Asphalt	Switch to Emulsified Asphalts	Pechan, 1989
Industrial Maintenance Coatings*	Phase I VOC Limits (Based on SCAQMD's Rule 1113)	Pechan, 1997
Machinery and Railroad Equipment Coating*	VOC Content Limits (Based on SCAQMD Rule 1107)	Pechan, 1997
Marine Surface Coating	Incineration	Pechan, 1994a
Metal Can and Coil Coating*	Incineration	Pechan, 1994a
Metal Furniture/Appliances/Miscellaneous Parts Coating*	VOC Content Limits (Based on SCAQMD Rule 1107)	Pechan, 1997
Miscellaneous Surface Coating - Electronics*	Add-on Control Equipment/Low-VOC Coatings (Based on SCAQMD's Rule 1164)	Pechan, 1997
Motor Vehicle and Mobile Equipment Surface Coating	Incineration	Pechan, 1994a
Nonroad Gasoline Engines	Federal Reformulated Gasoline	Pechan, 1994a
Oil and Natural Gas Production Fields	RACT for Ozone Nonattainment Areas Extended to Attainment Areas (Based on Equipment Inspection & Maintenance Program)	Pechan, 1989
Open Burning	Advisory Program	Pechan, 1994a

APPENDIX B.2 (continued)

DOCUMENTATION OF CONTROL MEASURES BY SOURCE CATEGORY[1]

Source Category[2]	Control Measure Description	Reference[3]
Open-Top and Conveyorized Degreasing*	Low-VOC Solvents (Based on SCAQMD's Rule 1122)	Pechan, 1997
Pesticide Application	Reformulation (Based on California Federal Implementation Plan Rule for Ozone Nonattainment Areas)	Pechan, 1994a
Rubber & Plastics Manufacture*	Low-VOC Coatings (Based on SCAQMD's Rule 1145)	Pechan, 1997
Service Stations - Stage I	Pressure Vacuum Valves Installed on Underground Storage Tank Vents + Vapor Balance	Pechan, 1994a
Service Stations - Underground Tanks	Pressure Vacuum Valves Installed on Underground Storage Tank Vents + Vapor Balance	Pechan, 1994a
Traffic Marking Paints*	Phase I VOC Limits (Based on SCAQMD's Rule 1113)	Pechan, 1997
Web Offset Lithography*	New CTG Level of Control	Pechan, 1997
STATIONARY POINT NO_x SOURCES		
Ammonia - Natural Gas - Fired Reformers*	Oxygen Trim + Water Injection	Pechan, 1997
Ammonia - Natural Gas - Fired Reformers*	Selective Catalytic Reduction	Pechan, 1997
Ammonia - Oil-Fired Reformers*	Low-NO_x Burners	Pechan, 1997
Ammonia - Oil-Fired Reformers*	Selective Catalytic Reduction	Pechan, 1997
Cement Manufacturing - Dry Process	Mid-Kiln Firing	Pechan, 1996
Cement Manufacturing - Dry Process	Selective Catalytic Reduction	Pechan, 1996
Cement Manufacturing - Dry Process	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996
Cement Manufacturing - Wet Process	Mid-Kiln Firing	Pechan, 1996
Cement Manufacturing - Wet Process	Selective Catalytic Reduction	Pechan, 1996
Gas Turbines - Natural Gas	Low-NO_x Burners	Pechan, 1996
Gas Turbines - Natural Gas	Selective Catalytic Reduction + Low-NO_x Burners	Pechan, 1996
Gas Turbines - Natural Gas	Selective Catalytic Reduction + Steam Injection	Pechan, 1996
Gas Turbines - Natural Gas	Selective Catalytic Reduction + Water Injection	Pechan, 1996
Gas Turbines - Oil	Selective Catalytic Reduction + Water Injection	Pechan, 1996
Gas Turbines - Oil	Water Injection	Pechan, 1996
Glass Manufacture - Container	Oxy-Firing	Pechan, 1996
Glass Manufacture - Container	Selective Catalytic Reduction	Pechan, 1996
Glass Manufacture - Pressed/Blown	Oxy-Firing	Pechan, 1996
Glass Manufacturing - Flat	Oxy-Firing	Pechan, 1996
Glass Manufacturing - Flat	Selective Catalytic Reduction	Pechan, 1996
ICI Boilers - Bagasse*	Selective Noncatalytic Reduction - Urea Based	Pechan, 1997
ICI Boilers - Coal/Cyclone	Natural Gas Reburn	Pechan, 1996
ICI Boilers - Coal/Cyclone	Selective Noncatalytic Reduction	Pechan, 1996
ICI Boilers - Coal/Fluidized Bed Combustion	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996
ICI Boilers - Coal/Stoker	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996
ICI Boilers - Coal/Wall	Low-NO_x Burners	Pechan, 1996
ICI Boilers - Coal/Wall	Selective Catalytic Reduction	Pechan, 1996
ICI Boilers - Coal/Wall	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996
ICI Boilers - Coke*	Low-NO_x Burners	Pechan, 1997
ICI Boilers - Coke*	Selective Catalytic Reduction	Pechan, 1997
ICI Boilers - Coke*	Selective Noncatalytic Reduction - Urea Based	Pechan, 1997
ICI Boilers - Distillate Oil	Low-NO_x Burners	Pechan, 1996
ICI Boilers - Distillate Oil	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1996
ICI Boilers - Distillate Oil	Selective Catalytic Reduction	Pechan, 1996
ICI Boilers - Liquid Waste*	Low-NO_x Burners	Pechan, 1997
ICI Boilers - Liquid Waste*	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1997
ICI Boilers - Liquid Waste*	Selective Catalytic Reduction	Pechan, 1997
ICI Boilers - Liquified Petroleum Gas*	Low-NO_x Burners	Pechan, 1997
ICI Boilers - Liquified Petroleum Gas*	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1997
ICI Boilers - Liquified Petroleum Gas*	Selective Catalytic Reduction	Pechan, 1997
ICI Boilers - Municipal Solid Waste/Stoker	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996

APPENDIX B.2 (continued)

DOCUMENTATION OF CONTROL MEASURES BY SOURCE CATEGORY[1]

Source Category[2]	Control Measure Description	Reference[3]
ICI Boilers - Natural Gas	Low-NO_x Burners	Pechan, 1996
ICI Boilers - Natural Gas	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1996
ICI Boilers - Natural Gas	Oxygen Trim + Water Injection	Pechan, 1996
ICI Boilers - Natural Gas	Selective Catalytic Reduction	Pechan, 1996
ICI Boilers - Process Gas*	Low-NO_x Burners	Pechan, 1997
ICI Boilers - Process Gas*	Oxygen Trim + Water Injection	Pechan, 1997
ICI Boilers - Process Gas*	Selective Catalytic Reduction	Pechan, 1997
ICI Boilers - Residual Oil	Low-NO_x Burners	Pechan, 1996
ICI Boilers - Residual Oil	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1996
ICI Boilers - Residual Oil	Selective Catalytic Reduction	Pechan, 1996
ICI Boilers - Wood & Bark Waste/Stoker	Selective Noncatalytic Reduction - Urea Based	Pechan, 1996
Incinerators (Commercial/Institutional)*	Selective Noncatalytic Reduction	Pechan, 1997
Incinerators (Industrial)*	Selective Noncatalytic Reduction	Pechan, 1997
Internal Combustion Engines - Gas, Diesel, Liquified Petroleum Gas*	Ignition Timing Retard	Pechan, 1997
Internal Combustion Engines - Gas, Diesel, Liquified Petroleum Gas*	Selective Catalytic Reduction	Pechan, 1997
Internal Combustion Engines - Natural Gas	Low Emission Combustion	Pechan, 1996
Internal Combustion Engines - Natural Gas	Nonselective Catalytic Reduction	Pechan, 1996
Internal Combustion Engines- Oil	Ignition Timing Retard	Pechan, 1996
Internal Combustion Engines- Oil	Selective Catalytic Reduction	Pechan, 1996
Iron & Steel Mills- Reheating	Low-NO_x Burners	Pechan, 1996
Iron & Steel Mills- Reheating	Low-NO_x Burners + Flue Gas Recirculation	Pechan, 1996
Iron & Steel Mills- Annealing	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1996
Lime Kilns*	Mid-Kiln Firing	Pechan, 1997
Lime Kilns*	Selective Catalytic Reduction	Pechan, 1997
Lime Kilns*	Selective Noncatalytic Reduction - Urea Based	Pechan, 1997
Medical Waste Incinerators	Selective Noncatalytic Reduction	Pechan, 1996
Municipal Waste Combustors	Selective Noncatalytic Reduction	Pechan, 1996
Nitric Acid Manufacturing	Extended Absorption	Pechan, 1996
Nitric Acid Manufacturing	Nonselective Catalytic Reduction	Pechan, 1996
Open Burning	Advisory Program	Pechan, 1994a
Process Heaters (Industrial) - Distillate Oil*	Ultra-Low-NO_x Burners	Pechan, 1997
Process Heaters (Industrial) - Distillate Oil*	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Distillate Oil*	Low-NO_x Burners + Selective Noncatalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Liquified Petroleum Gas*	Ultra-Low-NO_x Burners	Pechan, 1997
Process Heaters (Industrial) - Liquified Petroleum Gas*	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Natural Gas	Ultra-Low-NO_x Burners	Pechan, 1996
Process Heaters (Industrial) - Natural Gas	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1996
Process Heaters (Industrial) - Natural Gas	Low-NO_x Burners + Selective Noncatalytic Reduction	Pechan, 1996
Process Heaters (Industrial) - Other Fuel*	Ultra-Low-NO_x Burners	Pechan, 1997
Process Heaters (Industrial) - Other Fuel*	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Process Gas*	Ultra-Low-NO_x Burners	Pechan, 1997
Process Heaters (Industrial) - Process Gas*	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Process Gas*	Low-NO_x Burners + Selective Noncatalytic Reduction	Pechan, 1997
Process Heaters (Industrial) - Residual Oil	Ultra-Low-NO_x Burners	Pechan, 1996
Process Heaters (Industrial) - Residual Oil	Low-NO_x Burners + Selective Catalytic Reduction	Pechan, 1996
Process Heaters (Industrial) - Residual Oil	Low-NO_x Burners + Selective Noncatalytic Reduction	Pechan, 1996
Space Heaters (Industrial) - Distillate Oil*	Selective Catalytic Reduction	Pechan, 1997
Space Heaters (ICI) - Natural Gas*	Oxygen Trim + Water Injection	Pechan, 1997
Space Heaters (ICI) - Natural Gas*	Selective Catalytic Reduction	Pechan, 1997
Utility Boilers - Coal/Cyclone[4]	Selective Catalytic Reduction	EPA, 1996

APPENDIX B.2 (continued)

DOCUMENTATION OF CONTROL MEASURES BY SOURCE CATEGORY[1]

Source Category[2]	Control Measure Description	Reference[3]
Utility Boilers - Coal/Tangential[4]	Selective Catalytic Reduction	EPA, 1996
Utility Boilers - Coal/Wall[4]	Selective Catalytic Reduction	EPA, 1996
Utility Boilers - Natural Gas/Tangential[4]	Selective Catalytic Reduction	EPA, 1996
Utility Boilers - Natural Gas/Wall[4]	Selective Catalytic Reduction	EPA, 1996
STATIONARY AREA/NONROAD NO_x SOURCES		
Commercial/Institutional - Natural Gas Consumption*	Replace Conventional Water Heaters with Low-NO_x Units	Pechan, 1997
Commercial/Institutional - Natural Gas Consumption*	Replace Conventional Water Heaters & Space Heaters with Low-NO_x Units	Pechan, 1997
Industrial Coal Combustion	RACT Extended to Sources with NO_x Emissions of 25 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Industrial Coal Combustion	RACT Extended to Sources with NO_x Emissions of 50 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Industrial Natural Gas Combustion	RACT Extended to Sources with NO_x Emissions of 25 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Industrial Natural Gas Combustion	RACT Extended to Sources with NO_x Emissions of 50 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Industrial Oil Combustion	RACT Extended to Sources with NO_x Emissions of 25 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Industrial Oil Combustion	RACT Extended to Sources with NO_x Emissions of 50 tpy or more (Based on Low-NO_x Burners)	Pechan, 1996
Open Burning	Episodic Ban (Modeled as one measure for VOC and NO_x)	Pechan, 1994a
Residential Natural Gas Combustion	Replace Conventional Water Heaters with Low-NO_x Units	Pechan, 1996
Residential Natural Gas Combustion	Replace Conventional Water Heaters & Space Heaters with Low-NO_x Units	Pechan, 1996
STATIONARY POINT PM-10 AND PM-2.5 SOURCES		
Coal Cleaning - Material Handling*	Water Suppression	Pechan, 1997
Coal Cleaning - Material Handling*	Local Hood Vented to Fabric Filter	Pechan, 1997
Coal Cleaning - Material Handling*	Local Hood Vented to Venturi Scrubber	Pechan, 1997
Coal Cleaning - Thermal Dryers*	Venturi Scrubber	Pechan, 1997
Coke Manufacture - Oven Pushing*	Partial Shed Vented to Fabric Filter	Pechan, 1997
Coke Sizing & Screening - Cold*	Total Enclosure Vented to Fabric Filter	Pechan, 1997
Grain Elevators*	Oil Suppression	Pechan, 1997
ICI Boilers - Coal	Fabric Filter	Pechan, 1995
ICI Boilers - Gas	Fabric Filter	Pechan, 1995
ICI Boilers - Oil	Fabric Filter	Pechan, 1995
ICI Boilers - Wood/Bark Waste*	Electrostatic Precipitator	Pechan, 1997
Iron & Steel Production - Casthouses*	Local Hood Vented to Fabric Filter	Pechan, 1997
Iron & Steel Production - Casthouses*	Total Enclosure Vented to Fabric Filter	Pechan, 1997
Iron & Steel Production - Hot Metal Transfer*	Movable Canopy Hood Vented to Fabric Filter	Pechan, 1997
Kraft Process*	Demister	Pechan, 1997
Kraft Process*	Scrubber	Pechan, 1997
Kraft Process*	Electrostatic Precipitator	Pechan, 1997
Mineral Products - Dryers/Furnaces*	Fabric Filter	Pechan, 1997
Mineral Products - Dryers/Furnaces*	Venturi Scrubber	Pechan, 1997
Mineral Products - Loading/Storage*	Water Suppression	Pechan, 1997
Mineral Products - Material Handling*	Water Suppression	Pechan, 1997
Mineral Products - Material Handling*	Local Hood Vented to Fabric Filter	Pechan, 1997
Mineral Products - Material Handling*	Local Hood Vented to Venturi Scrubber	Pechan, 1997
Mineral Products - Vehicle Travel*	Chemical Suppression	Pechan, 1997
Ore Crushing & Grinding Operations*	Fabric Filter	Pechan, 1997
Ore Crushing Operations*	Fabric Filter	Pechan, 1997
Ore Grinding Operations*	Fabric Filter	Pechan, 1997

APPENDIX B.2 (continued)

DOCUMENTATION OF CONTROL MEASURES BY SOURCE CATEGORY[1]

Source Category[2]	Control Measure Description	Reference[3]
Phosphate Rock Calcining*	Venturi Scrubber	Pechan, 1997
Primary Metals Production - Material Handling*	Water Suppression	Pechan, 1997
Primary Metals Production - Material Handling*	Local Hood Vented to Fabric Filter	Pechan, 1997
Primary Metals Production - Material Handling*	Local Hood Vented to Venturi Scrubber	Pechan, 1997
Primary Metals Production - Vehicle Travel*	Chemical Suppression	Pechan, 1997
Surface Mining - Loading/Storage*	Water Suppression	Pechan, 1997
Surface Mining - Vehicle Travel*	Chemical Suppression	Pechan, 1997
Utility Boilers - Coal	Fabric Filter	Pechan, 1995
Utility Boilers - Gas	Fabric Filter	Pechan, 1995
STATIONARY AREA/NONROAD PM-10 AND PM-2.5 SOURCES		
Agricultural Burning	Bale Stack/Propane Burning	Pechan, 1995
Agricultural Tilling*	Soil Conservation Plans	Pechan, 1997
Beef Cattle Feedlots	Watering	Pechan, 1995
Construction Activities*	Dust Control Plan	Pechan, 1997
Nonroad Heavy Duty Diesel Engines*	Retrofit Program	Pechan, 1997
Paved Roads - Rural	Vacuum Sweeping	Pechan, 1995
Paved Roads - Urban	Vacuum Sweeping	Pechan, 1995
Prescribed Burning*	Increase Fuel Moisture	Pechan, 1997
Residential Wood Combustion*	Public Awareness & Education Program/Mandatory Curtailment	Pechan, 1997
Unpaved Roads - Rural *	Chemical Stabilization	Pechan, 1997
Unpaved Roads - Urban*	Hot Asphalt Paving	Pechan, 1997
STATIONARY POINT SO_2 SOURCES		
Chemical Manufacturing*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
ICI Boilers*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
Mineral Products*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
Petroleum Industry*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
Primary Metal Production*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
Pulp and Paper Industry*	Flue-Gas Desulfurization Scrubber	Pechan, 1997
ON-HIGHWAY VEHICLE SOURCES		
Gasoline Vehicles & Trucks*	Federal Reformulated Gasoline	Pechan, 1997
Gasoline Vehicles & Trucks*	Transportation Control Package	Pechan, 1997
Heavy-Duty Diesel Vehicles*	Retrofit Program	Pechan, 1997
Light-Duty Gasoline Trucks*	Tier 2 Standards	Pechan, 1997
Light-Duty Gasoline Vehicles & Trucks*	Fleet Inherently Low-Emission Vehicle	Pechan, 1997
Light-Duty Gasoline Vehicles & Trucks*	High Enhanced Inspection & Maintenance Program	Pechan, 1997

Notes: [1] Complete list of control measures included in ERCAM.
[2] Measures followed by an asterisk (*) are new or revised control measures for this RIA.
[3] References for measures documented in previous reports.
[4] For the integrated ozone/PM/Regional Haze cost analysis, NO_x control measures for utility boilers are modeled using the Integrated Planning Model rather than ERCAM (EPA, 1996). Note that the measures shown for the utility boilers in this table are not the complete list of measures that may have been modeled in the IPM analysis. See reference EPA, 1996.

BARCT=Best Available Retrofit Control Technology; CARB=California Air Resources Board; CTG=Control Techniques Guideline document; ICI=Industrial, Commercial, and Institutional; RACT=Reasonably Available Control Technology; SCAQMD=South Coast Air Quality Management District; SOCMI=Synthetic Organic Chemical Manufacture Industry; and tpy=tons per year.

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APPENDIX C

COSTS AND BENEFITS OF ACHIEVING THE CURRENT PM_{10} AND OZONE STANDARDS

1.0 CURRENT PM_{10} STANDARD RESULTS IN BRIEF

Based on projected emission levels for the year 2010, this analysis estimates that 45 counties need additional reductions beyond those currently mandated in the Clean Air Act (CAA) and partial attainment of the current ozone national ambient air quality standard (NAAQS) to meet the current particulate matter (PM_{10}) NAAQS. The control cost associated with achieving partial attainment in 31 of these counties and full attainment in 14 counties is estimated to be $1.1 billion (1990 dollars). The estimated national annual monetized benefits associated with partial attainment of the current standard is approximately $5.3 billion to $5.4 billion.

2.0 CURRENT OZONE STANDARD RESULTS IN BRIEF

Based on projected emissions levels for the year 2010, this analysis estimates that 9 nonattainment areas (82 counties) are projected to need additional reductions beyond those currently mandated in the CAA to meet the current ozone NAAQS. The control cost associated with achieving partial attainment in 8 nonattainment areas (69 counties) and full attainment in 1 nonattainment area (13 counties) is estimated to be $0.6 billion (1990 dollars). The estimated national annual monetized benefits associated with partial attainment of the current standard is approximately $1.2 billion to $1.6 billion.

3.0 INTRODUCTION

The 2010 CAA baseline discussed in Chapter 4 contains all control measures mandated by the CAA to meet the current PM_{10} and ozone standards. Also included in this baseline is a NOx cap-and-trade program for utilities and large industrial boilers located in the 37-States of the Ozone Transport Assessment Group (OTAG) that is being adopted to facilitate attainment of the current ozone standard. Starting from this baseline, this analysis projects that several areas do not attain the current PM_{10} and ozone standards. Therefore, in this analysis, additional control measures are selected for specific areas with the goal of attaining the current standards in the analysis year 2010.

This appendix presents the incremental emission reduction, air quality, and cost impacts associated with control measures selected to meet the current PM_{10} and ozone standards, as well as the benefits associated with the estimated air quality improvements. The following sections in this chapter cover:

- Emissions, air quality, and cost impacts for the current PM_{10} standard only;
- Emissions, air quality, and cost impacts for the current ozone standard;
- Emission reduction, air quality improvement, and control cost results for the current PM_{10} standard;
- Benefits of attaining the current PM_{10} standard;
- Benefits of attaining the current ozone standard; and
- Analytical uncertainties, limitations, and potential biases.

4.0 ANALYSES OF THE CURRENT PM_{10} STANDARD

This section presents the benefits and emission, air quality, and cost impacts associated with control measures selected to meet the current PM_{10} standard incremental to the 2010 CAA baseline and partial attainment of the current ozone standard. The partial attainment analysis of the current ozone standard is presented in Section 5.0 of this appendix.

4.1 CURRENT PM_{10} STANDARD EMISSIONS, AIR QUALITY, AND COST ANALYSIS RESULTS

The methodology used to select control measures for the current PM_{10} standard differs from the methodology presented in Chapter 6 for selecting $PM_{2.5}$-related control measures. After PM_{10} nonattainment counties are identified, control measures are selected to reduce PM_{10} concentrations from the set of source category-control measure combinations in the violating county only. This model for control measure selection is believed to be consistent with current

PM_{10} implementation practices which focus on local sources of PM_{10} emissions. Control measures with a cost per microgram per cubic meter reduced of more than $1 billion are not included in this analysis. A sensitivity analysis on this threshold level is conducted and presented in Appendix D. Thresholds of $500 million and $2 billion are examined.

The estimated number of initial and residual PM_{10} nonattainment counties for the $1 billion per microgram per cubic meter reduced threshold is presented in Table C.1, along with the estimated annual control cost associated with the control measures that are selected. The control measures selected are estimated to reduce the number of initial nonattainment counties by 14 at an annual cost of $1,100 million.

Table C.1 Estimated Number of Initial and Residual Nonattainment Counties and Incremental Annual Cost for the Current PM_{10} Standard

Control Region	Number of Counties Violating the Current PM_{10} Standard		Annual Cost of Partial Attainment ($million/yr)
	Initial	Residual	
Midwest/Northeast	6	5	380
Southeast	1	0	2
South Central	4	2	230
Rocky Mountain	12	9	210
Northwest	7	4	140
West	15	11	130
Nation	45	31	1,100

Table C.2 presents the average baseline and post-control PM_{10} concentrations by control region for the 45 initial and 31 residual nonattainment counties. The regional average annual values for the residual nonattainment areas indicate that projected residual nonattainment is driven by 24-hour rather than annual violations (i.e., all the average annual average concentration values are less than 50 $\mu g/m^3$).

4.2 CURRENT PM_{10} STANDARD BENEFITS ANALYSIS

The methodology (e.g., post-control air quality estimation, concentration-response functions, economic valuation) used to estimate national benefits associated with partial and full attainment of the current PM_{10} standard is identical to the methodology presented in Chapter 12 for estimating benefits associated with the $PM_{2.5}$ NAAQS alternatives. Partial and full attainment benefits for the current PM_{10} standard are estimated incremental to partial and full attainment, respectively, of the current ozone standard.

Table C.3 presents national annual health and welfare benefits attributable to partial attainment of the current PM_{10} standard. Partial attainment PM benefits are estimated as approximately \$5.3 billion to \$5.4 billion annually. The portion of the population in the year 2010 expected to live in the nonattainment counties is approximately 24.0 million. Not presented in Table C.7 are full attainment PM_{10} benefits. Estimation of full attainment benefits is more uncertain than partial attainment estimation because the sources from which additional emissions will be reduced are unknown. An explanation of this limitation is presented in Section 12.9 of Chapter 12. Despite the limitation, full attainment estimates are presented here for completeness purposes. National annual monetized benefits associated with full attainment of the current PM_{10} standard are estimated at approximately \$12.4 billion to \$13.8 billion, annually. Both partial and full attainment benefits estimates are likely to be underestimated due to the inability to quantify all benefits categories. See Section 12.10 in Chapter 12 for a discussion of the benefits analysis limitations.

Table C.2 Average Initial and Post-Control PM_{10} Concentrations for Projected Initial and Residual Nonattainment Counties for the Current PM_{10} Standard[a]

Control Region	Initial Nonattainment Counties				Residual Nonattainment Counties			
	Initial		Post-Control		Initial		Post-Control	
	Annual	24 Hour	Annual	24 Hour	Annual	24 Hour	Annual	24Hour
Midwest/Northeast	39.6	252.5	35.6	216.9	41.2	272.0	36.6	229.5
Southeast	42.8	157.1	41.2	151.3	--	--	--	--
South Central	39.2	168.8	35.9	153.7	41.2	177.0	36.9	157.0
Rocky Mountain	30.8	196.4	28.9	183.3	27.4	206.3	26.2	194.5
Northwest	33.6	192.4	31.5	183.5	34.0	219.2	32.2	207.5
West	44.1	236.5	42.6	229.7	45.8	260.6	45.2	257.3
Nation	37.9	213.7	35.7	200.0	37.9	235.9	36.1	221.7

a Initial nonattainment incremental to 2010 CAA baseline and partial attainment of the current ozone standard.

TABLE C.3 PM_{10}: National Annual Health and Welfare Benefits Estimates[a]

Estimates are incremental to partial attainment of the current ozone NAAQS (year = 2010)

ENDPOINT[b]	Partial Attainment Scenario	
	Incidences Reduced	**Monetized Benefits (billions of 1990$)**
***1. Mortality[c]: short-term exposure** **long-term exposure**	620 600	$2.950 $2.860
***2. Chronic Bronchitis**	7,710	$2.010
Hospital Admissions: *3. all respiratory (all ages) all resp. (ages 65+) pneumonia (ages 65+) COPD (ages 65+) *4. congestive heart failure *5. ischemic heart disease	 330 780 280 240 210 230	 $0.004 $0.010 $0.004 $0.004 $0.003 $0.005
***6. Acute Bronchitis**	1,720	$0
***7. Lower Respiratory Symptoms** (# of days) ***8. Upper Respiratory Symptoms** (# of cases) shortness of breath asthma attacks	17,840 6,300 15,050 17,010	$0 $0 $0 $0.001
***9. Work Loss Days**	179,490	$0.015
***10. Minor Restricted Activity Days (MRADs)**	1,490,350	$0.057
***11. Consumer Cleaning Cost Savings**	N/A	$0.039
***12. Visibility**	N/A	$0.320
TOTAL HEALTH BENEFITS using short-term mortality using long-term mortality		 $5.4 $5.3

N/A = not applicable

[a] Totals may not completely agree due to rounding

[b] Only endpoints denoted with an * are aggregated into total benefits estimates

[c] Mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

5.0 ANALYSES OF THE CURRENT OZONE STANDARD

This section presents the benefits, and emission and cost impacts associated with control measures selected to meet the current ozone standard incremental to the 2010 CAA baseline.

5.1 OZONE EMISSIONS AND COST ANALYSIS

The methodology used to select control measures for the current ozone standard is nearly identical to the methodology presented in Chapter 7 for selecting control measures for the alternative 8-hour standards. The chief difference is that a National Ozone Strategy is not applied for the current ozone standard prior to local control measure selection. After ozone nonattainment areas are identified and emission reduction targets are established, VOC and/or NOx control measures are selected from the set of control measure-source combinations from inside nonattainment boundaries. Control measures with an average annual incremental cost per ton of more than $10,000 are not included in this analysis. A sensitivity analysis on this threshold level is conducted and presented in this chapter. Thresholds of $7,000, $20,000, and no cut-off are examined.

Table C.4 presents the cost results for partial attainment of the current ozone standard under alternative dollar per ton control measure selection thresholds. Total annual control costs increase as the dollar per ton threshold is gradually lifted.

Table C.5 presents the VOC and NOx reductions achieved as a percent of reductions needed under alternative dollar per ton control measure selection thresholds. The percent of VOC reductions achieved ranges from 30 to 38 percent, and the percent of NOx reductions achieved ranges from 52 to 62 percent.

Table C.4 Estimated Annual Control Cost for the Current Ozone Standard Under Alternative Dollar Per Ton Control Measure Selection Thresholds

$/Ton Control Measure Selection Threshold[a]	Annual Cost ($million/year)
$7,000	300
$10,000	610
$20,000	820
No Cut-Off	1,100

a The $10,000 per ton control measure selection threshold is considered in the main analysis; all other thresholds are sensitivity analyses.

Table C.5 National Summary of Local VOC and NOx Emission Reductions Achieved as Percent of Reductions Needed for the Current Ozone Standard Under Alternative Dollar Per Ton Control Measure Selection Thresholds[a]

$/Ton Control Measure Selection Threshold[b]	2010 CAA Baseline Emissions (tons per day)		Target Reductions (tons per day)		Reductions Achieved Relative to Targets (tons per day)		Percent Achieved Relative to Targets	
	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx
$7,000	5,368	2,199	1,723	515	509	266	30%	52%
$10,000	5,368	2,199	1,723	515	610	285	35%	55%
$20,000	5,368	2,199	1,723	515	643	302	37%	59%
No Cut-Off	5,368	2,199	1,723	515	657	320	38%	62%

a Emission reduction targets and achieved reductions are incremental to the 2010 CAA Baseline. Reductions in pollutants not targeted in each area are not included in this table.

b The $10,000 per ton control measure selection threshold is considered in the main analysis; all other thresholds are sensitivity analyses.

5.2 OZONE BENEFITS ANALYSIS

The methodology (e.g., post-control air quality estimation, concentration-response functions, economic valuation) used to estimate national benefits associated with partial and full attainment of the current ozone standard is identical to the methodology presented in Chapter 12 for estimating benefits associated with the ozone NAAQS alternatives. Partial and full attainment benefits for the current ozone standard are estimated incremental from the 2010 baseline.

Table C.6 through and C.8 present national annual health and welfare benefits attributable to partial attainment of the current ozone standard. Partial attainment ozone benefits are estimated as approximately $1.2 to $1.6 billion, annually. The portion of the population in the year 2010 expected to live in the identified nonattainment areas is approximately 51.4 million. Not presented in Tables C.6 through C.8 are full attainment benefits associated with the current ozone NAAQS. Full attainment ozone benefits estimation is limited for the same reason as the PM full attainment analysis. Given this limitation, ancillary PM benefits are proportionally scaled to ozone benefits. See Section 12.9 for a discussion of this limitation and the proportional scaling procedure. Despite the limitation, full attainment estimates are presented here for completeness purposes. National annual monetized benefits associated with full attainment of the current ozone NAAQS are estimated as approximately $3.5 billion to $4.8 billion, annually. Both partial and full attainment benefits estimates are likely to be underestimated due to the inability to quantify all benefits categories. See Section 12.10 in Chapter 12 for a discussion of the benefits analysis limitations.

TABLE C.6 Ozone : National Annual Health Benefits Estimates[a]

Estimates are incremental to the 2010 CAA Baseline

(year = 2010)

ENDPOINT[b]	Partial Attainment Scenario: Incidences Reduced	Partial Attainment Scenario: Monetized Benefits (billions of 1990 $)
Ozone Health:		
***1. Mortality**	120	$0.570
Hospital Admissions		
*2. all respiratory (all ages)	520	$0.007
all resp. (ages 65+)	1,620	$0
pneumonia (ages 65+)	620	$0.010
COPD (ages 65+)	200	$0.003
emer. dept. visits for asthma	230	$0.002
***3. Acute Respiratory Symptoms** (any of 19)	52,360	$0.001
asthma attacks	110	$0
MRADs	1,140	$0
***4. Mortality from air toxics**	1	$0.003
Ancillary PM Health:		
***1. Mortality[c]: short-term exp.**	50	$0.240
long-term exposure	150	$0.700
***2. Chronic Bronchitis**	340	$0.090
Hospital Admissions:		
*3. all respiratory (all ages)	60	$0.001
all resp. (ages 65+)	40	$0
pneumonia (ages 65+)	10	$0
COPD (ages 65+)	10	$0
*4. congestive heart failure	10	$0
*5. ischemic heart disease	10	$0
***6. Acute Bronchitis**	300	$0
***7. Lower Respiratory Symptoms**	3,110	$0
***8. Upper Respiratory Symptoms**	280	$0
shortness of breath	560	$0
asthma attacks	3,320	$0
***9. Work Loss Days**	33,140	$0.003
***10. Minor Restricted Activity Days (MRADs)**	276,160	$0.011
TOTAL MONETIZED HEALTH BENEFITS		
using short-term PM mortality	N/A	$0.920
using long-term PM mortality	N/A	$1.380

N/E = not estimated

N/A = not applicable

[a] Totals may not completely agree due to rounding

[b] Only endpoints denoted with an * are aggregated into total benefits estimates

[c] Mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

TABLE C.7 Ozone : National Annual Welfare Benefits Estimates[a]
Estimates are incremental to the 2010 CAA Baseline
(millions of 1990$; year = 2010)

Category	Partial Attainment Scenario: Monetized Benefits
Commoditiy Crops	$38
Fruits and Vegetables	$147
Commercial Forests	$4
Worker Productivity	$14
Consumer Cleaning Cost Savings	$2
Visibility	$29
TOTAL MONETIZED WELFARE BENEFITS	$234

TABLE C.8 Ozone : Total National Benefits Estimates[a]
Estimates are incremental to the 2010 CAA Baseline
(billions of 1990$; year = 2010)

Category	Partial Attainment Scenario: Monetized Benefits
Health Benefits	$0.92 - $1.4
Welfare Benefits	$0.23
TOTAL MONETIZED BENEFITS	$1.2 - $1.6

6.0 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

Generally, the same uncertainties, limitations, and potential biases cited in Sections 6.7, 7.6, and 12.10 apply to the analyses and results presented in this chapter.

[a] Totals may not completely agree due to rounding

APPENDIX D

CONTROL COST SENSITIVITY ANALYSES

1.0 INTRODUCTION

This appendix presents the methodology and results for sensitivity analyses performed for a few key cost analysis parameters. A sensitivity analysis is performed on:

- The average annual incremental dollar per ton threshold for control measures selected in the analysis of the 0.08 3rd Max. ozone alternative;
- The dollar per microgram per cubic meter reduced threshold for control measures selected in the analysis of the $PM_{2.5}$ 15/50 alternative;
- The number of monitored counties in the analysis of the $PM_{2.5}$ 15/50 alternative;
- The adjustment factor applied to fugitive dust emission predictions in the analysis of the $PM_{2.5}$ 15/50 alternative;
- Attainment of the 0.08 3rd Max. ozone alternative incremental to partial attainment of the $PM_{2.5}$ 15/50 alternative; and
- Attainment of the $PM_{2.5}$ 15/50 alternative incremental to partial attainment of the 0.08 3rd Max. ozone alternative.

If attainment of the current ozone and/or PM_{10} standards is necessary to estimate the effect of these sensitivity analyses on the impacts of the 0.08 3rd Max. ozone standard and/or the $PM_{2.5}$ 15/50 standard, then the same sensitivity analysis is also performed for the current ozone and/or PM_{10} standards. Results for the current standards is presented in Appendix C.

These sensitivity analyses were performed in advance of the analyses presented in the main body of this report. The 98th percentile 24-hour PM air quality data used in the analyses presented in the main body of this report is more current than the 98th percentile PM air quality data used in these sensitivity analyses. Therefore, some direct comparisons between the results presented in this appendix and the results presented in Chapters 6 and 7 may not yield identical outcomes. Nonetheless, the conclusions drawn from the results of these sensitivity analyses are still valid.

2.0 ALTERNATIVE COST PER TON CONTROL MEASURE SELECTION THRESHOLDS IN THE OZONE COST ANALYSIS

The analysis documented in Chapter 7 of this report is based on an average annual incremental cost per ton control measure selection threshold of $10,000 (1990 dollars). This section presents the emission reduction and cost results for control measure selection under alternative dollar per ton thresholds: $7,000, $20,000, and no cut-off.

Table D.2.1 presents the national summary of emission reductions achieved as a percent of targeted levels for alternative average annual incremental dollar per ton control measure selection thresholds. For the range of control measure selection thresholds presented, VOC reductions achieved as a percent of targeted reductions is a narrow range from 33 to 38 percent. The NOx reductions achieved as a percent of targeted reductions is also a narrow range from 20 to 26 percent.

Table D.2.2 provides the distribution of reductions achieved versus reductions needed under alternative cost per ton control measure selection thresholds for the 0.08 3rd Max. alternative. As shown in this table, when the average annual incremental cost per ton control measure selection threshold is completely removed, one additional area is modeled to achieve enough reductions to reach full attainment. Under the more restrictive alternative thresholds, this same area achieves from 87 to 95 percent of the targeted reduction levels. When the threshold is lowered from $10,000 per ton to $7,000 per ton, the distribution does show a shift toward the lower quintile, with 4 more areas achieving less than 20 percent of their target levels.

Table D.2.1 National Summary of VOC and NOx Reductions Achieved as a Percent of Reduction Targets Under Alternative Dollar Per Ton Control Measure Selection Thresholds: 0.08 3rd Max. Standard[a]

Threshold	Target Reductions (tons per day)		Reductions Achieved Relative to Targets (tons per day)		Percent Achieved Relative to Targets (Percent)		Shortfall (tons per day)	
	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx
$7,000/ton	4,598	3,648	1,519	728	33%	20%	3,079	2,920
$10,000/ton[b]	4,598	3,648	1,706	803	37%	22%	2,928	2,845
$20,000/ton	4,598	3,648	1,740	878	38%	24%	2,858	2,770
No Cut-off	4,598	3,648	1,750	933	38%	26%	2,848	2,715

a Emission reduction targets and achieved reductions are incremental to the 2010 CAA Baseline. Reductions in pollutants not targeted in each area are not included in this table.

b The $10,000/ton control measure selection threshold is used in the analyses presented in Chapter 7 of this report.

Table D.2.2 Distribution of Percent Progress Toward Achieving VOC and NOx Emission Reduction Targets Under Alternative Dollar Per Ton Control Measure Selection Thresholds: 0.08 3rd Max. Alternative

Threshold	Number of Initial Nonattainment Areas[a]						
	< 20%	20 - 40%	40 - 60%	60 - 80%	> 80%	Full Attain-ment	Total Number of Areas
$7,000/ton	10	10	5	1	1	1	28
$10,000/ton[b]	6	13	5	1	2	1	28
$20,000/ton	6	12	6	1	2	1	28
No Cut-off	6	12	5	2	1	2	28

a Number of areas incremental to the 2010 CAA baseline.

b The $10,000/ton control measure selection threshold is used in the analyses presented in Chapter 7 of this report.

Table D.2.3 presents the national control cost results under alternative average annual incremental cost per ton control measure selection thresholds. When the control measure selection threshold is removed, the total annual cost increases nearly 60 percent from $1.3 billion to $2.1 billion, yet as shown in Table D.2.2, only one more area achieves full attainment.

Table D.2.3 National Cost Summary Under Alternative Dollar Per Ton Control Measure Selection Thresholds: 0.08 3rd Max. Standard

Control Measure	Annual Control Cost (Millions 1990$)[a]			
	$7,000/ton	$10,000/ton	$20,000/ton	No Cut-off
National Ozone Strategy	330	330	330	330
Local Control Measures	720	1,000	1,400	1,800
Total	1,100	1,300	1,700	2,100

a Costs are incremental to the current ozone standard, to which the same $/ton threshold is applied. Totals may not agree due to rounding.

The relative insensitivity of modeled progress toward attainment is explained to some degree by control measure development efforts that tended to focus on known, currently available technologies with relatively reasonable implementation costs. Nonetheless, given the set of control measures in the analysis database, the conclusion is that the $10,000 per ton threshold does not seriously constrain modeling of full attainment, but does potentially prevent unreasonably high predictions of economic impacts.

3.0 ALTERNATIVE DOLLAR PER MICROGRAM PER CUBIC METER REDUCED CONTROL MEASURE SELECTION THRESHOLD IN THE PM COST ANALYSIS

The analysis presented in Chapter 6 of this document is based on a control measure selection threshold of $1 billion per microgram per cubic meter reduced. This section presents the projected number of nonattainment counties and cost results for control measure selection under alternative dollar per microgram per cubic meter reduced thresholds. A $500 million and a $2 billion threshold are examined. Limiting the pool of available control measures is intended to eliminate selection of control measures that either: 1) have little or no effect on air quality in a projected nonattainment county; or 2) are extremely costly relative to the air quality benefit they achieve in a projected nonattainment county and therefore are unlikely to ever be implemented.

Tables D.3.1 and D.3.2 present the estimated number of initial and residual nonattainment counties by control region for the current PM_{10} standard and the $PM_{2.5}$ 15/50 standard under alternative cost per microgram per cubic meter reduced control measure selection thresholds. The number of residual nonattainment counties for the current PM_{10} standard declines from 30 to 29 under the $2 billion threshold. The number of initial nonattainment counties for the $PM_{2.5}$ 15/50 alternative declines from 85 to 84 under the $2 billion threshold due to additional air quality improvements achieved for the current PM_{10} standard to which the same threshold is applied. The number of residual nonattainment counties for the $PM_{2.5}$ 15/50 alternative increases by 10 percent, from 40 to 44, when the cost per microgram per cubic meter reduced threshold is cut in half to $500 million. The number of residual nonattainment counties for the $PM_{2.5}$ 15/50 alternative decreases by 10 percent, from 40 to 35, when the cost per microgram per cubic meter threshold is doubled to $2 billion.

Tables D.3.3 shows the total national control cost under alternative cost per microgram per cubic meter reduced control measure selection thresholds for the current PM_{10} standard and the $PM_{2.5}$ 15/50 alternative. Starting with the $500 million threshold, when the threshold is doubled to $1 billion, the total cost of partial attainment of the $PM_{2.5}$ 15/50 standard increases by over 55 percent. When the cost per microgram per cubic meter threshold is doubled again to $2 billion, the total incremental cost of partial attainment of the $PM_{2.5}$ 15/50 standard increases by only about 10 percent. This apparently small increase in the incremental cost the $PM_{2.5}$ 15/50 alternative under the $2 billion threshold is explained by the large increase in incremental cost of the accompanying current PM_{10} standard, to which the same $2 billion threshold is applied. When the threshold is doubled to $2 billion, some relatively expensive control measures that are otherwise only selected in the $PM_{2.5}$ analysis are selected in the preceding analysis of the current

Table D.3.1 Summary of Initial and Residual Nonattainment Counties Under Alternative Cost per μg/m³ Control Measure Selection Thresholds[a]: Current PM_{10} Standard

Control Region	$500 Million Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	5	1	5	5	1	5
Southeast	0	0	0	0	0	0
Rocky Mountain	12	0	12	8	0	8
South Central	4	1	4	2	1	2
West	15	4	15	11	3	11
Northwest	7	0	7	4	0	4
Nation	43	6	43	30	5	30

Control Region	$1 Billion Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	5	1	5	5	1	5
Southeast	0	0	0	0	0	0
Rocky Mountain	12	0	12	8	0	8
South Central	4	1	4	2	1	2
West	15	4	15	11	3	11
Northwest	7	0	7	4	0	4
Nation	43	6	43	30	5	30

Control Region	$2 Billion Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	5	1	5	5	1	5
Southeast	0	0	0	0	0	0
Rocky Mountain	12	0	12	8	0	8
South Central	4	1	4	1	0	1
West	15	4	15	11	3	11
Northwest	7	0	7	4	0	4
Nation	43	6	43	29	4	29

a Number of Tier 1 monitored counties. Initial nonattainment counties are determined incremental to partial attainment of the current ozone standard.

Table D.3.2 Summary of Initial and Residual Nonattainment Counties Under Alternative Cost per μg/m³ Control Measure Selection Thresholds[a]: $PM_{2.5}$ 15/50 Alternative

Control Region	$500 Million Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	35	33	8	12	11	4
Southeast	8	8	0	1	1	0
Rocky Mountain	14	8	9	11	7	6
South Central	7	6	3	3	3	1
West	15	11	14	14	10	11
Northwest	6	0	6	3	0	3
Nation	85	66	40	44	32	25

Control Region	$1 Billion Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	35	33	8	11	9	4
Southeast	8	8	0	1	1	0
Rocky Mountain	14	8	9	9	6	4
South Central	7	6	3	2	2	0
West	15	11	13	14	10	11
Northwest	6	0	6	3	0	3
Nation	85	66	39	40	28	22

Control Region	$2 Billion Threshold					
	Initial Nonattainment			Residual Nonattainment		
	Total	Annual	24-Hour	Total	Annual	24-Hour
Midwest/Northeast	35	33	8	9	7	4
Southeast	8	8	0	1	1	0
Rocky Mountain	13	8	8	7	5	2
South Central	7	6	2	2	2	0
West	15	11	13	13	10	10
Northwest	6	0	6	3	0	3
Nation	84	66	37	35	25	19

a Number of Tier 1 monitored counties. Initial nonattainment counties are determined incremental to partial attainment of the current ozone and PM_{10} standards, and the National $PM_{2.5}$ Strategy.

Table D.3.3 Summary of National Annual Control Costs Under Alternative Cost per µg/m^3 Control Measure Selection Thresholds[a] (Million 1990$)

Current PM_{10} Standard

Region	$500 Million Threshold	$1 Billion Threshold	$2 Billion Threshold
Midwest/Northeast	240	290	320
Northwest	130	140	160
Rocky Mountain	200	210	230
South Central	160	210	1,600
Southeast	--	--	--
West	100	130	180
National $PM_{2.5}$ Strategy	--	--	--
National Total[b]	840	990	2,500

$PM_{2.5}$ 15/50 Standard

Region	$500 Million Threshold	$1 Billion Threshold	$2 Billion Threshold
Midwest/Northeast	2,100	3,400	5,000
Northwest	190	260	430
Rocky Mountain	530	940	1,300
South Central	240	1,800	680
Southeast	130	130	130
West	290	380	539
National $PM_{2.5}$ Strategy	2,600	2,600	2,600
National Total[b,c]	6,100	9,500	10,600
Total of Current PM_{10} and $PM_{2.5}$ 15/50 Alternative[c]	6,900	10,500	13,100

a Costs for the current PM_{10} standard are incremental to partial attainment of the current ozone standard. Costs for the $PM_{2.5}$ 15/50 alternative are incremental to partial attainment of the current PM_{10} standard to which the same thresholds are applied.

b Totals may not agree due to rounding.

c The national totals include the cost of the National $PM_{2.5}$ Strategy. However, the Integrated Planning Model (IPM) used to assess utility sector impacts does not include the same control region definitions used in the PM Optimization Model, so the incremental $PM_{2.5}$ cost shown for each control region does not include the cost of the National $PM_{2.5}$ Strategy.

PM_{10} standard. A more illustrative estimate is the total combined cost of the current PM_{10} standard and the $PM_{2.5}$ 15/50 alternative, which is presented at the bottom of Table D.3.3. When the threshold is doubled from $1 billion to $2 billion, the combined incremental cost increases by about 25 percent.

The conclusion is that a few additional counties are estimated to reach full attainment of the PM alternatives as the cost per microgram per cubic meter reduced threshold is raised from $500 million to $1 billion, and again from $1 billion to $2 billion. The proportional increase in cost is greater than the proportional increase in the number of attaining counties in all cases.

4.0 ALL MONITORED COUNTY PM COST ANALYSIS

The analysis documented in Chapter 6 of this report is based on a set of 504 counties containing PM_{10} monitors that have met what this report refers to as *Tier 1* data completeness criteria for estimating $PM_{2.5}$ concentrations. The criteria and the monitoring tiers are discussed in Section 4.4.2.5 of Chapter 4. There are additional monitored counties (Tiers 2 and 3) for which the relatively incomplete data can be used to assess the potential for nonattainment with alternative $PM_{2.5}$ standards. For some of these monitored counties, attainment designations are modeled on only 1 or 2 data points every year. Since the data is less complete, including these counties in the analysis generates results that are inherently less certain.

In the analysis presented in Chapter 6, control measures are targeted at Tier 1 monitored counties that are projected to violate the standard. In the analysis presented in this appendix, control measures are targeted at all monitored counties that are projected to violate the standard. Table D.4.1 shows the estimated number of residual nonattainment counties (when all monitored counties are counted) for both the current PM_{10} standard and the alternative $PM_{2.5}$ 15/50 standard under different control measure targeting assumptions. This table illustrates two key points. For the $PM_{2.5}$ 15/50 alternative, the number of *identified* residual nonattainment areas increases by 30 percent, from 41 to 53, when all monitored counties are counted (see Table 6.6 in Chapter 6). The second point is that targeting controls at the full set of potentially violating monitored counties only reduces the number of monitored counties in residual nonattainment from 53 to 50.

The partial attainment cost associated with targeting all monitored counties is presented in Table D.4.2. When control measures are targeted at all potentially violating monitored counties, the national cost increases by $1.1 billion, or 12 percent.

Table D.4.1 Projected Number of Residual Nonattainment Counties: All Monitored Counties (Tiers 1, 2, and 3)

Control Region	PM_{10} 50/150 Current Standard					
	Controls Targeted to Tier 1 Potentially Violating Monitored Counties Only			Controls Targeted to All Potentially Violating Monitored Counties		
	Total	Annual	24 Hour	Total	Annual	24 Hour
Midwest/Northeast	6	1	6	6	1	6
Southeast	1	0	1	1	0	1
Rocky Mountain	9	1	9	9	1	9
South Central	5	1	3	3	1	3
West	13	3	13	11	3	11
Northwest	8	1	7	4	0	4
Nation	40	7	39	34	6	34
Control Region	**$PM_{2.5}$ 15/50 Standard**					
	Controls Targeted to Tier 1 Potentially Violating Monitored Counties Only			**Controls Targeted to All Potentially Violating Monitored Counties**		
	Total	**Annual**	**24 Hour**	**Total**	**Annual**	**24 Hour**
Midwest/Northeast	12	10	4	12	10	4
Southeast	2	1	1	2	1	1
Rocky Mountain	14	10	6	12	9	4
South Central	3	3	0	3	3	0
West	16	11	13	16	11	12
Northwest	6	3	4	5	2	4
Nation	53	38	28	50	36	25

Table D.4.2 Summary of Partial Attainment National Annual Control Costs Under Alternative Control Measure Targeting Scenarios[a] (Million 1990$)

Region	PM_{10} 50/150 Current		$PM_{2.5}$ 15/50	
	Tier 1 Monitored Counties Only	All Monitored Counties	Tier 1 Monitored Counties Only	All Monitored Counties
Midwest/Northeast	290	300	3,400	3,600
Northwest	140	170	260	390
Rocky Mountain	210	210	940	1,500
South Central	210	220	1,800	1,900
Southeast	--	4	130	190
West	130	145	380	450
National $PM_{2.5}$ Strategy	--	--	2,600	2,600
National Total[b]	990	1,000	9,500	10,600

a Costs for the 15/50 standard are incremental to attainment of the current PM_{10} standard for which the same all monitored county analysis is also performed.

b The national totals include the cost of the National $PM_{2.5}$ Strategy. However, the Integrated Planning Model used to assess utility sector impacts does not include the same control regions used in the PM Optimization Model, so the incremental $PM_{2.5}$ cost shown for each control region does not include the cost of the National $PM_{2.5}$ Strategy. All totals may not agree due to rounding.

5.0 FUGITIVE DUST ADJUSTMENT FACTOR IN THE PM COST ANALYSIS

This appendix presents the results associated for a 0.10 fugitive dust adjustment factor for the current PM_{10} standard and the $PM_{2.5}$ 15/50 alternative. The analysis presented in Chapter 6 is based on a fugitive dust adjustment factor of 0.25. This means that all fugitive dust emission projections are reduced by 75 percent to reduce the effect of fugitive dust on modeled PM air quality predictions. As discussed in Chapter 4, the 0.25 adjustment in general does a good job of accounting for the tendency of the PM air quality model to overestimate the impact of fugitive dust emissions on predicted PM air quality. However, in some areas, the 0.25 adjustment factor may not be large enough to compensate for the tendency of the PM air quality model to overestimate the impact of fugitive dust emissions on predicted PM air quality. For these areas,

a 0.10 adjustment factor may be more appropriate (i.e., fugitive dust emission projections are reduced by 90 percent). The analysis in this appendix tests this hypothesis.

Table D.5.1 presents the projected number of residual nonattainment counties under each of the fugitive dust adjustment factor scenarios. As shown, the number of residual counties does not change significantly. Only 3 additional counties are modeled to achieve full attainment of the 15/50 standard.

Table D.5.2 presents the average post-control PM concentrations in projected residual nonattainment counties. This table confirms that the 0.10 fugitive dust adjustment factor has only a minor affect on the resulting average air quality in residual nonattainment counties.

Table D.5.3 presents the national annual control cost summary under each fugitive dust adjustment factor scenario. The annual control cost associated with partial attainment of the 0.10 fugitive dust adjustment factor is more than $2.3 billion less than the 0.25 fugitive dust adjustment factor case. The largest savings in cost for the 0.10 adjustment case occur in the South Central and Midwest/Northeast regions.

The conclusion is that the 0.10 adjustment has a minor effect on projected residual nonattainment and post-control air quality in the residual counties, but that the cost of achieving the resulting degree of attainment is significantly lower.

Table D.5.1 Projected Number of Residual Nonattainment Counties: 0.25 and 0.10 Fugitive Dust Adjustment Factors (Tier 1 Monitored Counties)

Control Region	PM_{10} 50/150 Current Standard					
	0.25 Fugitive Dust Adjustment Factor			0.10 Fugitive Dust Adjustment Factor		
	Total	Annual	24 Hour	Total	Annual	24 Hour
Midwest/Northeast	5	1	5	5	1	5
Southeast	0	0	0	0	0	0
Rocky Mountain	8	0	8	8	0	8
South Central	2	1	2	1	0	1
West	11	3	11	11	3	11
Northwest	4	0	4	4	0	4
Nation	30	5	30	29	4	29

Control Region	$PM_{2.5}$ 15/50 Standard					
	0.25 Fugitive Dust Adjustment Factor			0.10 Fugitive Dust Adjustment Factor		
	Total	Annual	24 Hour	Total	Annual	24 Hour
Midwest/Northeast	11	9	4	9	8	3
Southeast	1	1	0	0	0	0
Rocky Mountain	9	6	4	8	5	3
South Central	2	2	0	3	3	0
West	14	10	11	14	10	11
Northwest	3	0	3	3	0	3
Nation	40	28	22	37	26	20

Table D.5.2 Average Post-Control $PM_{2.5}$ Concentrations by Region Under Alternative Fugitive Dust Adjustment Factors[a]

Current PM_{10} Standard				
Region	**0.25 Fugitive Dust Adjustment Factor**		**0.10 Fugitive Dust Adjustment Factor**	
	Annual	**24-Hour**	**Annual**	**24-Hour**
Midwest/Northeast	18.2	63.0	18.6	64.2
Southeast	16.6	40.1	--	--
Rocky Mountain	16.3	50.6	15.9	50.3
South Central	17.5	47.2	17.1	48.4
West	16.8	66.1	16.9	66.2
Northwest	11.4	56.4	11.3	56.0
Nation	16.7	59.4	16.6	60.0

$PM_{2.5}$ 15/50 Alternative				
Region	**0.25 Fugitive Dust Adjustment Factor**		**0.10 Fugitive Dust Adjustment Factor**	
	Annual	**24-Hour**	**Annual**	**24-Hour**
Midwest/Northeast	16.2	56.5	16.8	58.5
Southeast	15.2	36.5	--	--
Rocky Mountain	14.8	46.2	14.7	46.5
South Central	16.1	43.3	15.9	45.1
West	16.1	63.3	16.2	63.7
Northwest	10.5	52.0	10.5	51.7
Nation	15.4	55.1	15.5	56.2

a Tier 1 monitored counties only.

Table D.5.3 Summary of Partial Attainment National Annual Control Costs Under Alternative Fugitive Dust Adjustment Factor Scenarios[a] (Million 1990$)

Region	Current PM_{10} Standard		$PM_{2.5}$ 15/50	
	0.25 Adjustment	0.10 Adjustment	0.25 Adjustment	0.10 Adjustment
Midwest/Northeast	290	290	3,400	2,600
Northwest	140	130	260	250
Rocky Mountain	210	200	940	760
South Central	210	90	1,800	540
Southeast	--	--	130	30
West	130	130	380	380
National $PM_{2.5}$ Strategy	--	--	2,600	2,600
National Total[b]	990	850	9,500	7,200

a Costs for the 15/50 standard are incremental to attainment of the current PM_{10} standard for which the same all monitored county analysis is also performed.

b The national totals include the cost of the National $PM_{2.5}$ Strategy. However, the Integrated Planning Model used to assess utility sector impacts does not include the same control regions used in the PM Optimization Model, so the incremental $PM_{2.5}$ cost shown for each control region does not include the cost of the National $PM_{2.5}$ Strategy. All totals may not agree due to rounding.

6.0 EMISSION REDUCTION, AIR QUALITY, AND COST IMPACT RESULTS FOR THE $PM_{2.5}$ 15/50 ALTERNATIVE FOLLOWING THE 0.08 3rd MAX. OZONE ALTERNATIVE

This section discusses the emission reduction, air quality, and cost impact results for the $PM_{2.5}$ 15/50 alternative following partial attainment of the 0.08 3rd Max. ozone alternative. The results discussed in this section are estimated incremental to partial attainment of the current ozone and current PM_{10} standards, and the 0.08 3rd Max. standard.

The number of counties estimated in residual nonattainment for the $PM_{2.5}$ 15/50 standard and the overall amount of emission reductions achieved remains unchanged when the standard is analyzed incremental to partial attainment of the 0.08 3rd Max. alternative. This is because the total set control measures selected, and their associated emissions and air quality impacts, does not change significantly. However, due to the overlap of ozone nonattainment areas for the 0.08

3rd Max. standard and nonattainment counties for the $PM_{2.5}$ 15/50 alternative, the set of control measures selected specifically for the $PM_{2.5}$ 15/50 standard incremental to the 0.08 3rd Max. is smaller than the set of control measures selected for 15/50 incremental to the baseline.

Evidence of this smaller set of control measures specific to the $PM_{2.5}$ 15/50 standard incremental to the 0.08 3rd Max. should be reflected in a lower incremental cost of the $PM_{2.5}$ standard when it follows an ozone standard relative to the incremental cost of the same $PM_{2.5}$ standard measured against the baseline. Table D.6.1 presents the estimated control cost for current PM_{10} standard and the $PM_{2.5}$ 15/50 alternative incremental to partial attainment of the proposed 0.08 3rd Max. and incremental to the baseline (i.e., partial attainment of the current ozone and PM_{10} standards). When analyzed incremental to partial attainment of the 0.08 3rd Max. ozone standard, the total cost savings is slightly more than $100 million. The apparent small overall cost savings shown in Table D.6.1 is not conclusive evidence of a lack of synergy. Full attainment results for the alternative ozone standards might reveal additional synergies that would result in greater cost savings and additional progress toward attainment of the $PM_{2.5}$ standard.

Table D.6.1 Partial Attainment Cost Summary for Current PM_{10} Standard and the $PM_{2.5}$ 15/50 Alternative--Total Annual Cost, Tier 1 Monitored Counties (Million 1990$)

Region	Incremental to Baseline[a]		Incremental to 0.08 3rd Max[b]	
	Current PM_{10} Standard	$PM_{2.5}$ 15/50	Current PM_{10} Standard	$PM_{2.5}$ 15/50
Midwest/Northeast	290	3,400	290	3,300
Northwest	140	260	140	260
Rocky Mountain	210	940	210	940
South Central	210	1,800	210	1,800
Southeast	--	130	--	110
West	130	380	120	350
National $PM_{2.5}$ Strategy	--	2,600	--	2,600
National Total[c]	990	9,500	970	9,400
Combined Total	10,500		10,400	

a Costs for the current PM_{10} strategy are incremental to partial attainment of the ozone standard. Costs for the $PM_{2.5}$ 15/50 standard are incremental to partial attainment of the current PM_{10} standard.
b Costs are incremental to partial attainment of the 0.08 3rd Max. ozone standard, which includes partial attainment of the current ozone standard.
c The national totals include the cost of the National $PM_{2.5}$ Strategy. However, the Integrated Planning Model used to assess utility sector impacts does not include the same control regions used in the PM Optimization Model, so the incremental $PM_{2.5}$ cost shown for each control region does not include the cost of the National $PM_{2.5}$ Strategy. All totals may not agree due to rounding.

7.0 EMISSION REDUCTION AND COST IMPACT RESULTS FOR 0.08 3rd MAX. OZONE ALTERNATIVE FOLLOWING THE ALTERNATIVE $PM_{2.5}$ 15/50 STANDARD

This section discusses the emission reduction and cost impact results for the 0.08 3rd Max. ozone alternative following partial attainment of the $PM_{2.5}$ 15/50 alternative. The results discussed in this section are estimated incremental to partial attainment of the current ozone and current PM_{10} standards, and the $PM_{2.5}$ 15/50 alternative.

The number of areas estimated in residual nonattainment for the 0.08 3rd Max. standard and the overall amount of emission reductions achieved remains unchanged when the standard is analyzed incremental to partial attainment of the $PM_{2.5}$ 15/50 alternative. This is because the total set control measures selected, and their associated emissions and air quality impacts, does not change significantly. However, due to the overlap of ozone nonattainment areas for the 0.08 3rd Max. standard and nonattainment counties for the $PM_{2.5}$ 15/50 alternative, the set of control measures selected specifically for the 0.08 3rd Max. standard incremental to the $PM_{2.5}$ 15/50 standard is smaller than the set of control measures selected for 15/50 incremental to the baseline.

Evidence of this smaller set of control measures specific to the 0.08 3rd Max. standard incremental to the $PM_{2.5}$ 15/50 alternative should be reflected in a lower incremental cost of the ozone standard when it follows a $PM_{2.5}$ standard relative to the incremental cost of the same ozone standard measured against the baseline. Table D.7.1 presents the estimated control cost for the 0.08 3rd Max. standard incremental to partial attainment of the $PM_{2.5}$ 15/50 alternative and incremental to the baseline (i.e., partial attainment of the current ozone standard). When analyzed incremental to partial attainment of the $PM_{2.5}$ 15/50 standard, the total cost savings is nearly $100 million. The apparent small overall cost savings shown in Table D.7.1 is not conclusive evidence of a lack of synergy. Full attainment results for the alternative $PM_{2.5}$ standard might reveal additional synergies that would result in greater cost savings and more progress towards attainment of the alternative ozone standard.

Table 7.10 National Summary of Partial Attainment Control Costs for Alternative Ozone Standards Following a $PM_{2.5}$ Standard

Control Measure	Annual Control Cost (Millions 1990$)	
	Incremental to Partial Attainment of the Current Ozone Standard	Incremental to $PM_{2.5}$ 15/50[b]
National Ozone Strategy	330	330
Local Control Measures	1,020	920
Total[c]	1,350	1,250

a Costs are incremental to the partial attainment of the current ozone standard.

b Costs are incremental to partial attainment of the $PM_{2.5}$ 15/50 alternative, which includes partial attainment of the current ozone and PM_{10} standards.

c Totals may not agree due to rounding.

APPENDIX E

REGIONAL HAZE CALCULATION CONSTANTS

1.0 INTRODUCTION

The analysis of the regional haze improvement goals presented in Chapter 8, involves estimating visibility changes using an equation for light extinction. This equation requires data that is not readily estimated using the source-receptor matrix discussed in Chapters 4 and 6. This data is currently available for several Class I areas that contain monitors in the IMPROVE network. Data collected from these monitors for the years 1992 - 1995 is used in this analysis to fill-in the missing values. In this analysis, these values are assumed constant. Since in reality, some of these values are expected to change due to changes in emissions, holding these values constant understates the impact that certain emission reducing control measures are likely to have on visibility improvement.

2.0 CONCENTRATION AND RELATIVE HUMIDITY CONSTANTS

This section presents the concentration and relative humidity constants used to calculate atmospheric light extinction. The total atmospheric light extinction coefficient (b_{ext}) can be calculated as the summation of the individual scattering and absorption extinctions as shown in Equation 1.

$$b_{ext} = b_{sp} + b_{ab} + b_{sg} + b_{ag} \qquad \textit{Equation (1)}$$

where:

b_{sp} = light scattering due to particles;
b_{ab} = light absorption due to particles;
b_{sg} = light scattering due to gases;
b_{ag} = light absorption due to gases.

These four extinctions can be individually estimated based on a knowledge of the atmospheric concentrations and physical properties of the light scattering or absorption species that contribute to light extinction. Table E.1 lists the empirical coefficients C1 (*f*(RH)), C2 (OMC), C3 (b_{abs}), and C4 (SOIL) developed that are used in the equations described below to calculate visibility in counties containing Class I areas.

1. Light Scattering Due to Particles (b_{sp})

Light is scattered by particles suspended in the atmosphere, and the efficiency of this scattering per unit mass concentration is largest for particles with sizes comparable to the wavelength of light (~500 nm). These particles may result from natural sources, such as animal and plant organic material, aeolian dust, volcanic eruptions, and sea salt. When visibility is poor, however, most particles are found to be of manmade origin, from sources such as power plants, vehicle exhaust, biomass burning, suspended dust, and industrial activities. The most common chemical components of these particles include carbon, sulfate, nitrate, ammonium, and crustal materials (i.e., oxides of silicon, aluminum, iron, titanium, calcium, and other elements). The degree to which particles composed of these chemicals scatter light depends on their size, shape, and index of refraction.

In addition, atmospheric water is another important component of suspended PM. The liquid water content of ammonium nitrate, ammonium sulfate, and other soluble species increases with relative humidity, and is especially important when relative humidity exceeds 70 percent. Particles containing these compounds grow into the droplet mode as they take on liquid water, so the same concentration of sulfate or nitrate makes a much larger contribution to light extinction when humidities are high (>70 percent) than when they are low (<30 percent).

Table E.1 Regional Haze Constants for the Effects of Relative Humidity on Sulfate and Nitrate Scattering (*f*(RH)), Organic Aerosols (OMC), Elemental Carbon Absorption (b_{abs}), and Fine Soil (SOIL)

County	Class I Area Name	*f*(RH)	OMC	b_{abs}	SOIL
Lawrence Co AL	Sipsey W	4.453	4.041	19.445	0.607
Apache Co AZ	Mount Baldy W	2.121	1.490	7.500	0.508
Apache Co AZ	Petrified Forest NP	2.121	1.490	7.500	0.508
Cochise Co AZ	Chiricahua W	1.915	1.173	5.024	0.566
Coconino Co AZ	Sycamore Canyon W	2.015	1.132	4.441	0.446
Coconino Co AZ	Grand Canyon NP	2.015	1.132	4.441	0.446
Gila Co AZ	Sierra Ancha W	2.017	1.265	5.655	0.506
Gila Co AZ	Mazatzal W	2.017	1.265	5.655	0.506
Graham Co AZ	Galiuro W	1.915	1.173	5.024	0.566
Maricopa Co AZ	Superstition W	2.017	1.265	5.655	0.506
Pima Co AZ	Saguaro W	1.915	1.173	5.024	0.566
Yavapai Co AZ	Pine Mountain W	2.017	1.265	5.655	0.506
Madison Co AR	Upper Buffalo W	4.282	2.925	11.207	0.573
Polk Co AR	Caney Creek W	4.282	2.925	11.207	0.573
Calaveras Co CA	Mokelumme W	3.201	1.629	5.323	0.391
Del Norte Co CA	Redwood NP	7.116	1.497	3.845	0.126
El Dorado Co CA	Desolation W	3.201	1.629	5.323	0.391
Fresno Co CA	John Muir W	2.435	2.061	6.897	0.518
Fresno Co CA	Kaiser W	2.435	2.061	6.897	0.518
Fresno Co CA	Kings Canyon NP	2.435	2.061	6.897	0.518
Lassen Co CA	Caribou W	2.714	1.520	4.334	0.423
Los Angeles Co CA	San Gabriel W	2.140	2.684	10.146	0.878
Marin Co CA	Point Reyes W	4.453	1.306	4.736	0.233
Mariposa Co CA	Yosemite NP	2.435	2.061	6.897	0.518
Modoc Co CA	South Warner W	2.714	1.520	4.334	0.423
Mono Co CA	Minarets W	2.435	2.061	6.897	0.518
Monterey Co CA	Ventana W	2.757	2.026	8.663	0.423
Riverside Co CA	San Jacinto W	2.140	2.684	10.146	0.878
Riverside Co CA	Joshua Tree W	2.140	2.684	10.146	0.878
San Benito Co CA	Pinnacles W	2.757	2.026	8.663	0.423
San Bernardino Co CA	Cucamonga W	2.140	2.684	10.146	0.878
San Bernardino Co CA	San Gorgonio W	2.140	2.684	10.146	0.878
San Diego Co CA	Agua Tibia W	2.140	2.684	10.146	0.878
Santa Barbara Co CA	San Rafael W	2.287	2.373	8.521	0.698
Shasta Co CA	Thousand Lakes W	2.714	1.520	4.334	0.423
Shasta Co CA	Lassen Volcanic NP	2.714	1.520	4.334	0.423
Siskiyou Co CA	Marble Mountain W	7.116	1.497	3.845	0.126
Siskiyou Co CA	Lava Beds W	2.714	1.520	4.334	0.423

County	Class I Area Name	*f*(RH)	OMC	b_{abs}	SOIL
Trinity Co CA	Yolla-Bolly-Middle-Eel	2.714	1.520	4.334	0.423
Tulare Co CA	Sequoia NP	2.435	2.061	6.897	0.518
Tulare Co CA	Dome Land W	2.287	2.373	8.521	0.698
Tuolumne Co CA	Emigrant W	2.435	2.061	6.897	0.518
Tuolumne Co CA	Hoover W	2.435	2.061	6.897	0.518
Garfield Co CO	Flat Tops W	2.078	1.305	4.454	0.559
Gunnison Co CO	West Elk W	2.350	1.262	4.108	0.533
Larimer Co CO	Rawah W	2.078	1.305	4.454	0.559
Larimer Co CO	Rocky Mountain NP	2.078	1.305	4.454	0.559
Mineral Co CO	La Garita W	2.350	1.262	4.108	0.533
Montezuma Co CO	Mesa Verde NP	2.158	1.178	3.993	0.453
Montrose Co CO	Black Canyon of the Gun	2.350	1.262	4.108	0.533
Pitkin Co CO	Maroon Bells-Snowmass W	2.078	1.305	4.454	0.559
Routt Co CO	Mount Zirkel W	2.078	1.305	4.454	0.559
Alamosa Co CO	Great Sand Dunes W	2.350	1.262	4.108	0.533
San Juan Co CO	Weminuche W	2.485	1.141	4.806	0.446
Summit Co CO	Eagles Nest W	2.078	1.305	4.454	0.559
Citrus Co FL	Chassahowitzka W	4.453	2.965	15.481	0.642
Monroe Co FL	Everglades NP	4.453	2.965	15.481	0.642
Wakulla Co FL	St Marks W	4.047	2.989	13.189	0.518
Charlton Co GA	Okefenokee W	4.047	2.989	13.189	0.518
McIntosh Co GA	Wolf Island W	4.047	2.989	13.189	0.518
Butte Co ID	Craters of the Moon W	2.267	1.292	3.719	0.613
Elmore Co ID	Sawtooth W	2.267	1.292	3.719	0.613
Idaho Co ID	Selway-Bitterroot W	2.267	1.292	3.719	0.613
Edmonson Co KY	Mammoth Cave NP	3.979	3.287	17.624	0.374
Hancock Co ME	Acadia NP	4.073	1.867	8.199	0.191
Washington Co ME	Roosevelt Campobello IP	4.073	1.867	8.199	0.191
Washington Co ME	Moosehorn	4.073	1.867	8.199	0.191
Keweenaw Co MI	Isle Royal NP	3.661	1.670	5.344	0.262
Schoolcraft Co MI	Seney W	3.661	1.670	5.344	0.262
St. Louis Co MN	Boundary Waters Canoe A	3.661	1.670	5.344	0.262
St. Louis Co MN	Voyageurs NP	3.661	1.670	5.344	0.262
Stone Co MS	Breton W	4.453	4.041	19.445	0.607
Taney Co MO	Hercules-Glades W	4.282	2.925	11.207	0.573
Wayne Co MO	Mingo W	4.282	2.925	11.207	0.573
Beaverhead Co MT	Anaconda-Pintlar W	3.677	2.113	6.587	0.536
Beaverhead Co MT	Red Rock Lakes W	2.234	1.273	3.660	0.520
Flathead Co MT	Glacier NP	5.107	2.776	8.951	0.441
Lewis and Clark Co MT	Bob Marshall W	5.107	2.776	8.951	0.441
Lewis and Clark Co MT	Scapegoat W	5.107	2.776	8.951	0.441
Lewis and Clark Co MT	Gates of the Mtn W	3.677	2.113	6.587	0.536

County	Class I Area Name	*f*(RH)	OMC	b_{abs}	SOIL
Missoula Co MT	Mission Mountain W	5.107	2.776	8.951	0.441
Phillips Co MT	U.L. Bend W	3.677	2.113	6.587	0.536
Sanders Co MT	Cabinet Mountains W	5.107	2.776	8.951	0.441
Sheridan Co MT	Medicine Lake W	3.016	1.427	5.795	0.419
Elko Co NV	Jarbidge W	2.288	1.134	3.215	0.593
Coos Co NH	Presidential Range-Dry	4.337	1.511	6.865	0.216
Grafton Co NH	Great Gulf W	4.337	1.511	6.865	0.216
Atlantic Co NJ	Brigantine W	2.488	2.727	15.348	0.427
Chaves Co NM	Salt Creek W	2.192	1.420	6.168	0.779
Eddy Co NM	Carlsbad Caverns NP	2.192	1.420	6.168	0.779
Grant Co NM	Gila W	2.076	1.361	6.231	0.618
Lincoln Co NM	White Mountain W	2.076	1.361	6.231	0.618
Mora Co NM	Pecos W	2.053	1.419	5.172	0.478
Rio Arriba Co NM	San Pedro Parks W	2.053	1.419	5.172	0.478
Sandoval Co NM	Bandelier W	2.053	1.419	5.172	0.478
Socorro Co NM	Bosque del Apache W	2.076	1.361	6.231	0.618
Taos Co NM	Wheeler Peak W	2.350	1.262	4.108	0.533
Avery Co NC	Linville Gorge W	3.106	2.906	15.216	0.462
Graham Co NC	Joyce Kilmer-Slickrock	3.106	2.906	15.216	0.462
Haywood Co NC	Shining Rock W	3.106	2.906	15.216	0.462
Hyde Co NC	Swanguarter W	4.207	2.508	14.723	0.408
Burke Co ND	Lostwood W	3.016	1.427	5.795	0.419
McKenzie Co ND	Theodore Roosevelt NMP	3.016	1.427	5.795	0.419
Comanche Co OK	Wichita Mountains W	4.282	2.925	11.207	0.573
Curry Co OR	Kalmiopsis W	7.116	1.497	3.845	0.126
Grant Co OR	Strawberry Mountain W	5.527	2.178	7.509	0.351
Hood River Co OR	Mount Hood W	7.435	2.490	8.636	0.197
Jefferson Co OR	Mount Washington W	4.039	1.268	4.939	0.415
Klamath Co OR	Crater Lake NP	4.039	1.268	4.939	0.415
Klamath Co OR	Mountain Lakes W	4.039	1.268	4.939	0.415
Lake Co OR	Gearhart Mountain W	4.039	1.268	4.939	0.415
Lane Co OR	Three Sisters W	4.039	1.268	4.939	0.415
Lane Co OR	Diamond Peak W	4.039	1.268	4.939	0.415
Marion Co OR	Mount Jefferson W	4.039	1.268	4.939	0.415
Union Co OR	Eagle Cap W	5.527	2.178	7.509	0.351
Wallowa Co OR	Hells Canyon W	5.527	2.178	7.509	0.351
Custer Co SD	Wind Cave NP	3.016	1.427	5.795	0.419
Jackson Co SD	Badlands W	3.016	1.427	5.795	0.419
Polk Co TN	Cohotta W	3.106	2.906	15.216	0.462
Blount Co TN	Great Smokey Mountains	3.106	2.906	15.216	0.462
Brewster Co TX	Big Bend NP	1.895	1.597	7.178	0.771
Culberson Co TX	Guadalupe Mountains NP	2.192	1.420	6.168	0.779

County	Class I Area Name	*f*(RH)	OMC	b_{abs}	SOIL
Garfield Co UT	Bryce Canyon NP	2.558	1.096	4.108	0.472
San Juan Co UT	Capitol Reef NP	1.880	1.194	4.571	0.584
San Juan Co UT	Canyonlands NP	1.880	1.194	4.571	0.584
Grand Co UT	Arches NP	1.880	1.194	4.571	0.584
Washington Co UT	Zion NP	2.558	1.096	4.108	0.472
Bennington Co VT	Lye Brook W	4.337	1.511	6.865	0.216
Botetourt Co VA	James River Face W	4.207	2.508	14.723	0.408
Madison Co VA	Shenandoah NP	4.207	2.508	14.723	0.408
Jefferson Co WA	Olympic NP	7.435	2.490	8.636	0.197
King Co WA	Alpine Lakes W	7.435	2.490	8.636	0.197
Okanogan Co WA	Pasayten W	7.435	2.490	8.636	0.197
Okanogan Co WA	Glacier Peak W	7.435	2.490	8.636	0.197
Lewis Co WA	Mount Rainer NP	7.435	2.490	8.636	0.197
Whatcom Co WA	North Cascades NP	7.435	2.490	8.636	0.197
Yakima Co WA	Goat Rocks W	7.435	2.490	8.636	0.197
Yakima Co WA	Mount Adams W	7.435	2.490	8.636	0.197
Grant Co WV	Dolly Sods W	4.587	3.210	13.057	0.336
Tucker Co WV	Otter Creek W	4.587	3.210	13.057	0.336
Fremont Co WY	Fitrzatrick W	2.234	1.273	3.660	0.520
Teton Co WY	Yellowstone NP	2.234	1.273	3.660	0.520
Park Co WY	North Absaroka W	2.234	1.273	3.660	0.520
Park Co WY	Washakie W	2.234	1.273	3.660	0.520
Park Co WY	Teton W	2.234	1.273	3.660	0.520
Sublette Co WY	Bridger W	2.234	1.273	3.660	0.520
Teton Co WY	Grand Teton NP	2.234	1.273	3.660	0.520

The contributions of light scattering due to particles can be estimated by summing the individual light scattering effects of fine particle ammonium sulfate, fine particle ammonium nitrate, fine particle organic carbon, fine particle soil, and coarse particle mass (coarse particle mass is defined as mass difference between PM_{10} and $PM_{2.5}$). The individual scattering effect of each component is calculated by combining the pollutant concentration (in µg/m^3), coefficient, and extinction efficiency (m^2/g) as:

*fine particle ammonium sulftate = C1 * [Conc. of* $(NH_4)_2SO_4$*) µg/m*^{3} ** 3.0 m*^{2}*/g* *Equation (2)*

*fine particle ammonium nitrate = C1 * [Conc. of* (NH_4NO_3) *µg/m*^{3} ** 3.0 m*^{2}*/g* *Equation (3)*

fine particle organic carbon = C2 µg/m^3 ** 3.0 m*^{2}*/g* *Equation (4)*

fine particle soil = C4 Mm^{-1} *Equation (5)*

coarse particle mass = [Conc. of Coarse particle mass] µg/m^3 ** 0.6 m* *Equation (6)*

Where, C1describes the annual relativity humidity effect of scattering on fine particle ammonium sulfate and ammonium nitrate (*f*(RH)), and C2 and C4 describe the organic carbon and fine particle concentrations observed at each area, respectively (OMC and SOIL). The total light scattering due to particles (at each Class I area) is simply the summation of the individual scattering effects determined by Equations 2 through 6.

2. Light Absorption Due to Particles (b_{ab})

Elemental carbon (EC or black carbon) makes the most significant contribution to particle light absorption. High concentrations are seldom found in emissions from efficient combustion sources, though EC is abundant in motor vehicle exhaust, fires, and residential heating emissions. Additional light absorption has been shown in other studies to be caused by minerals in coarse particles, but its contribution is usually small. Horvath (1993) shows, from theoretical considerations and measurements, that each μg/m^3 of "black carbon" typically contributes 8 to 12 m^2/g to extinction. The site specific absorption reported values used for this study were derived from IMPROVE filter measurements made by the laser integrated plate method. This site specific absorption is shown as C_3 in Table 4.2 in units of Mm^{-1}.

3. Light Scattering by Gases (b_{ag})

The presence of atmospheric gases such as oxygen and nitrogen limits horizontal visual range to ~400 km and obscures many of the attributes of a target at less than half this distance. This "Rayleigh scattering" in honor of the scientist who elucidated this phenomena, is the major component of light extinction in areas where pollution levels are low, has a scattering coefficient of ~10 Mm^{-1}, and it can be accurately estimated from temperature and pressure measurements (Edlen, 1953; Penndorf, 1957). Values range from 9 Mm^{-1} at high altitudes to 12 Mm^{-1} at sea level, but is assumed in this analysis to be constant. A value of 10 Mm^{-1} is used for all sites as an approximation.

4. Light Absorption Due to Gases (b_{sg})

Nitrogen dioxide is the only gas likely to be present in Class I Areas that would cause significant absorption of visible light. Each μg/m^3 of nitrogen dioxide contributes ~0.17 Mm^{-1} of extinction at ~550 nm wavelengths (Dixon, 1940), so NO_2 concentrations in excess of 60 μg/m^3 (30 ppbv) are needed to exceed Rayleigh scattering. This contribution is larger for shorter wavelengths (e.g., blue light) and smaller for longer wavelengths (e.g., red light). For this reason, plumes rich in NO_2 often appear reddish-brown because much of the yellow, blue, and purple light is absorbed. Though NO_2 concentrations are much lower than this in most pristine areas, concentrations of several ppm can be found in coherent plumes near the source concentrations of NO_2 are not available for use in this study and therefore its concentration (and light absorption) is assumed to be negligible.

3.0 AVERAGE ANNUAL 90TH-TO-50TH PERCENTILE DECIVIEW VALUES

The outputs from the source-receptor matrix used to estimate air quality contributions of PM precursor emissions are expressed in terms of annual average values. These outputs are one of the key components of the RH optimization model that is used in this analysis to select control measures. The RH improvement targets analyzed in this analysis are expressed in terms of improvements in the 90th percentile values, or in other words, improvements in the average deciview value in the 20 percent worst days. In order to assess improvements in the average f the 20 percent worst days, a relationship between the 90th percentile deciview value and the mean deciview value must be established. This section contains the data used to establish this relationship.

Table E.2 contains the average annual ratio of the 90th percentile and 50th percentile deciview values for the set of rural IMPROVE Class I area sites from 1993 to 1995. The average ratio for the years 1993 to 1995 ranges from 1.39 to 1.46, with a three year average of 1.42. Using this ratio, a 1.0 deciview improvement in the 90th percentile value is equivalent to a 0.7 deciview improvement in the 50th percentile value. Likewise, a 0.67 deciview improvement in the 90th percentile value is equivalent to a 0.5 deciview improvement in the 50th percentile value.

Table E.2 1993-1995 Annual 90th/50th Percentile Deciview Ratio for Rural IMPROVE Sites Located in Class I Area Counties

Class I Code	Class I Area Name	State	Annual 90th/50th Percentile Ratio		
			1993	1994	1995
ACAD	Acadia	ME	1.51	1.51	1.50
BADL	Badlands	SD	1.45	1.45	1.36
BAND	Bandelier	NM	1.28	1.38	1.47
BIBE	Big Bend	TX	1.30	1.33	1.37
BRCA	Bryce Canyon	UT	1.34	1.25	1.48
BRID	Bridger Wilderness	WY	1.42	1.47	1.51
CANY	Canyonlands	UT	1.27	1.25	1.39
CHIR	Chiricahua	AZ	1.32	1.39	1.39
CRLA	Crater Lake	OR	1.81	1.47	1.75
DENA	Denali	AK	1.89	1.74	1.83
GLAC	Glacier	MT	1.36	1.31	1.41
GRCA	Grand Canyon	AZ	1.37	1.37	1.39
GRSA	Great Sand Dunes	CO	1.36	1.66	1.43
GRSM	Great Smokies	TN	1.21	1.44	1.33
GUMO	Guadalupe Mtns	TX	1.30	1.29	1.28
LAVO	Lassen Volcanic	CA	1.57	1.57	1.59
MEVE	Mesa Verde	CO	1.46	1.29	1.49
MORA	Mt Rainier	WA	1.27	1.43	1.46
PEFO	Petrified Forest	AZ	1.29	1.19	1.46
PINN	Pinnacles	CA	1.20	1.31	1.29
PORE	Pt Reyes	CA	1.66	1.40	1.48
REDW	Redwood	CA	1.44	1.28	1.40
ROMO	Rocky Mtn	CO	1.46	1.34	1.67
SAGO	San Gorgonio	CA	1.25	1.34	1.33
SHEN	Shenandoah	VA	1.23	1.33	1.37
TONT	Tonto	AZ	1.29	1.19	1.29
WEMI	Weminuche	CO	1.32	1.24	1.53
YELL	Yellowstone	WY	1.38	1.68	1.66
YOSE	Yosemite	CA	1.38	1.58	1.50
Annual Average 90th/50th Percentile Ratio			1.39	1.40	1.46
Average of 1993-1995					1.42

4.0 REFERENCES

Dixon, 1940: Dixon, J.K., “The Absorption Coefficient of Nitrogen Dioxide in the Visible Spectrum. *J. Chem. Phys*. 8:157, 1940.

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APPENDIX F

POTENTIAL CONTROL MEASURES MODELLED FOR THE 2010 FULL ATTAINMENT SCENARIO

APPENDIX F-1

EXAMPLES OF POTENTIAL CONTROL MEASURES MODELLED FOR THE 2010 FULL ATTAINMENT SCENARIO[1]

To provide policy makers with as much information as possible to aid implementation planning, a full attainment analysis of both standards (0.08 4th Max and $PM_{2.5}$ 15/65) is carried out. To estimate full attainment of the ozone standard, additional specified and unspecified control measures are assumed for areas still needing further reductions after the initial set of measures outlined in Chapters 5.0 - 7.0 are applied. After the partial attainment analysis, seventeen areas are estimated to need further NO_x or VOC emission reductions to reach full attainment of the 0.08 4th Max standard. The optional specified control measures described in this section are divided into three sectors: 1) stationary point sources; 2) stationary area sources; and 3) mobile sources (both on-road and off-road) as outlined below.[2] The cost of each measure is generally determined by examining the change in costs for one unit of the controlled source (e.g., one engine for mobile source technology measures, one gallon of fuel for reformulated fuel measures) and the associated tons reduced from that unit. The level of emissions remaining from specific source categories in areas still needing further reductions after the application of the first tier of measures is determined. The potential emission reductions available from the application of a measure are determined by applying a control factor to that level of residual emissions. In some cases, potential further reductions from certain source categories are calculated by estimating the number of units located in these areas. Control measures are then applied to those sources still needing reductions. For some source categories, there is more than one control strategy identified and choices are made as to the most appropriate. The table below outlines the mobile, area and point source measures assessed in this part of the analysis. Tier A in the table refers to control measures and associated emission reductions described in Chapters 5.0 - 7.0 of the main body of the RIA. Tier B refers to the additional control measures and associated emission reductions described in Chapter 9.0 of the RIA.

1 Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

2 For further information, see ICF (1997), NAAQS Control Measure Analysis, Draft Report , prepared for EPA, Office of Air and Radiation.

It should be emphasized that the following control measures are provided for illustrative purposes only. They are potentially relevant only for those areas of the country suffering from the worst levels of air pollution. Under the Clean Air Act, the primary responsibility for achieving ambient air quality standards falls to the states. Upon the setting of a new standard, the states begin a multi-year, sequenced process of monitoring and planning; the results of which are ultimately found in State Implementation Plans (SIPs). These SIPs are the blueprint of control strategies through which states meet their responsibility. While the federal government maintains primary responsibility for certain sources which are best controlled nationally (e.g., motor vehicles), and the CAA does provide some additional requirements, most decisions about which control strategies to utilize fall primarily to the states. This approach allows control decisions, including costs associated with those decisions, to be appropriately considered at the state and local level.

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Mobile Source Control Measures & Estimated Costs/Reductions[3]

Source Category	Control Measures	Estimated Residual NAA Reductions Available (tpd)	Estimated Average Incremental Cost Effectiveness (per ton, 1990$)
M1 Marine (commercial) Note M-A	Add selective catalytic reduction (SCR)	121.5 NO_x	$6,503
M2 On-road heavy duty diesel Note M-B	Introduce low NO_x engines early	143.3 NO_x	$845
M3 On-road heavy duty diesel Note M-C	New vehicles powered with natural gas	15.1 NO_x	$2,400
M4 On-road heavy duty diesel Note M-D	Repower with natural gas engines	8.6 NO_x	$6,839
M5 On-road heavy duty diesel Note M-E	Repower old units with 2004 standard certified engines	142.1 NO_x	$2,850
M6 On-road heavy duty diesel Note M-F	Aerodynamic devices	17.0 NO_x 1.7 VOC 0.5 SO_2 0.3 $PM_{2.5}$	$197 ($NO_x$) $181 (all)
M7 Non-road diesel Note M-G	Repower uncontrolled with 6.9 g/bhp-hr engine	86.9 NO_x	($167)
M8 Non-road diesel Note M-H	Retrofit engines for NO_x: ceramic coating	246.6 NO_x	$189
M9 Non-road diesel Note M-H	Retrofit engines for NO_x: water injection/emulsion	246.6 NO_x	$910

3 Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

Source Category	Control Measures	Estimated Residual NAA Reductions Available (tpd)	Estimated Average Incremental Cost Effectiveness (per ton, 1990$)
M10 Diesel locomotives Note M-I	Dual fuel diesel/LNG power	72.9 NO_x 1.6 $PM_{2.5}$	($452)
M11 Diesel locomotives Note M-J	Selective catalytic reduction (SCR)	143.1 NO_x	$2,073
M12 Diesel locomotives Note M-K	Reduced idling scenario at train yards	17.0 NO_x	$7,900
M13 Airports Note M-L	Electric-powered airport GSE	77.2 NO_x 31.6 VOC 5.0 $PM_{2.5}$	$0 for electric See Note M-N for other fuels
M14 Airports Note M-M	Vehicle-free gate	97.8 NO_x 40.0 VOC 6.3 $PM_{2.5}$	$0 narrow body $0 wide body
M15 Airports Note M-N	Reduced engine taxi, aircraft towing, congestion reduction	36.1 NO_x 0.1 $PM_{2.5}$	$0 for reduced taxi portion

NOTE M-A: Assumed 90 percent NO_x reduction for diesel commercial vessels (control factor of 0.1). Cost effectiveness calculated on a per vessel basis. One vessel with reduction of 25 tons NO_x has costs of SCR system ($1.3 million with 12 year lifetime), fluids, and catalyst replacement. Total annualized costs assuming 7 percent interest are $179,577; cost per ton is $6503 (1990$).

NOTE M-B: For this measure, the tons of NO_x reduced was estimated nationwide and multiplied by the ratio (31.43 percent) of residual NO_x in NAA (453,560) to nationwide NO_x from HDDE (1,442,982) to calculate emissions reduced in NAA. NO_x reductions are 0.27 tons/year per truck. A population of 650,000 trucks nationwide could have this measure applied. The cost is $2,000 with a lifetime of 12 years; cost per ton is $845 (1990$).

NOTE M-C: For this measure, the tons of NO_x reduced was estimated nationwide and multiplied by the ratio (31.43 percent) of residual NO_x in NAA (453,560) to nationwide NO_x from HDDE (1,442,982) to calculate emissions reduced in NAA. NO_x reductions are 0.57 tons/year per truck. A population of 32,663 trucks nationwide could have this measure applied. The incremental costs is $12,000 with a lifetime of 12 years. Cost per ton is $2,400 (1990$).

NOTE M-D: For this measure, the tons of NO_x reduced was estimated nationwide and multiplied by the ratio (31.43 percent) of residual NO_x in NAA (453,560) to nationwide NO_x from HDDE (1,442,982) to calculate emissions reduced in NAA. NO_x reductions are 0.4 tons/year per truck and this measure can be applied to 25,835 trucks. Costs assessed include adding LNG tank, purchasing and installing new engine. The truck owner benefits by avoiding the cost of a diesel engine rebuild and by receiving credit for the diesel engine trade-in. Net cost is $24,000 with a lifetime of 12 years; cost per ton is $6,839 (1990$).

NOTE M-E: For this measure, the tons of NO_x reduced was estimated nationwide and multiplied by the ratio (31.43 percent) of residual NO_x in NAA (453,560) to nationwide NO_x from HDDE (1,442,982) to calculate emissions reduced in NAA. NO_x reductions are 0.4 tons/year per truck. Applicable population is 435,000 trucks. Costs assessed include new engine purchase and installation, benefits are rebuild avoided and trade-in value. The incremental cost is $10,000 with a lifetime of 12 years; cost per ton is $2,850 ($1990).

NOTE M-F: This measure assumes installation of an aerodynamic device increases fuel economy by 10 percent and decreases emissions by 10 percent. We estimated that 30 percent of the truck population currently does not have a device installed, and that 50 percent of the trucks included in the HDDE can use such a device for a control factor of 0.985 [i.e., 1-(.3)(.5)(.1)]. Deflector cost is $1,092 with a lifetime of 8 years; cost per ton is $197 (1990$) for NO_x.

NOTE M-G: This measure reduces NO_x by approximately 50 percent. In 2010, the measure is applicable to engines that account for 30 percent of NO_x emissions from this source category, however, only 70 percent of these engines are estimated to be technically feasible for replacement. Thus, the control factor is 0.888 [i.e., 1-(.3)(.7)(.5)]. Costs assessed include purchase and installation of new engine, with benefits of rebuild cost avoided and old engine trade-in. Incremental costs are $10,000 with a lifetime of 10 years. Incorporating fuel savings, cost savings per ton is $167 (1990$).

NOTE M-H: Because these measures reduce NO_x when applied by 30 percent, we have assumed a control factor of 0.7 for NO_x. For water injection/emulsion, the cost estimate includes installation of a system costing $1,150 (1995$) with a lifetime of 6 years for an annualized cost of $241 (1995$). That system is installed on an engine for a reduction of 0.24 tons/year for a cost effectiveness of $1,005 (1995$) and $910 (1990$). For ceramic coatings, installation of a retrofit package with a lifetime of 10 years costs $5,000 for an annualized cost of $712 (1995$). The associated NO_x reduction is 3.4 tons/year for a cost effectiveness of $189 /ton(1990$).

NOTE M-I: Control factors for these measures were estimated as 0.786 and 0.825 for NO_x and PM, respectively [for NO_x, 1-(.95)(.5)(.45); for PM, 1-(.95)(.5)(.368)]. Costs included fuel savings for natural gas compared to diesel, and engine replacement costs. Annual cost savings are $18,877 and tons NO_x reduced per locomotive are 36.3, for a cost savings per ton $452 (1990$).

NOTE M-J: A control factor for NO_x of 0.58 is estimated for this measure. Approximately 95 percent of locomotive emissions come from line haul locomotives, 50 percent of them are eligible for an SCR system, and NO_x emissions are reduced 88 percent after installation of the system [i.e., 1- (.95)(.5)(.88)]. The cost estimate included equipping the locomotive with an SCR system, maintaining that system, and a fuel penalty. Annual cost per locomotive is $106,273 reducing 45 tons per year. Cost effectivenes is $2,073 (1990$) per ton.

NOTE M-K: Assumes diesel fuel cost of $1.34 per gallon (CA April, 1997 average) and a fuel savings of $1.54 * 10^8$ gallons of diesel fuel from reduced idling. A control factor of 0.95 was assumed for NO_x. Approximately 10 percent of locomotive emissions result from idling.; 50% reduction of idling emissions assumed reduced [i.e., 1-(.1)(.5)].

NOTE M-L: For purposes of analysis, a zero cost estimate was used for overall cost calculation. The following assumptions are used to calculate a cost effectiveness (in 1997$): the cost-effectiveness calculation is performed for a bag tractor, for other equipment, both costs and effectiveness will be higher, but the ratio is assumed to be the same; electric tractor cost includes $4,500 battery and $3,500 charger; LPG, CNG, electric are as reliable as gasoline/diesel engines; refueling facility costs are accounted for in LPG/CNG fuel costs; rebuild costs are battery replacement for electrics; unit of fuel mass for electrics is kW-hr, all others in GGE; and CNG/LPG emission rates are based on high quality "conversions."

Cost effectiveness depends on the type of conversion performed as follows:

Cost	Cost	Emission Benefit	Cost Benefit
($)	($)	(tons)	($/ton)
Gasoline	$29,925	3.26	$9,193
LPG	$11,603	8.57	$1,354
CNG	$29,588	9.90	$2,989
Electric	-$42,704	17.06	-$2,503

NOTE M-M: For purposes of analysis, a zero cost estimate was used for overall cost calculation. The following assumptions are used to calculate the cost effectiveness (in 1997$) of this measure: gate-based A/C costs are for 110-120 degF system, smaller units may be suitable in some areas; narrow body APU emissions are based on the GTCP85-98DHF APU used on the Boeing 737-300; and wide body APU emissions are based on the PW901A APU used on the Boeing 747-400.

The cost effectiveness depends on the size aircraft serviced. The measure has a net cost savings.

	Cost	Emission Benefit	Cost Benefit
Gate Type	($)	(tons)	($/ton)
Narrow-Body	-$921,117	60.12	-$15,321
Wide-Body	-$2,034,564	63.57	-$32,005

NOTE M-N: For purposes of analysis, a zero cost estimate was used for overall cost calculation. The following assumptions are used to calculate a cost effectiveness (in 1997$) $41,223 saved for the reduced engine taxi portion of this measure: Boeing B737-300 w/2 GE CFM56-3B engines; 20 minute taxi time; 4 minutes required for engine cool down; 4 minutes required for engine warmup; and costs for manual updates and pilot training marginal.

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Area Source Measures and Estimated Costs/Reductions

Source Category	Control Measures	Estimated Residual NAA Available Reductions (tpd)	Estimated Average Incremental Cost Effectiveness (1990$)
A1 Solvent Utilization - Wood Furniture Surface Coating	Reformulation Hybrid Waterborne Coatings	47.3 VOC	$1,926/ton VOC
	Reformulation Full and Hybrid Waterborne Coatings	32.7 VOC	$2,338/ton VOC
A2 Fuel Combustion - Residential/Industrial/ Commercial Distillate Fuel Note A-A	Low Sulfur Fuel Oil (340 ppm); 80 percent Reduction in SO_x Emissions	59.6 SO_x 0.25 $PM_{2.5}$	$1,910/ton SO_x

NOTE A-A: The cost was assumed to be $1.07 per barrel, which is based on the price differential between distillate oil and low sulfur diesel. The cost effectiveness includes an additional .10 per barrel charge for shipping resulting in a total cost differential of $1.17 per barrel. The cost provided assumes that increased demand will not increase the price differential of low sulfur distillate oil. If distribution is merely reallocated, there should be little price pressure. However, efforts, which result in significant additional production of low sulfur distillate, would likely raise the price differential since the cost of additional desulfurization capability is significantly higher than $2,000/ton. It should be noted that California's efforts to reduce sulfur content of diesel fuel resulted in an increase of approximately .10 per gallon, which equals about $7,100/ton. Note that SO_x and $PM_{2.5}$ values include 5.6 tpd and 0.02 tpd from point source emissions.

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Point Source Control Measures and Estimated Costs/Reductions[4]

Source Category	Tier A RIA Controls	Partial Attain. Estimated Residual Emissions (National Tons)	Partial Attain. Estimated Residual Emissions in NAA	Tier B Controls	Estimated Incremental Emissions Reductions (National)	Estimated Residual NAA Reductions Available from Tier B (tpd)	Estimated Average Incremental Cost Effectiveness
P1 Utility Boilers Note P-A	90% SO_x reduction over Title IV NO_x limit at 0.15 lb/MM BTU	5,250,000 SO_x 3,572,000 NO_x	So_x Not Estimated 355,000 NO_x	90% SO_x reduction over Title IV NO_x limit at 0.10 lb/MM BTU	2,403,000 SO_x 325,000 NO_x	SO_x Not Estimated 83.1 NO_x	$1,358 ton/$SO_x$ $4,436 ton/$NO_x$
P1 Utility Boilers Note P-B	95% SO_x reduction over Title IV NO_x limit at 0.05 lb/MM BTU	5,250,000 SO_x 3,572,000 NO_x	SO_x Not Estimated 355,000 NO_x	95% SO_x reduction over Title IV NO_x limit at 0.05 lb/MM BTU	2,880,000 SO_x 582,000 NO_x	SO_x Not Estimated 150.6 NO_x	$1,720 ton/$SO_x$ $5,885 ton/$NO_x$
P2 Stationary IC Engines Note P-C	Ignition Timing Retard		24,688	Conversion to electric		59.0 No_x 15.7 VOC	$2,000
P3 Industrial Boiler Note P-D SO_2 NO_x	FGD scrubbing .15 lb/MMBtu	178,850 SO_x 120,000 NO_x	SO_x Not Estimated NO_x 47,779	Gas conversion Gas conversion (.05 lb/MMBtu)		50.7 SO_x 82.7 NO_x	All convert at $5,000/ton; 80% at $1,000/ton $2,000/ton

4 Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Point Source Control Measures and Estimated Costs/Reductions (continued)

Source Category	Tier A RIA Controls	Partial Attain. Estimated Residual Emissions (National Tons)	Partial Attain. Estimated Residual Emissions in NAA	Tier B Controls	Estimated Incremental Emissions Reductions (National)	Estimated Residual NAA Reductions Available from Tier B (tpd)	Estimated Average Incremental Cost Effectiveness
P4 Chemical Manufacturing Process Vents (VOC) Note P-E	MACT	170,900	41,000	Lower MACT cutoff to $5,000/ton	7,700 tons	5.3	$3,000/ton
P4 Chemical Manufacturing Process Vents (VOC)	MACT	170,900	41,000	Lower MACT cutoff to $7,500/ton	11,600 tons	8.2	$4,300/ton
P4 Chemical Manufacturing Process Vents (VOC)	MACT	170,900	41,000	Lower MACT cutoff to $10,000/ton	15,500 tons	10.9	$5,500/ton
P5 Chemical Manufacturing Equipment Leaks (VOC)	MACT	19,400	4,700	Dual - mechanical sealed pumps	3,900 tons	2.8	$10,000/ton

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Point Source Control Measures and Estimated Costs/Reductions (continued)

Source Category	Tier A RIA Controls	Partial Attain. Estimated Residual Emissions (National Tons)	Partial Attain. Estimated Residual Emissions in NAA	Tier B Controls	Estimated Incremental Emissions Reductions (National)	Estimated Residual NAA Reductions Available from Tier B (tpd)	Estimated Average Incremental Cost Effectiveness
P6 Chemical Manufacturing Wastewater (VOC)	MACT	155,400	37,500	Lower MACT cutoff to $5,000/ton	38,400 tons	27.4	$3,000/ton
P6 Chemical Manufacturing Wastewater (VOC)	MACT	155,400	37,500	Lower MACT cutoff to $7,500/ton	56,000 tons	39.7	$4,300/ton
P6 Chemical Manufacturing Wastewater (VOC)	MACT	155,400	37,500	Lower MACT cutoff to $10,000/ton	73,000 tons	51.8	$5,500/ton
P7 Petroleum Refining Process Vents (VOC)	MACT	33,000	4,800	Lower MACT cutoff to $5,000/ton	14,000 tons	5.9	$4,000/ton
P7 Petroleum Refining Process Vents (VOC) Note P-F	MACT	33,000	4,800	Lower MACT cutoff to $7,500/ton	23,000	9.7	$4,900/ton
P7 Petroleum Refining Process Vents (VOC)	MACT	33,000	4,800	Lower MACT cutoff to $10,000/ton	26,400	11.2	$5,400/ton

Examples of Potential Control Measures Modelled for the 2010 Full Attainment Scenario
Point Source Control Measures and Estimated Costs/Reductions (continued)

Source Category	Tier A RIA Controls	Partial Attain. Estimated Residual Emissions (National Tons)	Partial Attain. Estimated Residual Emissions in NAA	Tier B Controls	Estimated Incremental Emissions Reductions (National)	Estimated Residual NAA Reductions Available from Tier B (tpd)	Estimated Average Incremental Cost Effectiveness
P8 Petroleum Refining Equipment Leaks (VOC)	MACT	47,400	7,000	More stringent leak detection program	21,300	9.1	$6,500/ton
P9 Petroleum Refining Wastewater (VOC)	MACT	11,000	1,600	Lower MACT cutoff to $5,000/ton	3,300	1.4	$4,000/ton
P9 Petroleum Refining Wastewater (VOC)	MACT	11,000	1,600	Lower MACT cutoff to $7,500/ton	4,900	2.1	$4,700/ton
P9 Petroleum Refining Wastewater (VOC)	MACT	11,000	1,600	Lower MACT cutoff to $10,000/ton	5,000	2.1	$5,000/ton
P10 TSDF Equipment Leaks (VOC) Note P-G	MACT	7,900	1,900	More stringent leak detection program	3,600	2.4	$6,500/ton
P11 TSDF Control Wastewater Tanks (VOC)	RCRA	44,000	10,600	Lower MACT cutoff to $5,000/ton	7,700	5.6	$4,000/ton

Source Category	Tier A RIA Controls	Partial Attain. Estimated Residual Emissions (National Tons)	Partial Attain. Estimated Residual Emissions in NAA	Tier B Controls	Estimated Incremental Emissions Reductions (National)	Estimated Residual NAA Reductions Available from Tier B (tpd)	Estimated Average Incremental Cost Effectiveness
P11 TSDF Control Wastewater Tanks (VOC)	RCRA	44,000	10,600	Lower MACT cutoff to $7,500/ton	11,000	7.9	$4,700/ton
P11 TSDF Control Wastewater Tanks (VOC)	RCRA	44,000	10,600	Lower MACT cutoff to $10,000/ton	15,400	10.9	$5,800/ton

NOTE P-A: National emissions estimated generated using Integrated Pollution Model (IPM). Reductions in residual nonattainment areas were generated by assuming a 33 percent NO_x reduction in the residual nonattainment areas over the values specified in Table D (i.e., the ratio of the NO_x emissions limits of 0.10 to 0.15).

NOTE P-B: National emissions estimated generated using IPM. Reductions in residual nonattainment areas were generated by assuming a 67 percent NO_x reduction in the residual nonattainment areas over the values specified in Table D (i.e., the ratio of the NO_x emissions limits of 0.05 to 0.15).

NOTE P-C: Based on information from Electric Power Research Institute (EPRI) and the NO_x Alternative Control Technology (ACT). Assumed prices are $0.03 per kWh, $2.00 per MM BTU for natural gas, and 6,000 hours of operation per year. Based on information from EPRI, we assumed that 88 percent of the engines could be converted.

NOTE P-D: The NO_x reductions are obtained by the conversion of the unit to natural gas, which is required to obtain the SO_x reductions. This methodology results in a NO_x cost effectiveness of about $2,000 (1990$) per ton.

NOTE P-E: For the chemical industry categories we used the costing methodology presented in the MACT background documents. We estimated national residual emissions from the category (e.g., Process Vents) and then assumed that the portion of emissions in residual nonattainment areas was the same as the ratio of national employment in SIC 28 to employment in SIC 28 in the residual nonattainment areas.

NOTE P-F: For the petroleum refining industry categories we used the costing methodology presented in the MACT background documents. We estimated national residual emissions from the category (e.g., Process Vents) and then assumed that the portion of emissions in residual nonattainment areas was the same as the ratio of national employment in SIC 291 to employment in SIC 291 in the residual nonattainment areas.

NOTE P-G For TSDFs we assumed that the portion of TSDFs in nonattainment areas was identical to that of the chemical industry (i.e., SIC 28).

APPENDIX F-2

EXAMPLES OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROL OF VOCs, NOx, AND PM[1]

INTRODUCTION

Air pollution control and prevention technologies continuously improve. Technologies are in place and successfully performing today that were on the drawing board ten years ago. As the demand for more innovative and cost-effective or cost-saving technologies increases, new technologies will move from the research & development or pilot program phase to commercial availability. Highlighted in the table below are a sample of emerging technologies for many industrial source categories and sources of combustion.

It is likely that many of these technologies will be available in the next ten to fifteen years to employ in air pollution control and prevention strategies as the demand for innovations increases. It is also likely that currently "unknown" technologies and practices will be operational within a decade. Environmental management in business today is quickly becoming a vital part of overall organizational management strategies. Businesses are striving to reduce operating costs through improved efficiency, productivity and reduced material and waste management costs. The ISO14000 Environmental Management Systems movement will be a mature part of business strategies in the near future. Pollution prevention programs are proliferating. In short, the demand for efficiency is causing significant reevaluation of industrial environmental management. The sampling of technologies on the following pages are indicative of the major investments in research and development that is occurring in all parts of the industrial economy.

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1 Inclusion of control measures in this analysis does not represent selection of such control measures in future implementation strategies. Measures are included for illustrative purposes only. All costs and emission reductions are estimates.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **On-Road and Non-Road Vehicles**

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
TOTAL CAR REDESIGN						
Partnership for New Generation Vehicle[1]	Alternative Vehicle/ Product Redesign	Multi-agency Federal partnership with US automakers and suppliers, and universities to develop advanced manufacturing technologies, near-term vehicle improvements, and prototypes with up to triple efficiency. The partnership is evaluating many of the individual technologies listed below such as lean NOx catalysts, CIDI engine, reformulated or alternative fuels for CIDI, CIDI fuel injection, EGR in addition to improved manufacturing processes that would allow higher temperatures or reduced weight. Other goals include reducing the vehicle weight, aerodynamics, rolling resistance, accessory energy use, and regenerative braking that increase vehicle efficiency and reduce emissions.	X	X	X	Currently narrowing the technology focus to move to 2000 goal of concept vehicles.
Hypercar[2]	Alternative Vehicle/ Product Redesign	Shift from steel-framed, internal-combustion, mechanical-drivetrain platforms to ultralight hybrid-electric platforms. The Hypercar concept was developed by the Rocky Mountain Institute in association with government, industry, and several additional organizations. Such hypercars would be two- to three times lighter, much lower in aerodynamic and rolling resistance, one to three orders of magnitude less polluting, and comparable or superior in other respects such as safety, performance, amenity, and cost. They would also use a fourth to a tenth as much fuel.	X	X	X	R&D. In 1994-95, about two dozen firms committed on the order of $1 billion to the intensely competitive development of ultralight hybrids

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Superplastic Advanced Manifolds[3]	Redesign	Double-wall +manifold offers the potential for substantial reductions in cold-start emissions by allowing the inner tube to heat quickly, resulting in a quicker "light-off" of the catalytic converter, thereby reducing hydrocarbon emissions.	X			Next step is to form full-length sections for evaluations by America's automakers.
Ceramic Technology for Advanced Heat Engines[4]	New technology	Ceramic engine components are desirable for their durability and longevity.				N/A

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
DIESEL ENGINES						
Small Compression Ignition Direct Injection (CIDI) Diesel Engines[5]	Expand applicability of CIDI engines to passenger car market	Research is being conducted into lightweight engine materials, alternative fuels, and catalytic converters in an effort to apply the advantages of CIDI engines (high thermal efficiency, operating flexibility, low start-up emissions) to passenger cars, while controlling negative characteristics (heavy engine components and production of sub-optimal levels of NOx and particulate emissions).	X			CIDI diesel engines are currently in production, but applicability to cars is limited. Advancements in emission controls and light weight engine materials are currently being investigated. Volkswagen introduced their TDI (Turbo-charged Direct Injection) Series in 1996 featuring a computer driven engine. With its precisely regulated fuel injection, turbo-charged air induction, a special cylinder head and manifold, European mileage test show an average fuel economy of 49 mpg with less carbon emitted than most gasoline engines.
Direct Injection (DI) Diesel V6[6]	Introduction of advanced DI engines to the mid- & large size passenger vehicle market	Targeted for the executive car, minivan, multipurpose, and sport utility market, cost effective features include electronic rotary fuel injection, fixed-geometry inlet prot, conventional wastegated turbocharger, cooled EGR, with advanced control algorithms, and an oxidation catalyst. As with the CIDI engine, the V6 DI engine will benefit from current DI engine research of light weight engines and parts and emission control technologies.	X			Installation of the DI V6 engine in an "executive" vehicle has confirmed effective fuel management and noise, vibration, and harshness control (NVH).

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
FUEL CELLS						
Fuel Cell Technologies[7]	Alternative Fuels	Development and demonstration of fuel cell technologies for on- and off-road mobile sources to improve the commercial viability of fuel cells, including improvements in power density, fuel storage, reformer efficiency, system integration, and cost reduction. This program is expected to result in several projects that would support promising fuel cell technologies for on- and off-road vehicles. Fuel cell technologies that will be considered include proton exchange membrane, solid oxide, direct methanol, phosphoric acid, and molten carbonate. Mobile source applications that will be considered in this category include light-, medium-, and heavy-duty on-road vehicles, locomotives, ships, utility vehicles, neighborhood electric vehicles, and other off-road equipment applications. Peripheral technologies involving fuel infrastructure, on-board fuel storage, and hydrogen reforming shall be included if they have potential to advance the commercial viability of fuel cell applications.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $1,000,000 as their share of research funding, of a total expected $5,000,000.
Fuel Cell Vehicle[8]	Alternative Fuels	Chrysler is teaming with Delphi Energy and Engine Management Systems to build within two years a "proof of concept" fuel cell vehicle that runs on gasoline. The technology will be a five-step process to refine gasoline on-board a vehicle. This could improve fuel efficiency by 50 percent, provide up to 400 miles range, be at least 90 percent cleaner, and cost no more than a current mid-size car.	X	X		Prototype Development. Production prototypes may be developed by 2005. Consumers might drive fuel cell-powered cars as early as 2010.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Protein Exchange Membrane Fuel Cell (PEMFC)[9]	New technology	These cells operate at relatively low temperatures (about 200 F), have high power density, can very their output quickly to meet shifts in power demand, and are suited for applications, such as in automobiles, where quick startup is required. According to the U.S. DOE, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras." Fueling stations are a large obstacle in introducing hydrogen powered vehicles to the public on a large scale. From the best calculations available, fueling stations are cost effective, and they are starting to be built across the country. A fueling station will cost $4.5 million to build, but will produce as well as dispense the fuel. Hydrogen fuel costs 3.8 cents per mile, while gas costs 4.5 cents per mile. 11 pounds of hydrogen would provide a 400 mile driving range for a mid-sized car. The tank for this fuel is 3 times the size of a gas tank, and fueling would take about ten minutes.	X	X	X	Ballard Systems in Vancouver has developed the best fuel cell engine to date. Ballard has produced a 40 foot transit bus with similar horsepower as a standard city bus (275 hp). Pilot programs utilizing these buses are set to begin in Chicago and Vancouver in 1998. Daimler Benz and Ballard have teamed up to form a new company for the development of light vehicles. It is the hope of this new entity to commercialize these vehicles by 2004. The Big Three are working to develop similar technologies with similar timeframes.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
HYBRID VEHICLES						
Hybrid Electric Buses[10]	Alternative Fuels	Advanced Vehicle Systems (AVS) (Chattanooga, TN) is involved in a public/private partnership with CARTA and other institutions such as DARPA, CALSTART, and others to create electric and hybrid/electric busses. Their latest test vehicle is a high speed gas turbine that can run on CNG, diesel, or peanut oil. The gas turbine is quiet, vibration free, and clean burning. Using hybrid technology allows these vehicles to overcome range concerns of transit officials. CAPSTONE developed the gas turbine and expects the addition of a catalytic combuster to allow this vehicle to meet California ULEV standards using diesel fuel.	X	X	X	AVS has approximately 60 vehicles in operation across the US. This latest technology represents the 4th generation of vehicle. Formal introduction of the vehicle is expected in July.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	**NOx**	**PM**	
Hybrid Vehicle Powerplant[11]	Alternative Fuels	Galileo Research has been conducting R&D on a new powerplant (HISEN-FPEG) to be used in Hybrid Electric Vehicles. It is expected to provide a small, lightweight, low polluting, low maintenance on-board generator at a low cost that will utilize a variety of available fuels and be very fuel efficient. The HISEN-FPEG generator set is constructed of two directly opposed engine pistons and heads with a linear generator between them. The piston-rod assembly shuttles back and forth in a straight line from compression-ignition to compression-ignition in its opposing cylinders. Attached to the piston-rod assembly are magnets which move within coils that generate electric power. A great deal of friction is reduced within the engine, due to a lack of side forces and the resultant design of only one moving part. The lack of a crankshaft also enables the HISEN-FPEG to achieve various compression ratios, which gives it the ability to utilize a variety of fuels, from gasoline to natural gas and hydrogen to diesel fuel. Computer control of the HISEN-FPEG's ignition timing and fuel injection system also enable ultra low emissions to be achieved.	X	X	X	R&D

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
ELECTRIC VEHICLES AND BATTERIES						
Electric Vehle Battery Development[12]	Alternative Fuels	The United States Advanced Battery Consortium (USABC) and the U.S. Department of Energy (DOE) have dedicated $106 million to continue R&D advanced batteries for electric vehicles. USABC will conduct research to continue cost reduction of mid-term electric vehicle batteries and develop long-term battery technologies.	X	X	X	R&D
Advanced battery technologies and charging systems for Electric Vehicle applications[13]	Alternative Fuels	Development and demonstration of advanced battery technologies and battery charging systems for electric vehicle (EV) applications. This project would finalize the development of a full-sized EV battery pack and demonstrate its feasibility in laboratory tests. Technology enhancements can utilize charging algorithms which decrease charging time and prolong battery life. These units would be able to recharge EVs at 25 kW power rates with recharging times of less than an hour. In this proposed project, the system design would be finalized. One or more chargers would be demonstrated in fleet and/or commercial applications. The proposed project will develop both on-board electronics that will automatically supply battery-charge information and a central management system to control charging of a fleet of EVs. When an EV is needed trip requirements can be matched to an EV with sufficient battery charge and that EV dispatched. The system will also control the charging of the EVs to maximize battery life and minimize power requirements for fleet charging during peak-demand periods.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $1,400,000 as their share of research funding, of a total expected $13,408,000.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Advanced Inductive Electric Vehicle Charger[14]	Alternative Fuels	Development and demonstration of an advanced EV charger for high-power, fast recharging. Such a system could be used with fleets or at commercial opportunity charging sites. The proposed project will modify five General Motors S-10 electric pick-up trucks to accept this high-power charging, with a six month demonstration. This phase would determine impacts on the electricity supply grid and EV battery performance.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $500,000 as their share of research funding, of a total expected $1,000,000.
Automated Electric Vehicle Charging System[15]	Alternative Fuels	Development of an automated system that would dock, or couple, an EV to a battery charging system. The project will address inductively and conductively coupled systems. This project is expected to build on previous research into such an automated system, resulting in a prototype test unit of a commercially viable system. This project, if successful, will improve the perceived convenience and, thus, commercial viability of EVs.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $150,000 as their share of research funding, of a total expected $350,000.
Electric Vehicles[16]	Alternative Fuels	Demonstration of Electric Vehicles with Rental Car Fleets. The California Department of General Services (DGS), in cooperation with Honda and National Rental Car, is conducting an electric vehicle demonstration at the Sacramento Metropolitan Airport. Electric vehicles are available for specified state agency employees in Sacramento on business. DGS has asked the AQMD if it would be interested in an expanded program at one or more Basin airports.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $200,000 as their share of research funding, of a total expected $500,000.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Advanced Batteries for Electric Vehicles[17]	Alternative Fuels	This proposed demonstration program will involve at least 500 EVs vehicles equipped with advanced batteries. The project is an incentive program for participating consumers of electric vehicles, who would be expected to pay at least $3,000 for an advanced battery pack option. Cosponsors would provide an incentive to purchase the advanced battery option by contributing about $10,000 per battery pack. The consumers would agree to installation of non-intrusive data-acquisition systems in their EVs and at charging facilities, to be interviewed, and to respond to questionnaires. The project will document the numerous technical and consumer impacts of advanced EVs. The basic program goals are to determine the effect of advanced batteries on travel behavior, vehicle performance, consumer acceptance, charging behavior, utility power systems, and the need for public charging opportunities.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $500,000 as their share of research funding, of a total expected $12,560,000.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
ALTERNATIVE FUELS						
Medium-Duty CNG Engine Conversion Kit[18]	Conversion to Alternative Fuel	Support for field demonstration of improved software and hardware for a medium-duty CNG engine conversion kit to support the existing medium-duty vehicle population. The SCAQMD previously supported field demonstration of the first generation kit in a contract with Thermo Power Corporation. This kit has operated well in the field. However, improvements in performance and fuel economy are needed if the kit is to be commercially viable. Hardware and software modifications to achieve improved performance and fuel economy are currently being developed. The proposed project would support field demonstration of the second generation kit.	X	X	X	Proposed development with field demonstration. The SCAQMD Technology Advancement program has proposed to provide $40,000 as their share of research funding, of a total expected $180,000.

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Propane/Butane Fuel Blends[19]	Alternative Fuel	Emissions testing on multiple light-duty vehicles using propane/butane blends, which may be cost-effective low-emission alternative fuels for light-, medium-, and heavy-duty vehicles. It is expected that the proposed project will result in emission benefits and help AQMD, ARB, the petroleum industry, and automobile manufacturers identify a potentially clean, cost-effective alternative fuel with capability for wide-scale application to all types of internal combustion engines. Generate data on emissions, lubricant compatibility, combustion chamber and intake valve deposits, component durability, and catalyst durability. Operate and evaluate three or more new vehicles for a minimum of 50,000 miles using selected butane/propane blends. Conduct periodic emission tests during mileage accumulation to determine the effects of operation on regulated emissions, speciated hydrocarbons, and the specific reactivity (ozone-forming potential) of exhaust emissions. At test completion dismantle engines and quantify and rate deposits.	X	X		Proposed R&D. The SCAQMD Technology Advancement program has proposed to provide $65,000 as their share of research funding, of a total expected $325,000.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Advanced alternative fuel heavy-duty engine technologies[20]	Advanced Technology	Development and demonstration of advanced alternative technologies to reduce emissions from various heavy-duty diesel truck applications. Three areas of development related to heavy-duty trucks, are expected to be included: advanced alternative fuel engine and component technologies; novel alternative fuels; and non-internal combustion engine, non-CFC refrigeration systems for transport trailers. The technologies of interest include: engine combustion chamber design optimization for reduced emissions; direct gaseous fuel injection hardware/software development; closed-loop engine control system sensor/software development. Projects will be sought to evaluate these new fuels and related low emission heavy-duty engine technologies in, preferably, multi-vehicle field demonstrations in Southern California.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $1,300,000 as their share of research funding, of a total expected $2,600,000.
Low Emission, Alternative Fuel Technologies for On-Road Applications[21]	Alternative Fuels and related Technology	Development and demonstration of low-emission, alternative fuel technologies for light-, medium-, and heavy-duty mobile sources. Alternative clean fuels that will be considered include, but are not necessarily limited to, natural gas, propane, methanol, ethanol, hydrogen, and Hythane. In addition, reformulated gasoline and diesel fuels have been developed that produce lower emissions. When used in conjunction with advanced emission controls, additives, and new engine technologies, these appear to have promise to meet some CARB LEV standards.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $750,000 as their share of research funding, of a total expected $2,100,000.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Clean Fuels from Municipal Solid Waste, Biomass, and Other Waste Fuels[22]	Alternative Fuels	Development and demonstration of technologies and/or production processes to synthesize clean alternative fuels from various energy-rich, renewable sources, such as biomass, municipal solid waste, landfill gas, and other low cost or "free" waste fuels. The project is expected to result in pilot-scale production demonstrations, scale-up process design and cost analysis, overall environmental impact analysis, and projections for ultimate clean fuel costs and availability, for alternative fuels that are determined to offer the most promise	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $100,000 as their share of research funding, of a total expected $200,000.
LNG Combustion Technology for Locomotives[23]	Alternative Fuels	Develop and demonstrate, via the GasRail USA program, LNG combustion technology for locomotives capable of reducing NOx emissions by 75% or more compared to conventional diesel technology. In partnership with Southwest Research Institute, the project would optimize a newly developed combustion technology in a multi-cylinder locomotive engine. This will be followed by integration of the combustion system into one or more Metrolink passenger locomotives for operation in the SCAQMD Basin.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $500,000 as their share of research funding, of a total expected $1,325,000.
Injector/ Intensifier System[24]		This system is designed to reduce NOx emissions from heavy-duty diesel vehicles through a new natural gas fuel injector system. The natural gas injector system will be fabricated installed and certified.		X		Pilot-scale demonstration and evaluation.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	**NOx**	**PM**	
ENGINE MANAGEMENT CONTROLS						
Adaptive Control Techniques for Engine Management[25]	On-board engine diagnostics	Non-linear adaptive control techniques control air/fuel ratios more precisely over a wider range of operating conditions and operate catalytic converters over the narrow range in which they are efficient. Adapts to aging or faulty engines and to varying fuel properties such as volatility.	X	X	X	Test vehicle and production facility have been obtained. Engine simulation models have been developed. Preliminary identification models have been developed.
Pressure/ Diaphragm Sensors (Fiber Optics)[26]	New technology	Combustion pressure sensors can be integrated with "smart" ignition systems and direct injection systems in which combustion pressure is used as a feedback parameter for engine control. Diaphragm sensors, in combination with pressure sensors, can be integrated into a "smart" fuel injector for simultaneous benefits of increased injector reliability and lower costs.	X	X		N/A
EXHAUST AFTERTREATMENT						
Exhaust Gas Recirculation[27]	Redesign	This specific technology makes EGR more effective by ensuring EGR is applied at the high loads heavy-duty diesel engines (HDDEs) often run at, and providing an acceptable air flow to ensure the fuel is being burnt efficiently. Continuing work includes assessments of EGR on engine durability, particulate emissions improvements, and transient engine performance.		X		Results show that NOx emissions were almost halved when 15% of the exhaust gases were recirculated. Particulate emissions, however, increased, demonstrating a need for a combustion system to be optimized for very low smoke.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Plasma Treatment of Automotive Exhaust[28]	New technology	Plasma (ionized gas) treatment of lean-burn exhaust emissions in both gasoline and diesel lean-burn engines. Current plasma systems (gas-phase plasma discharges) appear to have low NOx conversion and/or high energy consumption. An alternative approach is being pursued to improve emission reduction and energy consumption.	X	X		Tests confirm the possibility of lean NOx reduction. Major challenges are to reduce energy consumption and ensure the absence of unintended by-products.
Vacuum Insulated Catalytic Converter[29]	Redesign	Using a form of vacuum insulation and phase-change heat storage technology, the converter remains at operating temperatures for more than 24 hours after the engine has been turned off. Potential exists to reduce automotive emissions to ultra-low emission vehicle (ULEV) levels, or even to equivalent zero emission vehicle (EZEV) standards in some cases.	X	X		Tests showed a 80 to 96 percent reduction in HC and CO and a 50 percent reduction in NOx.
Non-Thermal Plasma Reactor[30]	New technology	"Packed-bed reactor" transforms exhaust gas pollutants into less harmful constituents. Simultaneous particulate and NOx removal in diesel engine exhaust	X	X		Test have shown that simultaneous reductions in NOx and PM are achievable. A consortium of diesel engine and equipment manufacturers has been formed to further investigate nonthermal plasma technology.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Lean Burn Catalysts[31]	New technology	Major challenges in this project are the development of a catalyst with the three following attributes: 1) Sufficient and selective lean NOx activity; 2) Robustness, particularly hydrothermal durability; and 3) economically practical. Development of a lean burn catalyst is critical for the commercialization of the lean burn engine.		X		A large number of lean NOx catalyst formulations have been investigated, including unique technologies such as aerogels.
Oxygen Enrichment Membrane[32]	New technology	Membrane system uses DuPont Teflon AF fiber as the oxygen exchange mechanism for a underhood module to feed oxygen-enriched air directly to the engine chamber. The membrane separates ambient air into oxygen-rich and nitrogen-rich streams. The oxygen rich stream is directed to the manifold to improve combustion, while the nitrogen rich stream can be fed into the exhaust as a plasma to reduce NOx emissions.	X	X		N/A
EOLYS System[33]	New technology	Combines the use of a particulate trap with the action of the catalytic additive to ensure that particulates are destroyed during combustion.			X	Reduces nearly 90% of diesel particulate emissions in tests. Rhone-Poulenc has also entered into a technical cooperation agreement with several diesel engine manufacturers in Europe and in the U.S.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
CHA NOx Removal System[34]	Emission Control	This system removes NOx pollutants from small stationary diesel engines. There are currently no feasible controls for these engines.		X		Prototype testing. The prototype will be tested on a 50-hp diesel engine at the CHA laboratory and will also be demonstrated at McClelland Air Force Base on a 50-hp diesel motor generator set for aircraft ground equipment.
Optimized automobile catalyst[35]	Redesign of traditional catalyst	Airflow Catalysts is attempting to reengineer the traditional automobile catalyst. The redesign is an effort to minimize costs by reducing the amounts of costly rare metals in the catalyst. The new design will seek to react all contaminants (NOx, HC, CO) in the same area of the converter, rather than in three separate areas. The company is also seeking to minimize the need for air injection for NOx control.	X	X		Developmental R&D. Preliminary results are expected in June, 1997. Conversation with Airflow Catalyst personnel.

Endnotes

1. Partnership for a New Generation of Vehicles Briefing, North American Vehicle Emissions Control Conference, December 11, 1996.
2. Rocky Mountain Institute.
3. CRADA: Pacific Northwest, Y-12 in Oak Ridge Tennessee, and Lawrence Livermore.
4. Ceramic Technology Project (CTP) (AlliedSignal Corporation) (Allison Engine Company).
5. United States Council for Automotive Research (USCAR); Department of Defense (TACOM / TARDEC); Ricardo North America; AVL LIST GmbH.
6. Perkin's Technology (Engineering consultancy of diesel engine manufacturer VarityPerkins).

7. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

8. Chrysler Corporation; Delphi Energy and Engine Management Systems.

9. Ballard Systems (Vancouver); Allied Signal (CA); Energy Partners (FL); Dow Chemical (MI, AR); Electrochem (MA); International Fuel Cells (CT); H-Power (NJ, CA); Daimler-Benz (Germany); Honda Motor Corp.; Toyota Motor Corp.; Chrysler Corp.; General Motors Corp.; Ford Motor Corp.

10. Conversation with Joe Ferguson, Advanced Vehicle Systems, Chattanooga, TN, May 29, 1997

11. Galileo Research, Inc.

12. United States Advanced Battery Consortium 810-641-1446.

13. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

14. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

15. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

16. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

17. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

18. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

19. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

20. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

21. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

22. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

23. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

24. Valley Detroit Diesel Allison and Westport Research. This is an Innovative Clean Air Technology (ICAT) .

25. Cooperative Research and Development Agreement (CRADA): USCAR and Los Alamos National Laboratory.

26. Optrand.

27. TNO Road-Vehicles Research Institute.

28. CRADA: Department of Energy's Office of Energy Research at the Pacific Northwest National Laboratory and Low Emissions Partnership (LEP) of USCAR.

29. CRADA; DOE's National Renewable Energy Laboratory (NREL) and Benteler Industries, Inc.

30. Southwest Research Institute (SwRI); AEA Technology.

31. CRADA: DOE's Sandia National Laboratories, Argonne National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Lockheed Martin Energy Systems, and Low Emissions Partnership (LEP) of USCAR.

32. DuPont.

33. Rhone-Poulenc.

34. CHA Corporation. Their co-funding partners are the Sacramento Municipal Utility District, McClellan Air Force Base, and Gerling Applied Engineering.

35. Conversation with Airflow Catalyst personnel.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Electricity Generation

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
THIN FILM PHOTOVOLTAIC (PV)[1]						
Amorphous silicon (a-Si)	Substitution	A solar film on which research efforts is focused because of its potential for increased unit efficiency and ease of manufacturing. Efficiency gains are evident: from less than one percent in 1974 to 10.2 percent in 1994. Researchers are currently seeking laboratory efficiency ratings of 13 percent. Lower efficiency ceiling of a-Si compared to crystalline silicon offset by lower manufacturing costs.	X	X	X	Commercially available but R&D efforts ongoing. Possible enhancements: electron cyclotron resonance deposition, hot wire deposition, and radio frequency glow discharge.
Cadmium telluride	Substitution	A solar film on which research effort is focused due to its likely ease of production, likely improved efficiency and ability to compete with crystalline silicon modules. Laboratory efficiency ratings have reached 16 percent with commercial efficiency of 6 percent. Research indicates manufacturing techniques are likely very low cost, including electrodeposition, spraying, and high rate evaporation.	X	X	X	Commercially available but R&D efforts ongoing. Research efforts are focusing on lowering module costs and increasing reliability.
Copper indium diselenide (CIS)	Substitution	A solar film on which research effort is focused due to its ability to withstand outdoor exposure without significant deterioration. This film also appears easier to produce and gain efficiencies than alternatives. In 1995, a laboratory efficiency rate of 17.1 percent was recorded with 10.2 percent for a production prototype module.	X	X	X	Commercially available but R&D efforts ongoing. Research to better understand alloy properties should simplify fabrication processes.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Thin-layer crystalline silicon	Substitution	A solar film on which research effort is focused because it is likely to blend the production ease of other film technologies with the efficiency of silicon crystals.	X	X	X	Commercially available but R&D efforts ongoing. Research is focused on thinning the film to less than 50 micrometers which should make it financially feasible.
CRYSTAL PHOTOVOLTAIC TECHNOLOGY[1]						
Crystalline Silicon	Substitution	Silicon crystals were the first technology explored and applied to market devices. Research continues because it is the only technology with demonstrated long term reliability, competitive cost, and high efficiency. Newer cells have demonstrated a 24% efficiency rating. Commercial production modules are expected with an efficiency of 14%.	X	X	X	Commercially available (this technology currently dominates the PV market) but R&D efforts ongoing. Research efforts to increase pure silicon modules' efficiencies.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
PHOTOVOLTAIC CONCENTRATOR SYSTEMS[1]						
Gallium arsenide	Substitution	It is possible to increase any solar cell's efficiency by focusing a more direct source of solar energy on it. In application, cells need to withstand extreme conditions in order to see an efficiency increase. This alloy demonstrated an efficiency of 28 percent under concentrated sunlight.	X	X	X	These systems are used primarily in space applications where efficiency gains are important and conditions are harsh; R&D efforts ongoing.
Multi-junction cells (gallium arsenide and III-V alloys)	Substitution	It is possible to increase any solar cell's efficiency by focusing a more direct source of solar energy on it. In application, cells need to withstand extreme conditions in order to see an efficiency increase. This alloy demonstrated an efficiency in excess of 30 percent under concentrated sunlight. The expectation is to exceed 32 percent efficiency.	X	X	X	These systems are used primarily in space applications where efficiency gains are important and conditions are harsh; R&D efforts ongoing.
Thermo PV (TPV)	Substitution	Using superconducting materials to turn solar energy into heat to creates steam to then generate electricity.	X	X	X	R&D efforts ongoing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
PHOTOVOLTAIC MANUFACTURING[1]						
PV Manufac-turing (PVMat)	Substitu-tion	One of the primary hindrances to PV market acceptance is the difficulty in taking laboratory results and replicating them under real world conditions. A public-private partnership, funded for 5 years at $118 million, sought to address this problem by improving PV manufacturing processes, module development, and balance of system (BOS) components. For example, BOS components account for 50% of the system cost but 99% of repair issues. The goal was to increase PV module supply [currently demand outstrips supply (as of May, firms are taking no further orders for 1997)] and ensure that the U.S. production remains internationally competitive.	X	X	X	Commercially available but R&D efforts ongoing. Goals are lower module cost (estimated 50% reduction) through better processes, such as increased automation to reduce process time and improving power inverters to 98% efficiency with a mean time between failures of 5 years.
Batteries	Substitution	Batteries used to store PV electricity in many PV applications are often the “weak link” in the system. Improved batteries could improve energy availability by upwards of 35%. In addition, improved battery life spans could reduce life-cycle costs by an average of 35%.	X	X	X	Commercially available but R&D efforts ongoing.
Photovoltaics for Military Applications		This technology involves demonstrating the use of photovoltaic technology, reducing the amount of pollutants from fossil-fueled electrical gensets within DOD, and enhancing energy security. The focus will be to develop a modular, standardized power processing center (PPC) that will service multiple source photovoltaic/engine hybrid and demand reduction applications.		X		Pilot

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
STATIONARY FUEL CELLS						
Solid Oxide Fuel Cell (SOFC)[2]	Developing technology	The solid oxide fuel cell generates power electrochemically, avoiding the air pollutants and efficiency losses associated with combustion processes. Fuels cells operate continuosly, generating power as long as natural gas, coal-derived gas, or other hydrocarbon fuels are supplied. The solid electrolyte allows for the simplest of fuel cell plant designs, and requires no external fuel reforming. Capable of using either natural gas or cleaned coal gas, it emits no sulfur pollutants and as much as 60 to 65 percent less carbon dioxide than a conventional coal-burning plant.	X	X	X	Commercial production should commence in 2001.
Phosphoric Acid Fuel Cell (PAFC)[3]	Developing technology	This is the most commercially developed type of fuel cell. It is already being used in such diverse applications as hospitals, nursing homes, hotels, office buildings, schools, utility power plants, and an airport terminal. Phosphoric acid fuel cells generate electricity at more than 40% efficiency, and nearly 85% if steamthat the fuel cell produces is used for cogeneration, compared to 30% for the most efficient internal combustion engine. Operating temperatures are in the range of 400 degrees F. These fuel cells also can be used in larger vehicles, such as buses and locomotives.	X	X	X	ONSI's PC25 converts 1,900 SCF per hour of natural gas into 200 kW of grid-connected or grid-independent premium power and up to 750,000 Btu/hr of useful thermal energy at up to 250 degrees fairhenheit. Fuel cell cogeneration power plants reached their millionth hour of operation in 1996. More than 60 phosphoric acid fuel cell units are in use, providing 200KW of power and useable heat. They are developing a reputation for excellent reliability.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Molten Carbonate Fuel Cell (MCFC)[4]	Developing technology	The molten carbonate fuel cell uses an electrolyte of lithium and potassium carbonates and operates at approximately 650C (1200F). Due to the high temperature involved, noble metal catalysts are not required for the cell electrochemical oxidation and reduction process. Molten carbonate fuel cells are being developed for natural gas and coal based power plants for the industrial and electric utility sectors. Molten carbonate fuel cells promise high fuel-to-electricity efficiencies and the ability to consume coal-based fuels. This cell operates at about 1,200 degrees F. The first full-scale molten carbonate stacks have been tested, and demonstration units are being tested in California in 1996. One project is attempting to demonstrate the use of landfill gas to fuel a molten carbonate fuel cell power plant. In the first phase of the project, a cost competitive, viable gas cleanup system will be developed. In the second phase, the cleanup system will be integrated into a power plant system. The effort will culminate with a demonstration of the gas cleanup system with the complete power plant system.	X	X	X	Demonstration of a MCFC that uses natural gas as the fuel and will use the fuel cell's waste heat, setting total expected efficiency levels at more than 70 percent. The first commercial fuel cell to run on renewable fuel was dedicated in late June of 1996 at a landfill in Groton, Connecticut. The 200 KW fuel cell system will clean up the landfill gas, convert its methane to electricity, and feed it to a nearby power grid. The Santa Clara Demonstration Project is the largest fuel cell power plant ever operated in the U.S. It contains 16 stacks, each capable of producing approximately 125 kilowatts of direct current power. Energy Reserach Corp. intends to build and begin operation of a second demonstration based on the same design.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Proton Exchange Membrane Fuel Cells (PEMFC)[5]	Developing technology	These cells operate at relatively low temperatures (about 200 degrees F), have high power density, can vary their output quickly to meet shifts in power demand, and are suited for applications, such as automobiles, where quick startup is required. According to DOE, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras."	X	X	X	See Mobil Fuel Cells discussion
Alkaline Fuel Cells (AFC)[6]	Devloping technology	Long used by NASA on space missions, these cells can achieve power generating efficiencies of up to 70 percent. They use alkaline potassium as the electrolyte. Until recently they were too costly for commercial applications, but several companies are examining ways to reduce costs and improve operating flexibility.	X	X	X	
Residential Fuel Cells[7]	Future technology	Fuel cell that is small enough to fit into a closet and capable of generating 2-10 kW of power.	X	X	X	Industry is focusing on larger fuel cells at present time. Developers are hoping to get this technology rolling in the next five years.

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
WIND POWER[8]						
Improved Airfoil Materials	Substitution	Utilization of wind power necessitates a device (airfoil) which will capture wind energy. By using newer materials and changing the number of blades, improved energy generation and lower costs may be achieved. Improved airfoil design using composite materials (fiberglass, wood/epoxy) and fewer blades (2-3) will reduce system cost while increasing energy conversions/efficiencies.	X	X	X	Commercially available but R&D efforts with new materials are ongoing.
Advanced Airfoil Retrofit	Substitution	Rather than using airfoils designed originally for the airline industry, systems using airfoils designed specifically for wind towers offer substantial savings. One estimate is that substitution of such airfoils onto existing towers causes a 20 - 30 percent increase in electricity generation.	X	X	X	Commercially available but R&D efforts ongoing.
Gearbox	Substitution	The turbine blades' rotation causes wear on a system's gearbox. By using improved gearboxes, it is possible to lower total system cost (gearboxes are approximately 20 percent of total system cost). If as projected, infinitely variable speed tower systems become available, then it would no longer be necessary to maintain a gearbox in a tower system. Improved design and use of composite materials will reduce system cost by increasing the system's life span.	X	X	X	Commercially available but R&D efforts ongoing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Manufacturing Techniques	Substitution	The manufacture of wind tower components is to date a labor intensive process (airfoils are traditionally hand laid). Development and use of computerized mass production techniques promises to reduce lay-up times and increase orders.	X	X	X	Commercially available but R&D efforts ongoing.
Computer Modeling	Substitution	The first step of wind power is siting the unit; if the unit over- or under-estimates the average wind speed, then the possible power generation capability is negatively impacted. Similarly, use of computers to measure the wind speed and simultaneously adjust the orientation of the wind foils can positively impact the power generation capability. Development of improved computer models that can lower the financial risk of wind power by better estimating the site's energy return is ongoing.	X	X	X	Commercially available but R&D efforts ongoing.
Control and Power Electronics	Substitution	Manual adjustment of individual controls on individual tower systems is expensive and time consuming. By using computers and electronic components on the systems it becomes possible to manipulate an entire farm in real time. It is expected that systems would also able to adjust to extreme weather conditions independently, thus avoiding catastrophic failures.	X	X	X	Commercially available but R&D efforts ongoing.

Endnotes

1. Personal communications with Ken Zweibel, Robert Foster, National Renewable Energy Laboratory, Golden, CO, Dr. Robert Williams, Princeton University; U.S. DOE, "National PV Program Plan for 1996-2000", January 1996; and U.S. DOE, Sandia Lab.

2. Dr. Steven Veyo, Westinghouse (PA); University of Missouri-Rolla; Allied Signal Aerospace (CA); Institute of Gas Technology (OH); SOFCO; Ztek

(MA).

3. International Fuel Cells (CT); Fuel Corp. of America (PA); ONSI Corporation.

4. Energy Research Corp. (CT); M-C Power (IL); International Fuel Cells Corp. (CT); EPRI (CA); DOE (DC).

5. See Mobil Fuel Cells discussion.

6. International Fuel Cells (CT).

7. South Coast Air Quality Management District (CA).

8. Personal communications with Susan Hock, National Renewable Energy Laboratories, Golden, CO.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **Solvent Utilization - Surface Coating (Industrial Adhesives)**

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Hot melt spray tool[1]	Process redesign	A newly-redesigned, solvent-free, hot melt spray tool is under to development to reduce VOC emissions. Further details not available.	X			N/A
Eastman AQ 1350 polymer[2]	Material substitution	A new water-dispersible hot-melt adhesive raw material, which can form the basis for use in a variety of applications including nonwoven products such as disposable diapers, packaging, bookbinding and labels. Products containing the water-dispersible adhesive are more easily repulped or recycled.	X			Introduced and commercialized in the fall of 1995.
Polyurethane reactive (PUR) technology[3]	Reformulation	New, accelerated-cure versions of hot-melt adhesives technology for recreational vehicle and building components customers has been developed. Also applicable to the profile wrapping segment of the woodworking industry, which can use the adhesives to make window and door components that withstand hot and cold temperatures, rain and snow. Users can increase process speeds, while at the same time produce stronger products in a solvent-free environment.	X			Full-scale demonstration; on verge of commercialization.
Advances in waterborne adhesives[4]	Reformulation	New waterborne adhesives for the flexible packaging industry now meet performance standards previously attainable only with solvent-borne formulations.	X			Commercially-available; strong initial sales in meat and cheese packaging and coffee bag lamination markets; being demonstrated to film converter industry.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Advances in solventless, 100% solids adhesives[5]	Reformulation	New generation solventless, 100% solids adhesives applicable for the film converter industry have been developed. With no solvents to incinerate, film converters can reduce operating costs and increase output by reallocating incineration capacity to other plant operations.	X			Being demonstrated to film converter industry.
Cold lens blocking methods ("Loctite Cold Bloc")[6]	Material substitution	New uv-curing "cold" blocking adhesive enables optical manufacturers to produce lens surfaces that are practically distortion free, and virtually eliminates the environmental concerns (solvents) of the current technique. This technique facilitates easy debonding using a variety of debonding agents and techniques. The adhesive is a significant advance in the lens blocking process, as it eliminates heat-induced blocking strain, which is the most significant problem encountered with current hot pitch blocking methods. Process reduces costly processing time, and is compatible with existing tooling.	X			Developmental R&D.
New UV-cure technology applications[7]	New application	New UV-cure applications are being developed for use in the automotive industry. These applications include coatings for metal and plastics, interior and exterior applications, adhesives, and gasketing.	X			Testing.
Electron Beam (EB) curing[8]	Reformulation/ Process redesign	EB curing with existing technology has already been shown to dramatically reduce or eliminate solvent emissions in wood finishing. Currently, new advances in EB equipment and processes are being developed, including a new, lower-energy EB system and a new transport system for the EB treatment of powders. EB processes result in improved product performance and higher productivity, but require different curing equipment, and in some cases, application may be more difficult.	X			First generation processes are commercially-available; refinements are in developmental R&D/testing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
EB-curable epoxy resins for composites[9]	Material substitution/ Process redesign	Major advancement in the formulation of epoxy resin systems capable of being cured (cross-linked) by ionizing radiation. This development could be the link in making polymer matrix composites and adhesives a cost-effective system for manufacturing a broad range of products in both high-tech and high-volume commercial applications. Further optimization of these resin systems is currently being performed for specific aircraft, aerospace, and defense applications. Substantially reduced manufacturing costs (25-65% less expensive) and curing times; and improvements in part quality and performance.	X			Currently used commercially for plastics, coatings, and food and medical sterilization. Testing now for new applications for composite products.
Non-acrylate Systems[10]	Material substitution	In the research development of UV and EB curable alternatives to acrylates, a number of "new" systems have been developed that reduce emissions, such as cationic systems, alternating free radical induced copolymerization of donor/acceptor type monomers, various hybrid systems, and photoinduced addition reactions for the formation of polymeric networks.	X			Development R&D.
Water-based aerosol adhesive[11]	Material substitution	Based on new technology, a water-based low VOC spray adhesive has been developed that offers bonding strength and heat resistance comparable to many typical solvent-based aerosol products. This adhesive can be used to bonds a range of substrates, including paper, fabrics, plastics, wood, and aluminum.	X			Available for commercial use in the near term.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Dual-cure photocatalyst technology[12]	Material substitution	Low-solvent, low-VOC coatings are being developed that use photocatalysts to react with the coating material and accelerate the curing process. These photocatalysts allow the coatings to cure from liquids to solids quickly under UV or visible light. A family of such photocatalysts is being developed and tested. Major uses include tape adhesives and protective topcoats for aircraft. Development of solventless backing saturants for electrical tape backings has essentially been completed. Optimal dual cure resin formulations have been identified and utilized in preparing complete tape constructions.	X			Full-scale demonstration
Advances in waterborne adhesives[13]	Material substitution	Morton's Water-Based Polymers Technology and Adhesive Technology Groups are involved in developing new and improving on existing Morton products such as: the use of HAP-free solvents for waterborne adhesive products and 100% solids flexible film adhesive laminations.	X			Developmental R&D, pilot research at pilot laminator in Woodstock, IL, in addition to some first round commercially-available products.

Endnotes

1. Adhesive Focus (electronic issue of GLUGURU's quarterly newsletter); Volume III, Issue 1, Winter 1997
2. 1996 R&D 100 Awards Competition. August 28, 1996.
3. National Starch and Chemical Company. 1997.
4. National Starch and Chemical Company. 1997.
5. National Starch and Chemical Company. 1997.
6. International Society for Optical Engineering (SPIE) abstracts; pp.30-35 (no date).

7. RadTech '96 Conference & Exhibition, Keynote Address.

8. RadTech'96 Conference & Exhibition, Wood/Furniture Coatings Session.

9. Researchers at DOE, Oak Ridge, with: AECL Technologies; Applied Poleramic; The Boeing Co.; Ciba-Geigy; E-Beam Services; Lockheed Fort Worth; Lockheed Martin Technologies -- Aero and Naval Systems; Nicolet Imaging Systems; Northrop Grumman; Sandia; and UCB Chemicals; 5/22/96.

10. RadTech' 96 Conference and Exhibition, Formulating Non-Acrylate Systems Session.

11. The 3M Company internet site (not dated).

12. Minnesota Mining and Mfg. Co., St. Paul, MN (3M), in partnership with the U.S. Department of Energy's Office of Industrial Technologies.

13. Morton Water-Based Polymers Technology and Adhesives Technology Groups (May 1997).

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Solvent Utilization - Surface Coatings

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Biomimetic coatings[1]	Reformulation	Synthetic routes are being developed for new water soluble polymers to enable the formulation of effective and durable waterborne protective coatings. The aim is to develop novel water-soluble polymers which on evaporation of water undergo a phase transformation similar to protein molecules where hydrophobic moieties, present in the polymer, form the matrix of the film. This approach to produce zero-VOC solvent systems avoids the water sensitivity and reductions in performance and durability experienced by the current generation of water-based coatings.	x			Developmental R&D.
Acrylic plastisols[2]	Material substitution	Acrylic plastisols are being investigated as a new type of low-solvent industrial coating. Consisting essentially of a dispersion of emulsion or suspension grade polymer in a high boiling solvent-plasticiser, the coating is applied to the substrate and then heated to allow the plasticiser to swell and dissolve the polymer particles. The result on cooling is a tough and flexible coating. The plastisol market has traditionally been dominated by polyvinyl chloride; however manufacturers are searching for alternative polymers. Acrylic polymers offer a number of distinct advantages over polyvinyl chloride such as superior exterior durability and a more favorable environmental image.	x			Completed initial developmental R&D.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Organic protective coatings and application technology[3]	Material substitution and reformulation	High performance, non-toxic, low VOC content coatings for Navy use are being developed, including investigation of low VOC polymer technology to produce low VOC binder systems. Reactive monomers and diluents and low molecular weight resins have been used to develop low viscosity binder systems for future near-zero VOC aircraft coatings. In addition, recent advances in water-borne resin technology has allowed for the development of a high performance water-borne topcoat which goes beyond mere compliance with environmental regulations. Non-toxic inhibitor systems have been developed and formulated into non-toxic aircraft corrosion inhibiting primers. Coating corrosion resistance, physical performance properties and VOC content were evaluated in the development of the best materials. The non-toxic inhibited primers have been optimized, and service evaluation at Navy maintenance facilities is in progress.	x			Field testing/verification.
Dual-cure photocatalyst technology[4]	Material substitution	Dual-cure photocatalyst technology is being researched for a variety of coating and adhesive uses, such as aerospace topcoats, aerospace primers, and solventless manufacture of tape backings. Significant progress has been made in improving the performance of the urethane/acrylate formulation being used for the aerospace topcoat application. Technical challenges have continued with the aerospace primer formulation.	x			Full-scale demonstration
New latex polymer application method[5]	Process redesign	New latex polymer application method eliminates the acetate rinse-out and the resultant solvent-contaminated water waste stream and distillation air emissions.	x			Testing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Mobile zone spray booth ventilation system[6]	Process redesign	New process design endeavors to reduce the volume of air to be treated from spray paint booths, thereby increasing efficiency and improving air pollution abatement (in particular, reducing VOC emissions). Most of the ventilation air is recycled through the booth to maintain laminar flow; the machinery is located on the supply side of the booth rather than on the exhaust side. 60 to 95% reduction in spray booth exhaust rate should result.	x			Full-scale demonstration engineering and production prototypes have been made.
Magnetically controlled deposition of metals using gas plasma[7]	Process redesign	Methods of spraying materials on a substrate in a controlled manner are being researched in an attempt to eliminate the waste inherent in the present process. Thin layers of secondary material are plated on substrates either by plating or spraying processes. Plating operations produce large amounts of hazardous liquid waste. Spraying, while one of the less waste intensive methods, produces `over spray' which is waste that is a result of the uncontrolled nature of the spray stream. In many cases the over spray produces a hazardous waste.	x?		x?	Developmental R&D.
Safe Yellow IC[8]	Material substitution	A product has been developed for enhancing powder coatings by increasing the flow of the resins, eliminating orange peel and allowing the replacement of more expensive organic pigment on a one for one basis. The manufacturers of this product say it is an improved coating with lower costs.	x			Recently made commercially available.
Advanced Acetylenic Glycol (AAG) technology[9]	Material substitution	To address the need for substrate wetting in waterborne systems, a new-generation surfactant has been developed based on Advanced Acetylenic Glycol (AAG) technology. The AAG technology provides greater flexibility and mobility, as well as other benefits.	x			Recently made commercially available.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Prepolymers and ultralow-viscosity reactive diluents technologies[10]	Material substitution	Two technologies have been developed to help solve formulation problems with decreased levels of VOCs in two-part, solventborne polyurethane coatings. One technology is a process to make narrow-molecular-weight-distribution, isocyanate-terminated polyurethane prepolymers. The other technology is the creation of ultralow-viscosity oxazolidine and aldimine/oxazolidine reactive diluents. Use of these materials achieves low-VOC formulations, controlled reactivity of low-VOC systems and enhanced coating performance, as well as formulation flexibility and ease of use.	x			Testing.
Foam-control agents[11]	Material substitution/ process redesign	More sophisticated foam-control agents are being developed and used as formulators move from solvent-based to waterborne coating systems. Foam is a common problem in waterborne systems, and it can adversely affect the coating's appearance and durability. Prudent use of foam control agents can minimize or eliminate the adverse effects of foam without impacting other surface properties.	x			Developmental R&D and testing.
Water-based, solvent-free and ultrahigh-solids coatings[12]	Material substitution	Water-based, solvent free and ultrahigh-solids coatings are being considered for development for the metal office furniture industry.	x			Developmental R&D.
Water-based coatings[13]	Material substitution	Morton's Water-Based Polymers Technology Group is involved in developing new and improving on existing Morton waterborne products such as: a new water-based, lead-free highway paint; a zero-VOC, waterborne color dispersion paint component; and water-based automotive plastic coatings.	x			Developmental R&D and commercially-available.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Polyol resins, crosslinkers and reactive diluents[14]	Material substitution	Recent developments with polyol resins, crosslinkers and reactive diluents will enable the future formulation of higher-solids, ultralow-VOC coatings and, ultimately, of solventless liquid coatings. In spite of the increasing popularity of waterborne and powder coatings, many companies see a future for higher-solids coatings and are investing in new technology, particularly for industrial (original equipment manufacturer) and special-purpose applications.	x			Developmental R&D.
Micro-emulsion technology[15]	Material substitution	New microemulsion technology creates an effective way to decrease VOC levels up to 50% or more and still maintain effective paint-stripping performance. This solvent technology allows water to be incorporated into hydrocarbon-based paint strippers while making minimal performance sacrifices.	x			Recently commercially available.
High solids aliphatic polyurethane coatings[16]	Material substitution	Three novel approaches to high solids aliphatic polyurethane coatings have been developed: a 100% solids, VOC free, instant setting, aliphatic polyurethane coating system; a high solids mix-and-apply aliphatic polyurethane coating system; and a high solids single component aliphatic polyurethane coating system.	x			Recently commercially available.
Aliphatic isocyanates[17]	Material substitution	Urethane technology provides strong linkage for molecules in coatings, and is finding its way into high-solid, powder, and waterborne technologies. For example, isophorone diisocyanate is gathering strength in the powder coatings market, while use of hexamethylene diisocyanate in waterbased coatings is expected to grow. A family of low-temperature unblocking isocyanates as also been developed, and is being marketed to the painting and coating industry.	x			Recently commercially available.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Waterborne primers[18]	Material substitution	Waterborne primers will be studied at three Ford truck plants and a BMW plant.	x			Field scale testing/verification.
Waterborne clearcoats[19]	Material substitution	Water-based clearcoats are under investigation at Ford.	x			Developmental R&D.
Powder-based primers[20]	Material substitution	GM is working on a prototype powder primer to try on one of its vehicle lines; such a primer would contain no VOCs. New chemistry research is being conducted on both epoxy and polyester powder primers.	x			Developmental R&D, prototype testing.
Clearcoat powder[21]	Material substitution	The Low Emission Paint Consortium is researching the development of a powder clearcoat, although this type of coating has many difficulties to overcome in terms of durability and appearance in comparison with current methods. A trade-off with powder coatings is that powder requires higher bake requirements and new equipment and application systems. Ford is working on a prototype powder clearcoat.	x			Developmental R&D, prototype testing.
Non-ozone depleting sealants for ammunition applications[22]	Material substitution	Research program aimed at investigating solvent-free or solvent-safe case mouth sealants for military ammunition by evaluating state-of-the-art, commercially-available non-ozone depleting sealants. Economic benefits include reduced costs (elimination of toxic ozone-depleting chemicals environmental protection activities), increased production rates, and reduced lot rejection rate (which currently averages 6% per year).	x			Conducting compatibility and long term evaluations, and then functional testing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
UV/ozone oxidation technique[23]	Process redesign	Technology development and demonstration activity targeted for Department of Defense painting operations to validate the recirculation/partitioning concept used with a novel UV/ozone oxidation technique to eliminate HAP and VOC discharges from paint spray booths and other booth designs. Preliminary results suggest that booth discharge flow reductions of up to 75% can be achieved.	x			Field evaluations in conjunction with additional developmental R&D.
Ultra Filtration[24]	Process redesign/ reuse	Decorative Coatings' technology center at Montataire, France is developing new technologies to improve waterborne paint waste reuse, thereby reducing new paint production and associated emissions. One of its initiatives is wastewater treatment by Ultra Filtration (UF). This is a major project, because up to 12 European sites may be involved. UF is a nonchemical membrane separation process, which separates the effluent into two streams: permeate (the treated water) and concentrate (UF sludge). The pollution level of the permeate is equivalent to that obtained after conventional treatment, but it is completely free of paint solids, which are held in the concentrate. So far, UF has proved to be an efficient solution for treating effluent from waterborne paint production. Industrial application of UF is economical provided that the concentrate is reused in making paint.	x			Prototype testing at multiple plants.
New photoinitiator systems[25]	Material substitution	Ciba is working on advanced photoinitiator systems that enable paints and coatings to dry rapidly without the need for heating or the release of solvents into the atmosphere. Key future research is targeting extending the range of photoinitiators for paints and coatings.	x			Developmental R&D and first generation commercially-available products.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Water-based solder masks[26]	Material substitution	Probimer7 water-based solder masks can help cut down on the use of solvents; these water-based coatings are used on printed wiring boards in the computer industry. In addition, the division's powder coating systems are applied to buildings and cars using electrostatic charge - avoiding the need for a solvent.	x			Developmental R&D and first generation commercially-available products.
Compatible innovative coatings[27]	Material substitution	Ciba is working on developing compatible powder, high solid and waterborne epoxy systems. Examples of areas of research include: new high flow solid epoxy resin for powder coating applications with smoother appearance; and new waterborne epoxy resins and epoxy hardeners with environmental advantages.	x			Developmental R&D.
New applications for powder coating[28]	Material substitution/ process re-design	A full "factory size" powder coat facility has been built to expand the application of powder coating to a new range of users.	x			Full scale demonstration.
Advances in transfer efficiency[29]	Process re-design	Investigations are being made to improve paint coating transfer efficiencies; for example, innovative nozzle designs, air flow, cleaning systems/procedures, and high-volume, low-pressure systems are being analyzed.	x		x	Developmental R&D and testing.
Supercritical CO_2 as a paint solvent[30]	Material substitution	Supercritical CO_2 is being investigated as a replacement for traditional paint solvents, eliminating VOC emissions.	x			Developmental R&D and testing.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Zero-VOC Industrial Maintenance Metal Coating[31]	Reformulation	This zero-VOC coating technology is intended for use as a topcoat on metal furniture. The resin formulation for the coating will be adjusted to provide acceptable drying times, flexibility and hardness, and ultraviolet, chemical and salt spray resistance.	x			Field demonstration and evaluation. The technology is expected to be followed by a full-scale demonstration at a commercial metal furniture manufacturing facility.
Dynamically Optimized Recirculation Coupled with Fluidized Bed Adsorption[32]	Reformulation/ Product Redesign	These two technologies (i.e., dynamically optimized recirculation to continually minimize exhaust volume flow rates; and a fluidized bed emissions control and solvent recovery technology using new adsorbing resins for cost-effective operation) will be used to reduce VOC emissions from coating and solvent operations. An existing paint booth recirculation system on a Steelcase furniture coating line will be modified to include dynamic recirculation.				This technology is being developed and CA EPA's Air Resources Board is confident that it could be commercialized within a few years.

Endnotes

1. Paint Research Association, UK and researchers at Southampton University (Applied Biocomposites Group); 1997.
2. Paint Research Association, UK; 1992.
3. Naval Air Warfare Center Aircraft Division, Warminster, PA., (not dated).
4. 3M, in partnership with the U.S. Department of Energy's Office of Industrial Technologies.
5. Los Alamos National Lab, DOE contract (1995).
6. Mobile Zone Associates, Nashville, TN, DOE (1994).
7. Idaho National Engineering Lab, DOE (1994).
8. Sino American Pigment Systems, working with Specialty Chemical Sales, Cleveland.
9. Air Products and Chemicals; article in PCI, Issue: March 1996.
10. Air Products and Chemicals Inc.; and ANGUS Chemical Co.; article in PCI, Issue: February 1997.

11. Ashland Chemical Co.; article in PCI, Issue: February 1997.
12. IVC Industrial Coatings; article in PCI, Issue: Sept. 1996.
13. Morton Water-Based Polymers Technology Group (May 1997).
14. Eastern Michigan University; article in PCI, Issue: May 1997.
15. Dow Chemical Co.; advertisement in PCI, no date.
16. Madison Chemical Industries, Canada; internet: not dated.
17. Chemical Marketing Reporter, February 14, 1994, p. 4.
18. Modern Paints and Coatings, v83, n7, p. 34(3). July 1993.
19. Modern Paints and Coatings, v83, n7, p. 34(3). July 1993.
20. Modern Paints and Coatings, v83, n7, p. 34(3). July 1993; Du Pont is the only supplier currently providing an all-vehicle powder primer.
21. Modern Paints and Coatings, v83, n7, p. 34(3). July 1993.
22. U.S. Army Armament, Research, Development, and Engineering Center; EnviroSense (March 1996).
23. Advanced Research Laboratory, Penn State University, PA; Research Triangle Institute, NC; EPA's Air and Energy Engineering Research Laboratory; and U.S. Marine Corps, Marine Corps Logistics Bases Envirosense (March 1996).
24. Morton, Decorative Coatings Business Unit (Plants involved are Dormelletto, Italy; Berlin, Germany; Montataire, France); 1995.
25. CIBA Speciality Chemical's Additives Division (May 1997).
26. CIBA Speciality Chemical's Performance Polymers division (May 1997).
27. CIBA Specialty Chemical's Performance Polymers division (May 1997).
28. National Defense Center for Environmental Excellence (May 1997).
29. National Defense Center for Environmental Excellence (May 1997).
30. National Defense Center for Environmental Excellence (May 1997).
31. Aerovironment Environmental Services and Adhesive Coating Company. This is an Innovative Clean Air Technology (ICAT).
32. Air Quality Specialists with two co-funding partners, Steelcase North America and Southern California Edison.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **Solvent Utilization - Nonindustrial (Consumer Products)**

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	Nox	PM	
Low VOC-Content substitutions	Chemical reformula-tion, product or feedstock substitution, repackaging, and direc-tions for use, consump-tion, storage, or disposal.	Product reformulation and changes in delivery methods to result in low-VOC consumer products. Over 200 categories of consumer products with emission reduction potential have been defined. Substitution to CO_2 propellants, detergent- or water-based solutions, and/or pump sprays vs. aerosols are being targeted. Consumer education and product labeling is also being pursued. CARB estimates an 85% VOC reduction in 2010 from the current consumer product inventory, but has not identified specific technologies.	X			Conceptual/ R&D phase. CARB has established a consumer products working group to establish mid- and long-term control measures. It is comprised of industry, environmental groups, ARB, US EPA, and local AQMDs. First met in Spring 1995.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Solvent Utilization - Degreasing

Technology (Name)	Control Strategy	Description	Emissions Controlled VOCs	Emissions Controlled Nox	Emissions Controlled PM	Technology Status
Solid State Metal Cleaning[1]	Materials Substitution	This technology involves metal cleaning processes that do not require the use of water or VOCs. The two technical objectives to be achieved involve: (1) developing and transitioning to using a cleaning process for large (and small) aircraft components that does not require the use of water or VOCs; and (2) developing a process that will allow components to proceed directly to the next step in the process for surface washing without the need for subsequent treatments involving water or organic solvents.	X		X	Prototype testing.
Combination Sorption/Catalyst Medium for Destruction of Halogenated VOCs - Dover AFB[2]	Emissions control	This technology involves development, evaluation, and optimization of an adsorbing catalyst that will be pilot tested as an alternative low-cost approach for eliminating air emissions which occur during waste water cleaning operations. Research is focusing on developing and optimizing a single medium which first will act as a sorbent to remove low concentration VOCs at room temperature and then act as a catalyst at about 350EC to destroy the VOC. The two major technical issues involve finding a sorbent that is also catalytically active and controlling the desorption reaction without excessive heat effects (catalyst deactivation).	X			N/A

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	Nox	PM	
Solvent Substitution and Low VOC Cleaners[3]	Substitution	This technology involves identifying low VOC content cleaning solvents for use on Navy aircraft, weapon systems, and ground support equipment and identifying replacements for methylene chloride based chemical paint strippers, such as solvent blend formulations and aqueous cleaners.	X			Implement optimized enzyme cleaners (6/98); implement optimized non-hazardous strippers (12/95; implement optimized low VOC wheel well cleaners (9/96); Implement no VOC A/C exterior cleaners (9/97); implement supercritical CO2 cleaning (9/99); implement lubricant low VOC solvent cleaners (9/99)

Endnotes

1. The Strategic Environmental Research and Development Program (SERDP); the Air Force Material Command, Aeronautical Systems Center, Wright Laboratory, Wright-Patterson AFB [http://es.inel.gov/new/funding/serdp/p2prj019.html].

2. EPA's Air and Energy Engineering Research Laboratory and the USAF. [http://es.inel.gov/new/funding/serdp/fy93cm2.html].

3. Naval Air Warfare Center Aircraft Division Warminster, the USAF, NAWCADWAR, Naval Aviation Depots and the Lead Maintenance Technology Center for Environment, DOE, and aerospace industry. [http://es.inel.gov/new/funding/serdp/p2prj017.html].

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **Solvent Utilization - Nonindustrial (Pesticide Applications)**

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Biopesticides[1]	Material Substitution	Biopesticides are typically microorganisms, pheromones or other substances found in nature that are generally recognized as presenting lower overall risk than most conventional chemical pesticides. Sixteen new biopesticide active ingredients have been registered for use in California. Examples include: 1-octen-3-ol; Bacillus sphaericus, serotype h-5a5b, strain 2362; and Neem oil.	X			Cal/EPA's Department of Pesticide Regulation registered 16 new reduced risk pesticide active ingredients in 1996.
Integrated Pest Management (IPM)[2]	New Cultural Practices	The purpose of IPM is to maximize the efficiency of pesticide applications, where necessary, and reduce the use of pesticides using a variety of chemical, nonchemical, and cultural techniques. IPM techniques include the use of chemical alternatives, resistant rootstocks, crop rotations, cover crops, biological controls, organic amendments and organic farming to provide competitive yields in the absence of conventional chemical applications. IPM reduces the grower's vulnerability to regulatory actions on pesticides and on pest resistance to chemical controls. US growers have experienced cost savings through the use of IPM techniques. For example, ICF estimated that a grower using IPM techniques iin CA vineyards instead of conventional methyl bromide fumigation may save as much as $340/acre.	X		X	The research base for IPM techniques is increasing, as is the demand for environment-ally friendly production practices.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Resistant Rootstocks and Cultivars[3]	Material Substitution	Resistant plant varieties (i.e., rootstocks and/or cultivars) can reduce or eliminate the need for pesticides. Several such rootstocks have been discovered including nematode resistant varieties of peppers, tomatoes and tobacco. Similarly, scientists recently isolated two genes, the RPS2 gene and the N gene, which fight off diseases and viruses, respectively, in the absence of chemicals.	X			Resistant cultivars are already being widely used in the US and new strains are being developed.

Endnotes

1. California EPA's Department of Pesticide Regulation *News Release*, January 10, 1997. Pesticides are also registered by the US EPA Office of Pesticide Programs.

2. Information on IPM available from EPA 1996, Klonsky 1992, Howe 1994, Liebman and Daar 1995, and McKenry 1995.

3. Sources include the EPA 1996, Institute for Agriculture and Trade Policy 1994, McKenry and Kretsch 1995, and Potter 1996.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: <u>Other Industrial Processes - Miscellaneous</u>

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			HC	NOx	PM	
Solventless Pyrotechnic Manufacturing	Product redesign	The goal of this technology is a field demonstration of the cryogenic processing technique as a solventless method to eliminate air pollutant and VOC emissions from the magnesium-teflon-viton (MTV) pyrotechnics manufacturing process. The cryogenic approach would result in fewer explosive operators being exposed to fewer hazardous situations compared to the current process, the solvent disposal cost would be eliminated, and the potential for an accidental ignition would be reduced. The Army has estimated a potential cost savings of $900,000 if their current 600,000 pounds per year "shock-gel" production process for flare decoys were replaced with the cryogenic process.	X			Pilot scale as of FY93

<u>Endnotes</u>

1. Naval Surface Warfare Center, manufacturers of cryogenic grinding equipment, and cryogenic grinding companies. [http://es.inel.gov/new/funding/serdp/41-solve.html].

2. DOD, DOE, Sandia National Laboratories. [http://es.inel.gov/new/funding/serdp/fy93en1.html].

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Waste Disposal and Recycling

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Combined Air and Water Pollution Control System[1]	Emission Control	This system, developed at NASA's Marshall Space Flight Center (MSFC), is a recirculating bioaquatic pollution control system which combines both wastewater and air pollution controls into one system. The system combines exhaust combustion gases with flowing wastewater which is then filtered through a rock/plant/microbial filtering system. The microorganisms living in and around the plant root form a symbiotic relationship with plant roots which results in increased degradation rates and removal of organic chemicals from wastewater.	X			Available for commercial applications. The patent number for this system is 4,959,084.
Pyrokiln Thermal Encapsulation Process[3]	Process Redesign	The Pyrokiln Thermal Encapsulation Process is designed to improve conventional rotary kiln incineration of hazardous waste and may reduce the total dust load to the air pollution control system and the amount of particulate emissions from the stack. The process is designed to immobilize the metals remaining in the kiln ash, produce an easily handled nodular form of ash, and stabilize metals in the fly ash, while avoiding the problems normally experienced with higher temperature "slagging kiln" operations.			X	Field testing/ verification.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Reactor Filter System (RFS)[4]	Emission Control	The RFS technology, developed by the Energy and Environmental Research Corporation (EER), is designed to control gaseous and entrained particulate matter emissions from the primary thermal treatment of sludges, soils, and sediments. RFS was designed to overcome the logistical problems associated with existing air pollution control devices required to control products of incomplete combustion (e.g., size not suitable for transport to remote Superfund sites).	X		X	Pilot-scale testing.

Endnotes

1. This system was developed as part of the NASA Technology Transfer Program.
2. EPA is working with the Membran Corporation to develop this technology.
3. EPA and Svedala Industries, Inc are working together to develop this technology.
4. EPA and the Energy and Environmental Research Corporation are working together to develop this technology.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Miscellaneous

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
PremAir™ Catalyst[1]	Ozone Destroying Catalyst	A catalyst has been developed by Engelhard Corporation that converts ground-level ozone to oxygen. The catalyst coverts a large percentage of ambient ozone to oxygen by passing ambient air over the surfaces coated with the catalyst. To be effective as pollution control measure, catalyst can be coated on surfaces that come into contact with large volumes of ambient air, including car radiators, air-conditioner condensers and other equipment. An 80% reduction in ambient ozone has been demonstrated on automobile radiators coated with the catalyst with no catalyst deterioration for over 10,000 miles.				Initial research and development efforts have focused on applying the technology to car radiators in order to destroy ozone. In a nine-month testing program conducted last year by Ford Motor Company and Engelhard, the catalysts destroyed a high percentage of the ozone contacted in months of on-road driving. However, the near-term environmental benefit of using the technology on unmodified vehicles (i.e., fans not modified to run while parked) is much less than the potential long-term benefits originally projected. For this reason, Ford decided not to use PremAir catalysts on its vehicles at this time, but is monitoring Engelhard's progress in further developing the technology for automotive applications. Engelhard is also conducting testing and development work on applications in air conditioners and other stationary equipment. SCAQMD is evaluating the effectiveness of applying the catalyst to residential and commercial air conditioning units located in the highest ozone levels in the basin; tests will be conducted this summer on four air conditioning units. The catalyst has also been applied to both radiator and air conditioner on buses in several areas.

Endnote

1. Engelhard Corporation; SCAQMD; David Johnson, E3 Ventures, Inc., May 21, 1997.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **Miscellaneous - Other Combustion**

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Membrane Gas Transfer Device[1]	Material Substitution	The Membran Corporation has developed a flautist, hollow-fiber membrane technology that dissolves high concentrations of oxygen, methane, or hydrogen into water by exploiting the high gas permeabilities of hollow-fiber microporous membranes. This technology eliminates emissions and the need for costly air pollution control equipment.	X?			This project was accepted into the SITE Emerging Technology Program in July 1994.
Ultra Low-NOx Gas-Fired Burner[2]	Product Redesign	An ultra low-NOx gas-fired burner is being developed to provide NOx emission levels comparable to selective catalytic reduction technology (SCR) at significantly lower costs for industrial air-preheat burners. The commercial availability of this technology would allow new and existing boilers and furnaces that use preheat to obtain a permit under stringent CA regulations without the use of costly SCR technology.		X		This technology has been effectively demonstrated and the CA EPA's Air Resources Board expects that it could be commercialized within a few years.

Endnotes

1. EPA is working with the Membran Corporation to develop this technology.

2. This is an Innovative Clean Air Technology (ICAT). Coen and Company, with co-funding from the Gas Research Institute is developing the ultra low-NOx gas-fired burner.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: Other Industrial Processes - Mineral Products

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Reburn and Enhance Gas Reburn[1]	Emission Control	Reburn and enhance reburn technologies are employed to reduce cement kiln NOx emissions by 40 and 70 percent, respectively. Cement kilns are among the largest, relatively uncontrolled sources of NOx in CA and there is still no acceptable method of reducing their emissions.		X		This technology has been effectively demonstrated and the CA EPA's Air Research Board has recognized it as a potential technology for commercialization within a few years.

Endnote

1. This is an Innovative Clean Air Technology (ICAT) and is funded by Acurex Environmental Corporation with matching funds from the US EPA and Coen Company.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Source Category: **Non-Road Sources - Lawn and Garden Engines**

Technology (Name)	Control Strategy	Description	Emissions Controlled: VOCs	Emissions Controlled: NOx	Emissions Controlled: PM	Technology Status
Direct fuel injection for 2-stroke chain saws[1]	Engine redesign	The lubricating oil and the fuel are supplied to the engine separately; emission results for this prototype chain saw were reported as 20 g/hp-hr for HC emissions. Stihl, a major manufacturer of handheld equipment, is developing a prototype mechanical direct fuel injection chain saw. No electronic control system is used. A few of the prototype chain saws have been evaluated in the field and the results were encouraging. NOx emissions are expected to rise, however. Estimates indicate an incremental cost of $200 per unit over traditional chain saws. With expected emission reductions, unit cost is $950/ton of HC.	X		X	Developmental R&D; prototype testing in the field
Vaporizing Carburetor[2]	Fuel Intake redesign	Fuel is vaporized in internal combustion engine to enable effective combustion in lean mode; the technology is relatively simple and cheap compared with catalysts. The Woodside Group, Inc. Has invested over $1 million in the development and testing of the technology applicable to lawn and garden engines, marine engines, and automobile engines. Emission reductions for prototype four stroke small lawn and garden engine and automobile engines were as low as 3 g/hp-hr for HC plus NOx emissions and 0.4 g/mile NOx, respectively. Modest NOx reductions are expected. Technology has much less in-use deterioration in emission than other existing technologies. A few engines equipped with vaporizing carburetor were tested with EPA and major engine manufacturers.	X	X		Developmental R&D; prototype testing; possible commercialization with U.S. firm who manufactures marine engines.

SUMMARY OF EMERGING TECHNOLOGIES FOR LOWER EMISSIONS OR CHEAPER CONTROLS OF VOCs, NOx, AND PM

Technology (Name)	Control Strategy	Description	Emissions Controlled			Technology Status
			VOCs	NOx	PM	
Clean Air Two-Stroke[3]	Product Redesign	This clean air two-stroke engine is being developed for utility engine applications and is expected to substantially reduce emissions of hydrocarbons, carbon monoxide and NOx. The design features an electronically controlled fuel injection system. This engine could achieve substantial emissions reductions from the small utility engine category, which is one of the highest emitting classes of engines.		X		BKM is designing and manufacturing prototype engines and testing them for emissions and durability. Results of an early prototype chainsaw engine showed substantial reductions in emissions. Fuel consumption was also reduced.
Zero Emission Power Sources for Commercial Lawn and Garden Equipment[4]	Alternative Fuels	Development and demonstration of zero emission power sources for commercial lawn and garden equipment. This program is expected to support several projects to develop zero emission alternative power sources for these applications. The projects are expected to develop refuelable electric power supplies, such as hydrogen fuel cells and refuelable batteries, such as zinc-air or aluminum-air, that can meet the needs and requirements of commercial gardeners with respect to availability of electric power, operating convenience, recharging time, operating time on a charge, and power output.	X	X	X	Proposed R&D and demonstration. The SCAQMD Technology Advancement program has proposed to provide $650,000 as their share of research funding, of a total expected $1,300,000.

Endnotes

1. Stihl engineer; other project funded by New York State Energy Research and Development Authority and Swiss Department of Forestry; Orbital prototype.

2. Woodside Group funded for technology development by major engine manufacturer until 1995.

3. This is an Innovative Clean Air Technology (ICAT). BKM Inc. is developing the technology along with funds from a consortium of engine manufacturers.

4. South Coast AQMD, Technology Advancement Plan, Clean Fuels Program www.aqmd.gov/tao.

APPENDIX G

ADMINISTRATIVE BURDEN AND COSTS SUPPORTING INFORMATION

APPENDIX G

ADMINISTRATIVE BURDEN AND COSTS SUPPORTING INFORMATION

G.1 IDENTIFICATION OF MILITARY ESTABLISHMENTS AFFECTED BY THE SELECTED NAAQS

The Agency selected military establishments potentially affected by the selected ozone and PM NAAQS from a number of Department of Defense (DOD) web pages and other DOD publications [US DOD 1996, 1997(a), 1997(b), 1997(c), 1997(d)]. Table G.1 displays the results of that selection for United States Army, Air Force, Navy and Marine Corp installations in the 50 States and Washington D.C. Table G.1 does not display information for the US Coast Guard or any National Guard or Reserve installations. Coast Guard operations are divided into 10 Coast Guard Districts, but a complete list of their location was not available for this analysis. National Guard and Reserve installations typically share many of their assets with military bases nearby. Differentiation between bases which share assets and those which do not could not be determined for this analysis. To avoid double counting, the Agency decided to exclude all National Guard and Reserve establishments.

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

				OZONE			$PM_{2.5}$
	Installation	**State**	**County**	**.08 5th**	**.08 4th**	**.08 3rd**	**15/65**
A	Anniston Army Depot	Alabama	Calhoun				
A	Ft. Ruckerr	Alabama	Dale				
N	NAVSTA Pascagoula	Alabama	Jackson				
A	Redstone Arsenal	Alabama	Limestone				
AF	Maxwell AFB	Alabama	Montgomery				
A	Ft. McClellan	Alabama	Taladega			Y	
A	Ft. Richardson	Alaska	Anchorage Borough				
AF	Elmendorf AFB	Alaska	Anchorage Borough				
AF	Eielson AFB	Alaska	Fbks North Star Borough				
A	Ft. Wairwright	Alaska	Fbks North Star Borough				
A	Ft. Greely	Alaska	Fbks North Star Borough				
A	Ft. Huachuca	Arizona	Cochise				
A	Camp Navajo	Arizona	Coconino				
AF	Luke AFB	Arizona	Maricopa	Y	Y	Y	Y
AF	Davis-Monthan AFB	Arizona	Pima				

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

				OZONE			$PM_{2.5}$
	Installation	**State**	**County**	**.08 5th**	**.08 4th**	**.08 3rd**	**15/65**
MC	MCAS Yuma	Arizona	Yuma				
A	Yuma Proving Ground	Arizona	Yuma				
AF	Little Rock AFB	Arkansas	Pulaski				
AF	Little Rock AFB	Arkansas	Pulaski				
A	Ft. Hunter Liggett	California	San Loius Obispo				
A	Oakland Army Base	California	Alameda	Y	Y	Y	Y
N	NAU Scotia	California	Humboldt				
AF	Edwards AFB	California	Kern		Y	Y	Y
N	NAS Lemoore	California	Kings		Y	Y	Y
A	Sierra Army Depot	California	Lassen				
N	NCBC Point Hueneme	California	Los Angeles	Y	Y	Y	Y
N	Seal Beach Naval Reserve	California	Los Angeles	Y	Y	Y	Y
AF	Los Angeles AFB	California	Los Angeles	Y	Y	Y	Y
N	NAS North Island	California	Los Angeles	Y	Y	Y	Y
A	Santa Anna Army Air Base	California	Orange	Y	Y	Y	Y
MC	MCAS El Toro	California	Orange	Y	Y	Y	Y
AF	March AFB	California	Riverside	Y	Y	Y	Y
AF	McClellan AFB	California	Sacramento	Y	Y	Y	Y
A	Ft. Irwin	California	San Bernadino	Y	Y	Y	Y
N	NAWC China Lake	California	San Bernadino	Y	Y	Y	Y
MC	MCAGCC 29 Palms	California	San Bernadino	Y	Y	Y	Y
MC	MCLB Barstow	California	San Bernadino	Y	Y	Y	Y
N	SUBASE San Diego	California	San Diego	Y	Y	Y	Y
MC	MCRD San Diego	California	San Diego	Y	Y	Y	Y
N	NAS North Island	California	San Diego	Y	Y	Y	Y
N	NAVSTA San Diego	California	San Diego	Y	Y	Y	Y
N	NAS Miramar	California	San Diego	Y	Y	Y	Y
MC	MCB Camp Pendelton	California	San Diego	Y	Y	Y	Y
AF	Vandenberg AFB	California	Santa Barbara	Y		Y	
AF	Onizuka AFB	California	Santa Clara	Y	Y	Y	Y
A	Presidion of Monterey	California	Santa Cruz	Y	Y	Y	Y
N	NAWC Point Mugu	California	Santa Cruz	Y	Y	Y	Y
N	NPS Monterey	California	Santa Cruz	Y	Y	Y	Y
AF	Travis AFB	California	Solano	Y	Y	Y	Y
AF	Beale AFB	California	Yuba	Y	Y	Y	Y
A	Ft. Carson	Colorada	El Paso				
AF	Peterson AFB	Colorado	El Paso				
AF	U.S. Air Force Academy	Colorado	El Paso				
AF	Falcon AFB	Colorado	El Paso				
N	SUBASE New London	Connecticut	New London				
AF	Dover AFB	Deleware	Dover				
AF	Tyndall AFB	Florida	Bay				
AF	Patrick AFB	Florida	Brevard				
N	NAVBASE Jacksonville	Florida	Duval				
N	NAS Cecil Field	Florida	Duval				

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

	Installation	State	County	OZONE .08 5th	OZONE .08 4th	OZONE .08 3rd	$PM_{2.5}$ 15/65
N	NAS Mayport	Florida	Duvall				
N	NAS Jacksonville	Florida	Duvall				
N	NAS Whiting Field	Florida	Escambia			Y	
N	NTTC Correy Station	Florida	Escambia			Y	
N	NAS Pensacola	Florida	Escambia			Y	
N	NAS Whiting Field	Florida	Escambia			Y	
N	NAS Key West	Florida	Florida Bay				
AF	MacDill AFB	Florida	Hillsborough				
AF	Hurltburt Field	Florida	Okaloosa				
AF	Eglin AFB	Florida	Okaloosa				
N	NTC Orlando	Florida	Seminole				
N	SUBASE Kings Bay	Georgia	Camden				
A	Ft. Benning	Georgia	Chatahoochie				
A	Fort Gillem	Georgia	Clayton	Y	Y	Y	Y
A	Ft. McPherson	Georgia	Clayton	Y	Y	Y	Y
N	NAS Atlanta	Georgia	Cobb	Y	Y	Y	Y
MC	MCLB Albany	Georgia	Dougherty				
AF	Warner-Robbins AFB	Georgia	Houston				
A	Hunter Army Airfield	Georgia	Liberty				
A	Ft. Steward	Georgia	Liberty				
AF	Moody AFB	Georgia	Lowndes				
A	Ft. Shafter / Schofield Barr.	Hawaii	Honalulu				
MC	MCB Kaneohe Bay	Hawaii	Honolulu				
AF	Hickam AFB	Hawaii	Honolulu				
N	NCTAMS EASTPAC	Hawaii	Honolulu				
A	Wheeler Army Airfield	Hawaii	Honolulu				
N	NAVSTA Pearl Harbor	Hawaii	Honolulu				
AF	Maui AFB	Hawaii	Maui				
AF	Mountain Home AFB	Idaho	Elmore				
N	NTC Glennview	Illinois	Lake		Y	Y	Y
A	Rock Island Arsenal	Illinois	Rock Island				
AF	Scott AFB	Illinois	St. Louis			Y	
AF	Grissom ARB	Indiana	Miami				
MC	MCSA Kansas City	Kansas	Wyandotte				
A	Ft. Riley	Kansas	Geary				
A	Ft. Levenworth	Kansas	Leavenworth				
AF	McConnell AFB	Kansas	Sedgwick				
AF	Forbes AFB	Kansas	Shawnee				
A	Ft. Knox	Kentucky	Bullitt				
A	Ft. Campbell	Kentucky	Christian				
A	Ft. Polk	Loiusianna	Vernon				
AF	Barksdale AFB	Louisianna	Bossier				
N	SUBASE New Orleans	Louisinana	Lafourche			Y	
N	NAS Brunswick	Maine	Cumberland				
A	Ft. Meade	Maryland	Anne Arundel	Y	Y	Y	Y

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

	Installation	State	County	OZONE .08 5th	OZONE .08 4th	OZONE .08 3rd	$PM_{2.5}$ 15/65
A	Ft. Deitrick	Maryland	Frederick	Y	Y	Y	Y
A	Aberdeen Proving Grounds	Maryland	Harford	Y	Y	Y	Y
N	NSGA Fort Meade	Maryland	Howard	Y	Y	Y	Y
AF	Andrews AFB	Maryland	Prince George's	Y	Y	Y	Y
N	U.S. Naval Academy	Maryland	Queene Anne's	Y	Y	Y	Y
N	NAWC Pawtuxet	Maryland	St. Mary's				
A	Ft. Ritchie	Maryland	Washington	Y	Y	Y	Y
AF	Westover AFB	Massachusetts	Hampden				
N	NAS South Weymouth	Massachusetts	Plymouth			Y	
AF	Hanscom AFB	Massachusetts	Suffolk			Y	
A	Ft. Devins	Massachusetts	Worcester			Y	
AF	Keesler AFB	Mississippi	Harrison				
N	NAVSTA Pascagoula	Mississippi	Jackson				
N	NAS Meridian	Mississippi	Lauderdale				
AF	Columbus AFB	Mississippi	Lowndes				
AF	Whiteman AFB	Missouri	Johnson				
A	Ft. Leonard Wood	Missouri	Pulaski				
AF	Malmstrom AFB	Montana	Cascade				
AF	Offutt AFB	Nebraska	Sarpy				
N	NAS Fallon	Nevada	Churchill				
AF	Nellis AFB	Nevada	Clark				
A	Ft. Monmouth	New Jersey	Atlantic	Y	Y	Y	Y
A	Ft. Dix	New Jersey	Burlington	Y	Y	Y	Y
AF	McGuire AFB	New Jersey	Burlington	Y	Y	Y	Y
A	Ocean Terminal Bayonne	New Jersey	Hudson	Y	Y	Y	Y
A	Picatinny Arsenal	New Jersey	Morris	Y	Y	Y	Y
N	NAWC Lakehusrt	New Jersey	Ocean	Y	Y	Y	Y
AF	Kirtland AFB	New Mexico	Bernalillo				
AF	Cannon AFB	New Mexico	Curry				
AF	Holloman AFB	New Mexico	Otero				
AF	Hancock Field	New York	Deleware				
A	Ft. Drum	New York	Jefferson				
A	Ft. Hamilton	New York	Kings	Y	Y	Y	Y
AF	Griffiss AFB	New York	Oneida				
A	U.S. Military Academy	New York	Orange	Y	Y	Y	Y
A	White Sands Missile Range	New Mexico	Otero				
MC	MCAS Cherry Point	North Carolina	Craven				
A	Ft. Bragg	North Carolina	Cumberland				
AF	Pope AFB	North Carolina	Cumberland				
MC	MCAS New River	North Carolina	Onslow				
MC	Camp Lejeune	North Carolina	Oslow				
AF	Seymour Johnson AFB	North Carolina	Wayne				
AF	Hector IAP	North Dakota	Cass				
AF	Grand Forks AFB	North Dakota	Grand Forks				
AF	Minot AFB	North Dakota	Ward				

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

				OZONE			$PM_{2.5}$
	Installation	State	County	.08 5th	.08 4th	.08 3rd	15/65
A	Ft. Sill	Oklahoma	Comanche				
AF	Vance AFB	Oklahoma	Garfield				
AF	Altus AFB	Oklahoma	Jackson				
AF	Tinker AFB	Oklahoma	Oklahoma				
A	Carlisle Barracks	Pennsylvania	Cumberland				
AF	Carlisle AFB	Pennsylvania	Cumberland				
A	Tobyhanna Army Depot	Pennsylvania	Lackawanna				
N	NAS Willow Grove	Pennsylvania	Montgomery	Y	Y	Y	Y
A	Ft. Adams	Rhode Island	Newport				
N	NETC Newport	Rhode Island	Newport				
MC	MCRD Parris Island	South Carolina	Beaufort				
MC	MCO Beufort	South Carolina	Beaufort				
N	NAVBASE Charleston	South Carolina	Charleston				
AF	Charleston AFB	South Carolina	Charleston				
A	Ft. Jackson	South Carolina	Richland				
AF	Shaw AFB	South Carolina	Sumter				
AF	Ellsworth AFB	South Dakota	Meade				
AF	Arnold AFB	Tennessee	Coffee				
N	NAS Memphis	Tennessee	Shelby		Y	Y	
AF	Kelly AFB	Texas	Bexar				
AF	Lackland AFB	Texas	Bexar				
A	Ft. Sam Houston	Texas	Bexar				
AF	Brooks AFB	Texas	Bexar				
A	Ft. Bliss	Texas	Hudspeth				
N	NAS Dallas	Texas	Dallas		Y	Y	Y
A	Hensley Field	Texas	Dallas		Y	Y	Y
N	Kingsville	Texas	Klebero				
AF	Reese AFB	Texas	Lubbock				
A	Ft. Hood	Texas	McLennan				
N	NAS Corpus Christi	Texas	Nueces				
N	NAVSTA Ingelside	Texas	San Patrico				
N	NAS Fort Worth	Texas	Tarrant		Y	Y	Y
AF	Dyess AFB	Texas	Taylor				
AF	Goodfellow AFB	Texas	Tom Green				
AF	Laughlin AFB	Texas	Val Verde				
AF	Sheppard AFB	Texas	Wichita				
AF	Hill AFB	Utah	Davis				
A	Dugway Proving Ground	Utah	Tooele				
A	Ft. Myer	Virginia	Arlingtom	Y	Y	Y	
A	Ft. Lee	Virginia	Colonial Heights			Y	
A	Ft. Belvoir	Virginia	Fairfax	Y	Y	Y	
A	Ft. Monroe	Virginia	Gloucester			Y	
AF	Langley AFB	Virginia	James City			Y	
A	Ft. Eustis	Virginia	James City			Y	
MC	Quantico	Virginia	Prince William	Y	Y	Y	

Table G.1 MILITARY ESTABLISHMENTS IN THE UNITED STATES

				OZONE			$PM_{2.5}$
	Installation	State	County	.08 5th	.08 4th	.08 3rd	15/65
A	Ft. Gordon	Virginia	Richmond City			Y	
N	NAS Oceana	Virginia	Suffolk			Y	
N	NAS Norfolk	Virginia	Suffolk			Y	
N	NAVPHIBASE Little Creek	Virginia	Suffolk			Y	
N	NAVBASE Norfolk	Virginia	Suffolk			Y	
A	Walter Reed	Washington	District of Columbia	Y	Y	Y	Y
AF	Bolling AFB	Washington	District of Columbia	Y	Y	Y	Y
N	NAVDIST Wash. D.C.	Washington	District of Columbia	Y	Y	Y	Y
N	NAS Whidbey Island	Washington	Island				
N	NAVBASE Seattle	Washington	King				
N	SUBASE Bangor	Washington	Kitsap				
N	Nav Shipyard Puget Sound	Washington	Kitsap				
N	Trident Training Facility	Washington	Kitsap				
A	Ft. Lewis	Washington	Pierce				
AF	McChord AFB	Washington	Pierce				
AF	Fort Lewis	Washington	Pierce				
N	NAVSTA Everett	Washington	Snohomish				
AF	Fairchild AFB	Washington	Spokane				
AF	F E Warren AFB	Wyoming	Laramie				
SUM OF COULUMNS		**214**		**52**	**58**	**77**	**58**

KEY

A	United States Army
AF	United States Air Force
N	United States Navy
MC	United States Marine Corp

Source: United States Department of Defense, 1996, 1997

G.2 OZONE STANDARD ANALYSIS

G.2.1 Total Incremental Ozone Burden and Cost Calculations

Table G.2 displays the sum of the burden hours derived from Tables 10.3 and 10.4 for States with nonattainment areas, along with the point estimate employed in the administrative cost chapter discussion. All burden estimates are incremental to the current standard and the analytical baseline derived for this RIA. “Annualized hours refer to the annual equivalent hours associated with the annualized cost of the item, according to the following formula:

FIGURE G.1 CALCULATION OF “ANNUALIZED HOURS”

$$\frac{\sum_{j=1}^{2} AV_{i,j}}{W_i} = Annualized\ Hours$$

where $AV_{i,j}$ represents the annualized value as displayed in Figure 10.2, for the ith respondent and its jth annualized category. W_i represents the wage associated with the ith respondent, as discussed in section 10.3.4. Table G.3 displays similar data for States without nonattainment areas. Costs are in real terms, in thousands of 1990 dollars.

Table G.2 ANNUAL OZONE ADMINISTRATIVE BURDEN AND COST WORKSHEETS FOR ALTERNATIVE EIGHT HOUR STANDARDS IN NONATTAINMENT AREAS

Costs are in thousands of $1990

	Federal		State		Federal		Non-Federal	
	Low	High	Low	High	Low	High	Low	High
.08 5th								
5-Year Annualized Hours	10	39	180	702	0	0	0	0
12-Year Annualized Hours	3	5	45	86	6	124	626	12,513
Annual Task Total	86	200	6,714	20,160	156	3,120	15,687	313,740
TOTAL HOURS PER YEAR	99	244	6,939	20,949	162	3,244	16,313	326,253
TOTAL COST PER YEAR (in 1990 $K)	$3	$8	$278	$838	$6	$110	$979	$19,575
.08 4th								
5-Year Annualized Hours	10	39	250	976	0	0	0	0
12-Year Annualized Hours	3	5	63	120	7	139	876	17,517
Annual Task Total	86	200	9,325	28,000	174	3,480	21,960	439,200
TOTAL HOURS PER YEAR	99	244	9,638	29,095	181	3,619	22,836	456,717
TOTAL COST PER YEAR (in 1990 $K)	$3	$8	$386	$1,164	$6	$123	$1,370	$27,403
.08 3rd								
5-Year Annualized Hours	10	39	290	1,132	0	0	0	0
12-Year Annualized Hours	3	5	73	139	9	184	1,016	20,319
Annual Task Total	86	200	10,817	32,480	231	4,620	25,473	509,460
TOTAL HOURS PER YEAR	99	244	11,180	33,750	240	4,804	26,489	529,779
TOTAL COST PER YEAR (in 1990 $K)	$3	$8	$447	$1,350	$8	$163	$1,589	$31,787

Table G.3 ANNUAL OZONE ADMINISTRATIVE BURDEN AND COST WORKSHEETS FOR ALTERNATIVE EIGHT HOUR STANDARDS IN ATTAINMENT AREAS

Costs are in thousands of $1990

	Federal		State		Federal		Non-Federal	
	Low	High	Low	High	Low	High	Low	High
.08 5th								
5-Year Annualized Hours	0	0	0	0	0	0	0	0
12-Year Annualized Hours	0	2	4	79	19	388	3,481	69,625
Annual Task Total	25	120	924	5,940	0	0	0	0
TOTAL HOURS PER YEAR	25	122	928	6,019	19	388	3,481	69,625
TOTAL COST PER YEAR (in 1990 $K)	$1	$4	$37	$241	$1	$13	$209	$4,177
.08 4th								
5-Year Annualized Hours	0	0	0	0	0	0	0	0
12-Year Annualized Hours	0	2	3	62	19	373	3,231	64,621
Annual Task Total	25	120	728	4,680	0	0	0	0
TOTAL HOURS PER YEAR	25	122	731	4,742	19	373	3,231	64,621
TOTAL COST PER YEAR (in 1990 $K)	$1	$4	$29	$190	$1	$13	$194	$3,877
.08 3rd								
5-Year Annualized Hours	0	0	0	0	0	0	0	0
12-Year Annualized Hours	0	2	3	53	16	328	3,091	61,819
Annual Task Total	25	120	616	3,960	0	0	0	0
TOTAL HOURS PER YEAR	25	122	619	4,013	16	328	3,091	61,819
TOTAL COST PER YEAR (in 1990 $K)	$1	$4	$25	$161	$1	$11	$185	$3,709

APPENDIX H

ECONOMIC IMPACT ANALYSIS SUPPORTING INFORMATION

1.0 SUMMARY OF PROFILE OF AFFECTED INDUSTRIES

1.1 INDUSTRY PROFILE - ECONOMIC AND FINANCIAL DATA

Economic data used in estimating the potential economic impacts of implementing control measures associated with the PM and ozone NAAQS and the RH rule follow the categorization established by the *Standard Industrial Classification Manual 1987* (Office of Management and Budget [OMB], 1987). The data are reported by 3-digit SIC code, and include: the number of firms and establishments, employment, and sales revenue. The six major sectors are:

- Manufacturing;
- Agriculture, Mining, and Construction;
- Transportation, Communications, and Utilities;
- Wholesale and Retail Trade and Real Estate;
- Services; and
- Public Administration.

The data referred to in this section are presented primarily on a 3-digit SIC code level. For eight industries this data is not available at the 3-digit SIC code level, and the data for these industries is presented at the 2-digit SIC code level.

The sales data referred to in this chapter were projected to 2010 production levels for consistency with the cost data that will be used in the EIA. Industry-specific growth factors were obtained from the Bureau of Economic Analysis (BEA).[4] Revenue data were also converted to 1990 price levels using the 1987-1990 gross domestic product (GDP) implicit price deflator (DOC, 1992).[5]

1.2 MANUFACTURING

The Industry Profile for the Review of the PM_{10} NAAQS presents the number of establishments, firms, and employees in a given SIC code for each manufacturing industry that may incur costs associated with one or more of the selected control measures. It also presents average revenue per establishment by SIC code.

1.3 AGRICULTURE/MINING/CONSTRUCTION

Establishment and revenue data are not available by employment size category for SIC codes in the agricultural production sector (2-digit SIC codes 01 and 02). The Census of Agriculture also reports the average revenue per farm for all farms, and the average revenue per farm for farms with less than $500,000 revenue from agricultural products sold. This data is available
in the Industry Profile for the Review of the PM_{10} NAAQS.

1.4 AGRICULTURAL SERVICES, FORESTRY, MINING, AND CONSTRUCTION INDUSTRIES

The Industry Profile for the Review of the PM_{10} NAAQS contains establishment, firm, employment, and revenue data for the industries in the agricultural services, forestry, mining, and construction sectors that are potentially affected by the PM, ozone, and regional haze control measures examined. The sources that were used to obtain this data include *County Business Patterns, Census of Mining Industries,* and *Census of Construction Industries.*

Revenue data are not available for the agricultural service and forestry SIC codes (i.e., 07 and 08). Because of this limitation, payroll data were used as a surrogate for revenue data.

However, it should be noted that the use of payroll data as a surrogate for revenue data will likely underestimate revenues.

1.5 TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

The Industry Profile for the PM_{10} NAAQS present the available Census data for the industries in the transportation, communications, and utility sectors potentially affected by the PM control measures examined. The 1992 data were converted to 2010 production levels and 1990 prices using the 1992 to 2010 BEA growth factor for the appropriate SIC code and the GDP implicit price deflator between 1990 and 1992.

1.6 WHOLESALE AND RETAIL TRADE AND REAL ESTATE, SERVICES

The Industry Profile for the PM_{10} NAAQS contains data for the wholesale trade, retail trade, and real estate sectors that were summarized from data published in *Enterprise Statistics*, the *1987 Census of Retail Industries*, and the *1992 Census of Financial, Insurance, and Real Estate Industries*. The 1992 data were converted to 2010 production levels and 1990 prices using the appropriate 1992-2010 BEA growth factor and the GDP implicit price deflator between 1990 and 1992. The Industry Profile also presents the establishment, firm, employment, and revenue data that were available from the Bureau of the Census for potentially affected SIC codes in the services sector. Individual publications used in developing the data were: *Enterprise Statistics 1987 Census of Service Industries*, and *1990 County Business Patterns*.

1.7 PUBLIC ADMINISTRATION

The Bureau of the Census publishes annual budget data for States and counties by government function (e.g., highways, public safety).

The Industry Profile for the Review of the PM_{10} NAAQS displays estimated expenditures in 2010 for affected government agencies. Except for SIC code 962, the list of agencies affected is based on the SIC codes listed with emissions sources in the NPI that are potentially affected by the PM, ozone, and RH control measures examined. Control of paved and unpaved road emissions directly impacts SIC code 962– Regulation and Administration of Transportation Programs. For control measures affecting point sources identified with SIC code 971–National Security, revenue data are presented on a national level only because the Federal government is the entity directly impacted.

1.8 REFERENCES

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Table H.1 Summary of the Number of SIC Codes with Potential Economic Impacts for the Sequenced Ozone and PM Alternatives in the Year 2010 (Expressed as Average Annual Costs to Sales Ratios; Control Costs and Sales are in 1990$)

Alternative	Total No. of SIC Codes Potentially Affected	SIC Codes Affected - 0.01 Percent or Greater	SIC Codes Affected - 0.1 Percent or Greater	SIC Codes Affected - 1 Percent or Greater	SIC Codes Affected - 3 Percent or Greater	SIC Codes Affected - 5 Percent or Greater
Ozone 0.08, 3rd max. following $PM_{2.5}$ 15/50	379	273	224	134	84	61
$PM_{2.5}$ 15/50 following Ozone 0.08, 3rd max.	364	215	191	130	93	75

Table H.2 Percentage of Potentially Affected Establishments in 3 digit SIC Codes Potentially Affected by the Ozone and PM NAAQS, and in All Establishments Nationwide

Standard	Percentage of Establishments Potentially Affected out of All Establishments in Potentially Affected SIC Codes	Percentage of Establishments Potentially Affected out of All Establishments Nationwide
Ozone		
0.08, 5th max.	0.10	0.04
0.08, 4th max**	0.13	0.05
0.08, 3rd max.	0.16	0.06
PM		
16/65	1.51	0.49
15/65***	2.53	0.82
15/50	2.57	0.86

* Establishment counts reflect annual cost to sales percentages of 0.01 percent or higher
** Represents selected ozone standard
*** Represents selected PM standard

Comparison of the Integrated Planning Model's Forecast of the Operating Characteristics, Costs and Emissions of the Electric Power Industry from 2000 to 2010 under the Base Case and Further Controls under the New NAAQS

Table H.3 of this appendix provides a comparison of the IPM forecasts for operation, costs, and air emissions from the electric power industry from 2000 to 2010 for the Base Case and for additional pollution controls under the new National Ambient Air Quality Standards (NAAQS). The Base Case has a cap-and-trade program providing summer season reductions in NOx emissions in the 37 states that are in the Ozone Transport Assessment Group (OTAG). The scenario with added pollution controls increases the emissions reductions of SOx beyond the current CAAA Title IV requirements. See Section 11.6 for details.

The table shows the differences in the two cases of the operation of existing generation capacity, new capacity additions, and pollution retrofits that occur over time. These results appear under sections 10, 11, and 12 of the table. To assist the review of the table in these sections a key to the abbreviations is provided below:

Abbreviation	**Term**
MW	Megawatt
IGCC	Integrated Gasification Combined Cycle (Coal Gasification Technology)
CC	Combined-Cycle Natural Gas
Ret.	Retrofit
O/G	Oil/Gas Steam Unit
SCR	Selective Catalytic Reduction Technology (Post-Combustion NOx Control)
SNCR	Selective Non-Catalytic Reduction Technology (Post-Combustion NOx Control)
Carbon Inj/CI	Carbon Injection Technology for Mercury Control
GWh	Gigawatt Hours (Million kilowatt hours)

Table H.3 Comparison of the Integrated Planning Model's Forecast of the Operating Characteristics, Costs, and Emissions of the Electric Power Industry from 2000 to 2010 under the Base Case and Further Controls under the new NAAQS

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
1. Reserve Margin Capacity (MW)	705,321	702,636	745,244	745,168	801,549	801,549
Plus Firm Purchases (MW)	22,262	22,262	22,262	22,262	22,262	22,262
Plus Transmission (MW)	-	-	-	-	-	-
Total Reserve Margin Capacity (MW)	727,583	724,898	767,506	767,430	823,811	823,811
2. Peak Load (MW)	593,184	593,184	640,202	640,202	688,958	688,958
Less DSM(MW)	-	-	-	-	-	-
Plus Firm Sales (MW)	19,962	19,962	19,962	19,962	19,962	19,962
Plus Transmission Out (MW)	-	-	-	-	-	-
Net Demand (MW)	613,146	613,146	660,164	660,164	708,920	708,920
3. Reserve Margin (%)	19	18	16	16	16	16
4. Generation (GWh)	3,306,624	3,304,206	3,597,954	3,595,938	3,914,411	3,911,231

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
Inter-Region Transmission (Gwh)	(11,232)	(10,309)	(11,549)	(9,923)	(10,428)	(8,719)
Pumping & Storage Losses (Gwh)	9,189	7,694	11,768	11,377	13,800	12,328
Plus Purchases (Gwh)	-	-	-	-	-	-
Less Sales (Gwh)	-	-	-	-	-	-
5. Total Supply for Demand (Gwh)	3,286,202	3,286,202	3,574,637	3,574,638	3,890,183	3,890,183
6. Projected Demand (Gwh)	3,286,203	3,286,203	3,574,638	3,574,638	3,890,183	3,890,183
Energy Not Served (Gwh)	-	-	-	-	-	-
Net Demand (GWh)	3,286,203	3,286,203	3,574,638	3,574,638	3,890,183	3,890,183
7. Dumped Energy (Gwh)	(1)	(1)	(1)	-	-	-
8. Total Supply for Demand (Gwh)	3,286,203	3,286,203	3,574,638	3,574,638	3,890,183	3,890,183
Less T&D Losses (Gwh)	252,933	252,933	275,133	275,133	299,420	299,420
9. Total Sales (Gwh)	**3,033,269**	**3,033,269**	**3,299,504**	**3,299,504**	**3,590,763**	**3,590,763**

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
Capacity Avoided Costs (US$/kW/a)	14	16	34	35	23	21
10. Capacity by Plant Type (MW)						
Scrubbed Coal	58,454	51,896	33,875	27,067	27,233	26,781
Unscrubbed Coal	111,732	133,017	41,394	105,169	22,990	69,709
Oil/Gas Steam	107,080	103,359	94,324	96,073	52,873	46,358
Nuclear	97,086	97,086	94,452	94,452	88,065	88,065
Hydroelectric	76,255	76,255	76,292	76,292	76,292	76,292
Combined Cycle (CC) Gas	22,946	22,946	51,976	61,808	106,608	136,682
IGCC	-	-	-	-	-	-
Turbine	54,159	54,338	71,677	64,726	79,320	60,219
Renewables	10,274	10,274	10,274	10,274	10,275	10,277
Pump Storage	21,069	21,069	21,069	21,069	21,069	21,069
Imports	11,200	11,200	11,200	11,200	11,200	11,200
Ret. Coal-CC	-	-	-	-	1,060	2,250
Ret. O/G-CC	-	-	-	-	34,117	33,620
Ret. Coal-IGCC	-	-	-	-	-	-
Ret. Scrubber	-	1,312	-	1,312	-	1,312
Ret. SCR	14,009	9,130	86,903	34,004	103,856	34,080
Ret. SNCR	114,338	81,068	134,909	95,387	141,607	98,629
Ret. SCR+Scrub	636	11,390	636	18,435	636	37,735

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
Ret. SNCR+Scrub	-	10,854	-	15,688	-	22,625
Ret. Gas Reburn	2,362	-	2,362	-	2,362	-
Ret. O/G SCR	13,361	17,083	23,698	21,889	31,662	34,323
Total	**714,962**	**712,277**	**754,922**	**754,846**	**811,227**	**811,227**
11. Capacity Additions and Changes by Plant Type (MW)						
Scrubbed Coal	-	-	-	-	-	-
Unscrubbed Coal	-	-	-	-	-	-
Oil/Gas Steam	-	-	-	-	-	-
Nuclear	-	-	-	-	-	-
Hydroelectric	-	-	-	-	-	-
Combined Cycle (CC) Gas	-	-	28,005	37,837	54,632	74,873
IGCC	-	-	-	-	-	-
Turbine	10,791	10,970	39,114	31,983	12,150	-
Renewables	-	-	-	-	2	3
Pump Storage	-	-	-	-	-	-
Imports	-	-	-	-	-	-
Ret. Coal-CC	-	-	-	-	1,060	2,250
Ret. O/G-CC	-	-	-	-	34,117	33,620
Ret. Coal-IGCC	-	-	-	-	-	-
Ret. Scrubber	-	1,312	-	-	-	-
Ret. SCR	14,009	9,130	72,894	24,874	16,953	76

	Year 2000		Year 2005		Year 2010	
	Base Case	New NAAQS	Base Case	New NAAQS	Base Case	New NAAQS
Ret. SNCR	114,338	81,068	20,570	14,319	6,783	3,243
Ret. SCR+Scrub	636	11,390	-	7,045	-	19,300
Ret. SNCR+Scrub	-	10,854	-	4,834	-	6,936
Ret. Gas Reburn	2,362	-	-	-	-	-
Ret. O/G SCR	13,361	17,083	10,337	4,810	8,006	12,468
Total	**155,500**	**141,809**	**170,920**	**125,703**	**133,703**	**152,769**
12. Generation by Plant Type (Gwh)						
Scrubbed Coal	401,864	368,328	238,055	198,502	199,427	196,850
Unscrubbed Coal	587,710	692,677	234,154	599,179	128,385	326,240
Oil/Gas Steam	189,828	193,732	148,258	152,020	33,307	28,355
Nuclear	640,836	640,836	613,324	613,324	565,867	565,867
Hydroelectric	276,632	276,632	276,735	276,735	276,735	276,735
Combined Cycle (CC) Gas	95,244	110,819	291,838	380,051	556,858	759,409
IGCC	-	-	-	-	-	-
Turbine	18,499	21,691	39,318	31,244	37,398	23,070
Renewables	80,984	80,984	80,984	80,984	80,984	80,984
Pump Storage	7,116	5,958	9,113	8,810	10,687	9,547
Imports	37,900	37,900	37,900	37,900	37,900	37,900
Ret. Coal-CC	-	-	-	-	7,663	15,332
Ret. O/G-CC	-	-	-	-	244,747	229,758

	Year 2000		Year 2005		Year 2010	
	Base Case	New NAAQS	Base Case	New NAAQS	Base Case	New NAAQS
Ret. Coal-IGCC	-	-	-	-	-	-
Ret. Scrubber	-	9,595	-	9,771	-	9,771
Ret. SCR	99,943	66,780	634,014	252,480	760,326	251,637
Ret. SNCR	789,262	561,764	915,088	643,064	913,213	602,239
Ret. SCR+Scrub	4,654	83,312	4,740	137,310	4,740	281,063
Ret. SNCR+Scrub	-	79,392	-	116,852	-	167,380
Ret. Gas Reburn	14,006	-	12,636	-	8,628	-
Ret. O/G SCR	62,105	73,764	61,797	57,710	47,545	49,092
Total	3,306,624	3,304,206	3,597,954	3,595,938	3,914,411	3,911,230
13. Capacity Factor by Plant Type (%)						
Scrubbed Coal	79	81	81	81	81	81
Unscrubbed Coal	60	59	65	65	64	53
Oil/Gas Steam	20	21	18	18	7	7
Nuclear	75	75	74	74	73	73
Hydroelectric	41	41	41	41	41	41
Combined Cycle (CC) Gas	47	55	64	70	60	63
IGCC	N/A	N/A	N/A	N/A	N/A	N/A
Turbine	4	5	6	6	5	4
Renewables	90	90	90	90	90	90
Pump Storage	4	3	5	5	6	5

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
Imports	39	39	39	39	39	39
Ret. Coal-CC	N/A	N/A	N/A	N/A	83	78
Ret. O/G-CC	N/A	N/A	N/A	N/A	82	78
Ret. Coal-IGCC	N/A	N/A	N/A	N/A	N/A	N/A
Ret. Scrubber	N/A	84	N/A	85	N/A	85
Ret. SCR	81	84	83	85	84	84
Ret. SNCR	79	79	77	77	74	70
Ret. SCR+Scrub	84	84	85	85	85	85
Ret. SNCR+Scrub	N/A	84	N/A	85	N/A	85
Ret. Gas Reburn	68	N/A	61	N/A	42	N/A
Ret. O/G SCR	53	49	30	30	17	16
Average	**53**	**53**	**54**	**54**	**55**	**55**
14. Total Annual Electric Generation Production Costs (1995$, MMUS$)*						
Variable O&M	2,687	2,997	2,955	3,403	3,139	3,965
Fixed O&M	19,095	19,175	19,547	19,638	19,588	19,888
Fuel	34,316	34,534	36,538	36,448	38,239	38,474
Capital (Levelized Estimate)	641	1,069	3,859	4,523	8,237	9,923
Total	**56,739**	**57,776**	**62,899**	**64,011**	**69,204**	**72,249**
15. Emissions						
SO_2	10,491	7,529	471	268	9,861	5,250
NOx (1,000 tons)-Annual	4,077	4,051	957	16	3,768	3,572

	Year 2000		Year 2005		Year 2010	
	Base Case	**New NAAQS**	**Base Case**	**New NAAQS**	**Base Case**	**New NAAQS**
NOx (1,000 tons)-Summer	-	-	-	-	-	-
CO_2 (1,000,000 Tons)	2,104	2,002	211	161	2,276	2,159
Carbon (1,000,000 Tons)	549	546	603	589	621	589
Mercury (Tons)	62	58	66	61	65	55

* Costs accounted for included those that relate to dispatch and determination of incremental costs above the base case. Some production costs that are not necessary for that calculation are not estimated in the model.

Table H.4 - Employment Changes in 2010 Associated with the 50 Percent Regional SO_2 Cap

Job Sector/Activity	Employment Changes (in 1,000 jobs)
Electric Generation Units	(1.42)*
Pollution Controls for Electric Generation Units	5.23
Coal Mining	(1.20)
Coal Transportation	(3.25)
Natural Gas Production	6.78
Net Total	**6.14**

* - Parentheses denote a negative change, or job losses.

Table H.5 Employment Changes in 2010 in Eastern and Western United States Coal Production Associated with the 50 Percent Regional SO_2 Cap

Area	Employment Changes (in 1,000 jobs)
Eastern United States	0.37
Western United States	(1.57)
Entire United States	**(1.20)**

* - parentheses denote a negative change, or job losses.

2.0 OVERVIEW OF THE EP INDUSTRY I-O MODEL

The environmental protection (EP) industry input-output (I-O) model identifies the production and service activities that constitute environmental protection (EP) activities in the U.S. economy. The identification of these activities is accomplished by decomposing the 1982 benchmark I-O table (U.S. Department of Commerce, BEA, 1984 and 1991) for the United States into EP and non-EP.[1] At the time the model was developed, this was the most recent economic census years for which benchmark I-O tables had been compiled. The 1982 EP I-O table was updated to 1985, 1988, and 1991 by assuming that the expenditure patterns for the various pollution abatement processes remained constant over time.

The EP I-O tables characterize the sectors whose output is used to comply with environmental regulations as well as the sectors that demand EP goods and services. Summing down the column of the EP I-O table for each industry identifies the sectors that demand EP goods and services, while summing across the row of the EP I-O table for each industry identifies which goods and services are purchased to perform EP activities (i.e. the goods and services that serve as inputs to EP activities). In addition, the EP I-O tables classify EP activities according to the following five categories: external EP activities, internal EP activities, fixed capital formation for EP, household EP activities, and government EP activities.

External EP activities refers to establishments in which EP constitutes the main or secondary production activity. The key identifying characteristic of external EP activities is that they are delivered to other establishments, or a third party. External EP activities are represented as separate rows and columns in an I-O matrix. In Diagram 1, the entries depicted by the shaded column (n+1) represent the dollar value of the products purchased as intermediate inputs from other sectors in the economy by the external EP activities sector. The corresponding shaded row

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[1]For details regarding construction of the EP I-O tables and limitations of the model see U.S. EPA, 1995a and 1995b.

in Diagram 1 represents the dollar value of the external EP activities that other industries purchase for use as an intermediate input.

Internal EP activities are for the establishment in which they are produced. Internal EP activities are ancillary activities analogous to administration or research and development activities. Internal EP activities are measured by inputs purchased for and combined as pollution abatement activity by a polluting industry and includes intermediate inputs and value added. Internal EP activities are not separated from the main activities of an establishment, and in this I-O framework, are accounted for by separating out that portion of total inputs used by polluting industries for pollution abatement. This adjustment is reflected by X_{ij}^{EP}, which represents intermediate inputs used for EP activities, in Diagram 1. The residual, X_{ij}^{NE}, represents intermediate inputs used for non-EP activities. Total value-added consists of value-added associated with EP activities, V_{ij}^{EP}, and value-added associated with non-EP activities, V_{ij}^{NE}.

The category **fixed capital formation for EP** represents the accumulation of fixed assets for EP and corresponds to gross private domestic investment in the I-O format. As an example, the purchase of a scrubber represents the accumulation of capital for air pollution abatement.

In addition, two other types of EP activities are performed in the United States. These are **EP activities performed by households and government**. Household and government EP activities are like EP investment activities in that they are represented by an adjustment to final demand in the I-O framework. Household, investment, and government EP activities are embodied in final demand, depicted by the adjustment Y_j^{EP} in Diagram 1. Final demand expenditures for non-EP activities are reprsented by Y_j^{NE}.

Application of the EP Industry I-O Model

To adjust for the assumption that all capital expenditures occur in one year (2010), annualized capital costs were used as a proxy for capital expenditures in a single year. For sectors where annualized capital costs were not reported separately, total annualized costs were disaggregated into annualized capital and operation and maintenance (O&M) costs. When capital expenditures were reported separately for one 3-digit industry within a 2-digit SIC category, then the fraction of capital expenditures in total annualized costs was applied to all other 3-digit industries within the 2-digit category. When capital costs were reported separately for more than one 3-digit industry, then average fraction of capital costs in total costs was applied to all remaining 3-digit industries. When capital expenditures were reported separately for no 3-digit industries within a 2-digit category, an industry-wide average was applied.

To determine which goods and services are purchased, a generic air pollution control capital expenditures spending pattern (from the EP industry report) was applied to the capital expenditures estimates. For O&M expenditures, the O&M expenditure pattern for each sector for the 1991 input-output table in the EP Industry report was used.

In addition, the following additional assumptions were made:

- In the EP industry study, no expenditures were assigned to I-O 25 (Transportation and Warehousing) in 1991 so an average of the expenditure pattern for all of the other sectors was used.

- For the electric utility sector (I-O 27), fuel-switching costs were excluded.

- The unassigned costs for SIC 49 and the joint sector emissions were assigned to the Electric Utilities (I-O 27).

- The unassigned cost of SIC 37 were assigned to Motor Vehicles (I-O 21).

- SIC 348 was assigned to the Other Transportation sector (I-O 22).

- Government expenditures (SIC 90s) were assumed to follow the pattern for Non-defense Federal Government expenditures. The 1982 input-output table was used to generate an expenditure pattern for Non-defense Federal Government expenditures.

To estimate EP employment in 2010, data on employment and payroll for manufacturing in 1990 from the *1991 Annual Survey of Manufactures* were used to estimate the cost per worker in 1990. An estimate for the cost per worker in 2010 was generated by assuming that real wages increase by 2.56 percent each year between 1990 and 2010. Dividing the estimates of the expenditures on employees generated by the EP I-O table by the estimate of the cost per worker in 2010 yielded an estimate of EP employment.[1] The employment associated with internal EP expenditures is 16,279 and the employment associated with government EP expenditures is 10,249. These estimates are fairly consistent with the estimates generated by the EP industry report. For example, direct EP employment in 1991 was 741,186 while total annualized EP expenditures in 1991 (in 1991 dollars) were roughly $134 billion. This gives an EP employment to EP expenditure ratio of about .0000055. For these calculations an expenditure figure of about $6.6 billion was used and the estimate of employment of 26,528 gives an EP employment to EP expenditure ratio of .000004.

EP employment is likely to be underestimated since the calculations did not include expenditures for Nonclassifiable Establishments, Transportation Control Package, and Enhanced I/M. These expenditures, totalling roughly $156 million, did not correspond to any of the EP I-O sectors. Multiplying the $156 million of omitted expenditures by the 1991 EP employment to expenditure ratio (.0000055) indicates that EP employment may be underestimated by as much as 861 employees.[2]

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[1] Essentially, it was assumed that wages increase at the same rate as labor productivity. According to the U.S. Bureau of Labor Statistics, labor productivity index numbers (output per unit of labor for all of manufacturing) were 37.3 in 1949 and 113.4 in 1993. This corresponds to an annual compound growth rate of labor productivity of approximately 2.56 percent between 1949 and 1993.

[2] This assumes that the 1991 ratio and not the one generated in this study (.000004) is the correct one. Using the ratio generated in this study indicates that EP employment is underestimated by 623 individuals.

Table H.6 lists the types of good and services purchased, as a percent of total expenditures.

Limitations of the Approach

The estimates presented above are driven by the expenditure patterns used to allocate capital and operating and maintenance expenditures to specific I-O categories. These expenditure patterns were derived from dated and, oftentimes, incomplete engineering studies. This posed difficulties for estimating EP activities for years beyond 1982 in the original EP industry study, since this required assuming that the expenditure patterns for the various pollution abatement processes remained constant over time. Since the estimates presented above are for 2010, they are implicitly base on the assumption that expenditure patterns will remain unchanged for about 30 years.

3.0 REFERENCES

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Figure H-1: The I-O Framework Modified to Display the EP Industry

TO / FROM	1	2	. . .	n	(n+1)	Y	X
1	$X_{11}^{NE}+X_{11}^{EP}$	$X_{12}^{NE}+X_{12}^{EP}$	. . .	$X_{1n}^{NE}+X_{1n}^{EP}$	$X_{1(n+1)}$	$Y_{1}^{NE}+Y_{1}^{EP}$	$X_{1}^{NE}+X_{1}^{EP}$
2	$X_{21}^{NE}+X_{21}^{EP}$	$X_{22}^{NE}+X_{22}^{EP}$		$X_{2n}^{NE}+X_{2n}^{EP}$	$X_{2(n+1)}$	$Y_{2}^{NE}+Y_{2}^{EP}$	$X_{2}^{NE}+X_{2}^{EP}$
.	.			.	.	.	.
.	.			.	.	.	.
.	.			.	.	.	.
n	$X_{n1}^{NE}+X_{n1}^{EP}$	$X_{n2}^{NE}+X_{n2}^{EP}$	. . .	$X_{nn}^{NE}+X_{nn}^{EP}$	$X_{n(n+1)}$	$Y_{n}^{NE}+Y_{n}^{EP}$	$X_{n}^{NE}+X_{n}^{EP}$
(n+1)	$X_{(n+1)1}$	$X_{(n+1)2}$	. . .	$X_{(n+1)n}$	$X_{(n+1)(n+1)}$	Y_{n+1}	X_{n+1}
V	$V_{1}^{NE}+V_{1}^{EP}$	$V_{2}^{NE}+V_{2}^{EP}$	. . .	$V_{n}^{NE}+V_{n}^{EP}$	V_{n+1}		
X	$X_{1}^{NE*}+X_{1}^{*EP}$	$X_{2}^{NE*}+X_{2}^{*EP}$	. . .	$X_{n}^{NE*}+X_{n}^{*EP}$	X_{n+1}		

Table H.6: Goods and Services Purchased by Type of EP Activity (as a fraction of total expenditures)

SIC codes	EP Industry I-O Sector	Internal EP Activities	Fixed Capital Formation (Investment)	Government EP Activities
011-085	1.Agriculture, forestry, and fisheries	0.0000	0.0000	0.0977
101-149	2.Mining	0.0000	0.0000	0.0075
152-179	3.Construction	0.0727	0.5870	0.1055
201-209	4.Food and kindred products	0.0000	0.0000	0.0232
211-214	5.Tobacco manufactures	0.0000	0.0000	0.0000
221-229	6.Textile mill products	0.0163	0.0150	0.0003
231-239	7.Apparel and other textile products	0.0000	0.0000	0.0003
241-249	8.Lumber and wood products	0.0000	0.0000	0.0001
251-259	9.Furniture and fixtures	0.0000	0.0000	0.0010
261-267	10.Paper and allied products	0.0000	0.0000	0.0019
271-279	11.Printing and publishing	0.0000	0.0000	0.0039
281-289	12.Chemicals and allied products	0.0120	0.0000	0.0034
291-299	13.Petroleum refining	0.0000	0.0000	0.0030
301-308	14.Rubber and plastic products	0.0000	0.0000	0.0014
311-319	15.Leather and leather products	0.0000	0.0000	0.0000
321-329	16.Stone, clay and glass products	0.0698	0.0000	0.0009
331-339	17.Primary metals	0.0000	0.0000	0.0020
341-349	18.Fabricated metal products	0.0000	0.0500	0.0034
351-359	19.Machinery, except electrical	0.0139	0.0720	0.0126
361-369	20.Electrical machinery	0.0000	0.0330	0.0203
371	21.Motor vehicles	0.0000	0.0000	0.0020
372-379	22.Other transportation equipment	0.0000	0.0000	0.0458
381-387	23.Instruments	0.0000	0.0280	0.0096

SIC codes	EP Industry I-O Sector	Internal EP Activities	Fixed Capital Formation (Investment)	Government EP Activities
391-399	24.Miscellaneous manufacturing	0.0000	0.0000	0.0008
401-478	25.Transportation and warehousing	0.0000	0.0370	0.0096
481-489	26.Communication	0.0000	0.0000	0.0127
491,493	27.Electric utilities	0.2282	0.0000	0.0071
492	28.Gas utilities	0.0115	0.0000	0.0015
501-573, 591-599	29.Trade	0.0000	0.0000	0.0148
602-653	30.Finance, insurance and real estate	0.0416	0.0000	0.0264
494-497, 581, 701-874	31.Other Services	0.2994	0.0000	0.1566
919-972	32.Government enterprises	0.0000	0.0000	-0.0010
part of 16-17	33.New sewer system facilities	0.0000	0.0000	0.0000
part of 16-17	34.Maintenance and repair of sewer system facilities	0.0000	0.0000	0.0000
494,4952	35.Water supply ("environmental")	0.0000	0.0000	0.0000
494,4952	36.Sewerage Systems	0.0000	0.0000	0.0000
495 (except 4952),496-497,part of 493	37.Solid Waste Management	0.0000	0.0000	0.0000
35646	38.Selected industrial air pollution control equipment	0.0000	0.1780	0.0000
	39.Noncomparable imports and scrap	0.0000	0.0000	0.0130
	40.Government industry	0.0000	0.0000	0.4181
	41.Other industry	0.0000	0.0000	-0.0060
	Payments to Employees	0.2346	0.0000	0.0000

SIC codes	EP Industry I-O Sector	Internal EP Activities	Fixed Capital Formation (Investment)	Government EP Activities
	Total	1.0000	1.0000	1.0000

NOTES

For reference, the total dollar values for these three EP activity categories are, respectively:
internal EP activities : $3.25 billion, capital expenditures: $2.22 billion, and government expenditures: $1.15 billion.

There are no external or household EP activities associated with these expenditures.

In generating these patterns, the expenses associated with Nonroad Engine Heavy Duty Retrofit ($8,193,930) seems to be most closely related to automotive repair shops and services, so these expenditures are assigned to Other Services (I-O 31). The expenses associated with Nonclassifiable Establishments (SIC 999--$1,291,000), Transportation Control Package ($12,570,000) and High Enhanced I/M ($141,773,000) are excluded due to the difficulty associated with assigning these expenditures to SIC codes.

I-O sectors 39-41 are special industries in the I-O table and do not correspond to any SIC codes. Government Industry (I-O 40) represents payments to government employees.

Explanatory Preface to Tables H.7 and H.8

The purpose of the cost-to-sales percentage analysis, the results of which are used in the selection criteria of industries for the qualitative market impact analysis, is to identify the most significant potential impacts for potentially affected establishments within each SIC code. In reviewing the analysis, it is useful to keep in mind that a high cost-to-sales percentage does not necessarily indicate the potential for significant impacts to an entire affected industry, since only a small percentage of establishments in the industry may be potentially affected. In fact, the number of establishments potentially affected by control measures generally represent a small component of the total industry.

It is also important to interpret the cost-to-sales results that are used in the selection criteria of industries for the qualitative market impact analysis with the understanding that the results are reported for potentially affected establishments and do not represent the average cost-to-average sales percentage across all establishments in an SIC code (i.e., both those identified as potentially affected and not potentially affected). A separate report presents the total costs and total revenue by control alternative across all establishments in each potentially affected SIC code. (See *Summary of Costs by SIC Code for Integrated Implementation of the Ozone and PM NAAQS*.) Because cost and revenue data are shown across all establishments in each SIC code, rather than for potentially affected establishments as in the cost-to-sales analysis, the summary of total costs by SIC code documented in the *Summary of Costs by SIC Code* often indicates very different results.

Finally, it is important to understand that the cost to sales analysis results, and therefore the qualitative market impact analysis results, can not accurately predict the actual year 2010 economic impacts resulting from implementation of the new NAAQS by the States. Instead, the purpose of the cost to sales and qualitative market impact analyses is to identify potentially significant economic impacts so that states can design implementation strategies to avoid any such impacts. In that regard, these analyses may be useful to States in their efforts to develop control strategies that minimize potentially adverse economic impacts.

Table H.7 Industries Meeting Selection Criteria for Qualitative Market Impact Analysis for the Ozone 0.08, 4th Max. Standard

SIC Code	SIC Description	Number of Establishments in Industry	Estimated Number of Establishments Potentially Affected	Percentage of Total Establishments Potentially Affected	Average Annual Cost-to-Sales Percentage
102	Copper Ores	47	2	4	29.3
109	Miscellaneous Metal Ores	319	4	1	2.3
141	Dimension Stone	190	1	1	1.6
144	Sand and Gravel	4,650	27	1	1.1
227	Carpets and Rugs	428	6	1	4.2
251	Household Furniture	10,102	60	1	3.5
282	Plastics Materials and Synthetics	1,365	25	2	1.2
284	Soap, Cleaners, and Toilet Goods	4,575	331	7	1.4
285	Paints and Allied Products	1,418	453	32	1.8
287	Agricultural Chemicals	1,736	70	4	4.2
324	Cement, Hydraulic	225	15	7	24.1
341	Metal Cans and Shipping Containers	1,009	146	14	4.7
343	Plumbing and Heating, Except Electric	1,499	18	1	33.1
359	Industrial Machinery, NEC	43,325	717	2	2.0
458	Airports, Flying Fields, & Services	2,777	29	1	12.8
494	Water supply	3,237	143	4	1.1

Table H.8 Industries Meeting Selection Criteria for Qualitative Market Impact Analysis for the $PM_{2.5}$ 15/65 Standard

SIC Code	SIC Description	Number of Establishments in Industry	Estimated Number of Establishments Potentially Affected	Percentage of Total Establishments Potentially Affected	Average Annual Cost-to-Sales Percentage
011	Cash Grains	405,008	6,394	2	1.4
013	Field Crops (except cash grains)	250,338	2,519	1	2.2
019	General Farms, Primarily Crop	48,847	660	1	3.5
08	Forestry	1,798	562	31	50.0
103	Lead and Zinc Ores	36	2	6	24.1
109	Miscellaneous Metal Ores	319	4	1	1.6
141	Dimension Stone	190	22	12	17.4
142	Crushed and Broken Stone	3,495	207	6	16.2
144	Sand and Gravel	4,650	62	1	4.9
147	Chemical and Fertilizer Minerals	231	6	3	57.1
149	Miscellaneous Nonmetallic Minerals	304	3	1	18.1
152	Residential Building Construction	113,986	14,696	13	17.4
153	Operative Builders	10,396	543	5	6.2
154	Nonresidential Building Construction	37,432	7,320	20	6.1
161	Highway and Street Construction	8,476	77	1	6.1
162	Heavy Construction (except highway)	20,299	989	5	5.1
204	Grain Mill Products	4,971	46	1	13.5
206	Sugar and Confectionery Products	2,142	14	1	2.8
207	Fats and Oils	1,128	7	1	1.8
242	Sawmills and Planing Mills	12,598	146	1	6.1
249	Miscellaneous Wood Products	6,980	43	1	4.4
262	Paper Mills	328	68	21	1.5
263	Paperboard Mills	225	24	11	1.4
281	Industrial Inorganic Chemicals	2,835	46	2	7.2
283	Drugs	2,630	14	1	2.6
286	Industrial Organic Chemicals	1,818	55	3	1.5
287	Agricultural Chemicals	1,736	12	1	9.0
295	Asphalt Paving and Roofing Materials	2,627	79	3	3.1
299	Misc. Petroleum and Coal Products	979	7	1	68.2
301	Tires and Inner Tubes	145	8	6	1.9
321	Flat Glass	124	1	1	1.1
322	Glass and Glassware, Pressed or Blown	1,008	12	1	8.2
324	Cement, Hydraulic	225	27	12	19.0
325	Structural Clay Products	1,183	15	1	3.8
328	Cut Stone and Stone Products	773	5	1	39.6
329	Misc. Nonmetallic Mineral Products	3,196	41	1	10.4
331	Blast Furnace and Basic Steel Products	2,588	51	2	16.6
332	Iron and Steel Foundries	2,392	20	1	1.9
333	Primary Nonferrous Metals	348	22	6	5.5
341	Metal Cans and Shipping Containers	1,009	12	1	4.8
343	Plumbing and Heating, Except Electric	1,499	16	1	40.6
359	Industrial Machinery, NEC	43,325	2,868	7	2.0
423	Trucking Terminal Facilities	147	1	1	6.2
491	Electric Services	4,934	121	2	5.8
496	Steam and air-conditioning supply	74	12	16	35.0
806	Hospitals	6,327	56	1	1.1
822	Colleges and Universities	2,973	43	1	10.0

Table H.9 Relative Market Impacts of SIC Codes for which Demand and Supply Elasticities Were Identified: Ozone 0.08, 4th Max. Alternative

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS
324 (Cement, Hydraulic)	1.61	-0.9	7.0	This industry has greatest impact potential of industries in this table due to the substantially higher costs for this industry; however, impacts will be attenuated due to the cost pass-through potential associated with the combination of slightly inelastic demand and very elastic supply
102 (Copper Ores)	1.25	-0.5	0.7	Along with SIC code 285, this industry has the 2nd greatest impact potential of industries in this table; although costs are higher than SIC code 285, there is significantly more ability for costs to be passed-through to consumers given inelastic demand
285 (Paints and Allied Products)	0.56	-1.4	1.0	Along with SIC code 102, this industry has 2nd greatest impact potential of industries in this table; although costs are lower than SIC code 102, impacts are likely to be similar because of the relative lack of cost pass-though potential resulting from elastic demand
287 (Agricultural Chemicals)	0.17	-1.5	1.0	Industry impacts are expected to fall into the middle of the range of impacts for industries in this table; although this industry's elasticity figures seem to indicate the smallest cost pass-through potential, costs fall into the middle range of costs in this table
109 (Misc. Metal Ores)	0.03	-0.7	0.5	Along with SIC codes 251 and 282, this industry has the least impact potential of industries in this table; although inelastic demand points toward greater cost pass-through than those SIC codes, the significantly lower supply elasticity for this industry may completely counteract this effect
251 (Household Furniture)	0.02	-3.4	8.8	Along with SIC code 109 and 282, this industry has the least impact potential of industries in this table; quantity change is expected to be large relative to the cost increase due to the combination of very elastic demand and supply; this combination makes cost pass-through difficult to determine
282 (Plastic Materials)	0.02	-1.7	3.3	Along with SIC code 109 and 251, this industry has the least impact potential of industries in this table; quantity change is expected to be large due to combination of very elastic demand and supply; this combination makes cost pass-through difficult to determine

Table H.10 Relative Market Impacts of SIC Codes for which Demand and Supply Elasticities Were Identified: $PM_{2.5}$ 15/65 Standard

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS
152 (Residntl. Bldg. Const.)	2.24	-1.1	3.0	This is one of three industries (see SIC codes 103 and 324) with greatest impact potential - 2nd highest costs, attenuated to a lesser degree than SIC code 324 by cost pass-through
324 (Cement, Hydraulic)	2.28	-0.9	7.0	This is one of three industries (see SIC codes 103 and 152) with greatest impact potential; highest cost industry impacts attenuated by cost pass-through potential associated with slightly inelastic demand/ and very elastic supply (producers' response greater than consumers' response)
103 (Lead and Zinc Ores)	1.34	-0.5	0.1	This is one of three industries (see SIC codes 152 and 324) with greatest impact potential because of combination of relatively high costs and lack of producer response to cost increase due to very inelastic supply
262 (Paper Mills)	0.31	-1.1	1.2	Impacts likely to fall at the high-end of the middle of range for industries in this table (although costs are lower than SIC code 331, potential for cost pass-through to customers is greater)
333 (Primary Nonferrous)	0.35	-0.8	1.2	Impacts likely to fall at the high-end of the middle range for industries in this table due to the combination of relatively high costs and pass-through potential (inelastic demand, elastic supply)
331 (Blast Furn./Basic Steel)	0.33	-1.9	1.2	After SIC codes 324, 152, and 103, this industry has the greatest impact potential (very elastic demand denotes low cost pass-through potential)
263 (Paperboard Mills)	0.15	-1.6	1.2	Impacts likely to fall in the middle of range for industries in this table; mid-level costs, and cost pass-through potential is smaller than for most other industries
287 (Agricultural Chemicals)	0.06	-1.5	1.0	Impacts likely to fall at the low-end of the range for industries in this table; relatively low costs but cost pass-through potential is smaller than for most other industries in table
019 (General Farms)	0.05	-0.5	0.8	Impacts likely to fall at the low-end of the range for industries in this table; relatively low costs and significant cost pass-through potential given inelastic demand
109 (Misc. Metal Ores)	0.02	-0.7	0.5	Impacts likely to fall at the low-end of the range for industries in this table; lowest costs and cost pass-through potential given inelastic demand
011 (Cash Grains)	0.02	-0.3	0.4	Along with SIC code 013, this industry has the lowest impact potential because of combination of lowest cost and relatively large cost pass-through potential due to inelastic demand
013 (Field Crops)	0.02	-0.7	1.0	Along with SIC code 011, this industry has the lowest impact potential because of combination of lowest cost and relatively large cost pass-through potential due to inelastic demand and unitary supply elasticity
332 (Iron & Steel Foundries)	0.02	-0.7	0.5	Impacts likely to fall at the low-end of the range for industries in this table; lowest costs and cost pass-through potential given inelastic demand

Table H.11 Relative Market Impacts for SIC Codes for which Only Demand Elasticities Were Identified: Ozone 0.08, 4th Max. Alternative

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS[1]
341 (Metal Cans/Containers)	0.68	-0.2	n/a	This is one of three industries (see SIC codes 284 and 458) with the greatest impact potential; substantially higher costs are estimated for this industry, however, based on very inelastic demand, impacts may be significantly attenuated by cost pass-through potential
343 (Plumbing and Heating)	0.40	-0.2	n/a	Impacts of 2nd highest cost industry will be significantly attenuated by very inelastic demand, which facilitates cost pass-through to consumers; impacts may fall in the middle range of industry impacts in table (depending on supply elasticity)
458 (Airports & Services)	0.13	-1.2	n/a	This is one of three industries (see SIC codes 284 and 341) with the greatest impact potential; costs are higher than most in this table, and elastic demand constrains cost pass-through potential
284 (Soap & Toilet Goods)	0.10	-3.0	n/a	This is one of three industries (along with SIC codes 341 and 458) with greatest impact potential, although costs fall in the middle range, cost pass-through is substantially restrained due to highly elastic demand
348 (Ordnance)	0.09	-0.2	n/a	Impacts for this industry are likely to fall in the middle range of industries in this table, costs are somewhat lower than most, and cost pass-through potential is large due to very inelastic demand
227 (Carpets and Rugs)	0.06	-1.5	n/a	Impacts for this industry are likely to fall in the middle range of industries in this table; costs are relatively low, but elastic demand constrains cost pass-through potential
494 (Water Supply)	0.05	-0.1	n/a	Along with SIC codes 349 and 359, this industry has least impact potential; while costs are relatively low, cost pass-through potential is high
349 (Misc. Fabricated Metal)	0.05	-0.2	n/a	Along with SIC codes 494 and 359, this industry has least impact potential; while costs are relatively low, cost pass-through potential is high
359 (Ind. Machinery, nec)	0.03	-0.5	n/a	Along with SIC codes 349 and 494, this industry has least impact potential; while costs are relatively low, cost pass-through potential is high

[1]Impact assessments in this table are more speculative than those based on both demand and supply elasticity information.
n/a - not available

Table H.12 Relative Market Impacts of SIC Codes for which Only Demand Elasticities Were Identified: $PM_{2.5}$ 15/65 Standard

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS[1]
High-Impact Potential (Relative to Other Industries in Table)				
080 (Forestry)	15.63	-0.9	n/a	This industry has the greatest impact potential because substantially higher costs are estimated for this industry; slightly inelastic demand indicates that cost pass-through potential is neither great nor small
496 (Steam & A/C Supply)	5.68	-1.2	n/a	This industry has the 2nd greatest impact potential, given its much higher costs than other industries, and the presence of elastic demand constraining the ability of producers to pass their costs onto consumers
154 (Nonresid. Bldg. Const.)	1.19	-1.0	n/a	Impact potential is relatively high due to 3rd highest cost and unitary demand elasticity
299 (Misc. Petrol. & Coal)	0.49	-0.4	n/a	Impact potential is relatively high based on relatively high cost, although cost-through potential is large given inelastic demand
343 (Plumbing and Heating)	0.43	-0.2	n/a	Impact potential is relatively high based on relatively high cost, however, impacts are lessened due to large cost pass-through potential indicated by inelastic demand
153 (Operative Builders)	0.32	-1.0	n/a	Potential impact is relatively high due to unitary demand elasticity and relatively high cost incidence
328 (Cut Stone Products)	0.26	-1.0	n/a	Given its higher than average costs and the pass-through potential associated with unitary demand elasticity, this industry has a relatively high impact potential
162 (Heavy Const-Nonhigh.)	0.25	-1.0	n/a	Potential impact is relatively high due to unitary demand elasticity and relatively high cost incidence
Middle-Impact Potential (Relative to Other Industries in Table)				
161 (High. & Street Const.)	0.06	-0.9	n/a	Impacts for this industry are expected to fall in the middle-range of industries in this table; basis for this assessment is the slightly lower than middle-range cost and a demand elasticity near unity
204 (Grain Mill Products)	0.13	-0.1	n/a	Impacts for this industry are estimated to fall in the middle range of industries in this table based on the combination of higher than middle-range cost and the large potential for cost pass-through associated with the most inelastic demand in this table
359 (Industrial Machinery)	0.13	-0.5	n/a	Impacts for this industry are predicted to fall on the high-end of the middle range of industries in this table due to the higher than middle-range cost and the potential for cost pass through to consumers
281 (Indus. Organic Chem.)	0.12	-0.2	n/a	Impacts for this industry are estimated to fall in the middle range of industries in this table; basis for this ranking is the middle-range costs and inelastic demand, which facilitate cost pass-through to consumers
301 (Tires and Inner Tubes)	0.11	-1.2	n/a	Impacts for this industry are estimated to fall on the high-end of the middle range of industries in this table due to the middle-range costs and relatively small potential for cost pass-through due to elastic demand
822 (Colleges & Universities)	0.14	-0.6	n/a	Impacts for this industry are predicted to fall on the high-end of the middle range of industries in this table; basis for this estimate is same costs as SIC code 491, but with much less elastic demand

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS[1]
295 (Asphalt Paving/Roofing)	0.09	-0.4	n/a	Impacts for this industry are predicted to fall in the middle range of industries in this table; basis for this estimate is the middle range cost estimate and the cost pass through potential associated with inelastic demand
329 (Misc. Nonmetallics)	0.13	-0.8	n/a	Impacts for this industry are expected to fall on the high-end of the middle range of industries in this table due to the higher than middle-range cost and the potential for cost pass-through indicated by demand elasticity near unity
491 (Electric Services)	0.14	-1.9	n/a	Impact potential is relatively high; although cost incidence falls into the middle range, very elastic demand indicates low cost-pass through potential
322 (Glass and Glassware)	0.10	-2.6	n/a	Impacts for this industry are estimated to fall on the high-end of the middle range of industries in this table due to the middle-range costs and small potential for cost pass-through due to very elastic demand
242 (Saw & Planing Mills)	0.07	-0.2	n/a	Impacts for this industry are predicted to fall on the low-end of the middle-range of industries in this table because of slightly lower than middle-range cost and inelastic demand, which facilitates cost pass-through to consumers
Low-Impact Potential (Relative to Other Industries in Table)				
399 (Misc. Manufacturers)	0.06	-0.6	n/a	This industry has impact potential relative to other industries in this table because of low cost and significant pass through potential associated with inelastic demand
341 (Metal Cans/Containers)	0.06	-0.2	n/a	Impacts for this industry are predicted to fall on the low-end of the middle-range of industries in this table because of the slightly lower than middle-range cost and inelastic demand, which facilitates cost pass-through to consumers
325 (Structural Clay Prods.)	0.05	-1.0	n/a	Impacts for this industry are expected to fall in the middle-range of industries in this table; basis for this assessment is the lower than middle-range cost and a unitary demand elasticity
423 (Truck Terminal Facils.)	0.04	-1.0	n/a	This industry has a relatively low impact potential; basis for this assessment is relatively low cost incidence and unitary demand elasticity
286 (Ind. Organic Chem.)	0.04	-0.8	n/a	Impacts for this industry are predicted to fall in the middle-range of industries in this table because of lower than middle-range cost and only slightly inelastic demand
207 (Fats and Oils)	0.01	-0.2	n/a	Along with SIC code 206, this industry has the least impact potential of industries in this table; basis for this ranking is the low cost and the large potential for cost pass-through associated with very inelastic demand
806 (Hospitals)	0.01	-1.7	n/a	This industry has very low impact potential relative to industries in this table; basis for this assessment is the low cost and relative lack of cost pass-through potential due to relatively high demand elasticity
321 (Flat Glass)	0.01	-1.0	n/a	This industry has very low impact potential relative to industries in this table; basis for this assessment is the second lowest demand elasticity associated with the lowest cost in this table
206 (Sugar & Confectionery)	0.02	-0.1	n/a	Along with SIC code 207, this industry has the least impact potential of industries in this table; ranking is based on the low cost and high cost pass-through potential associated with very inelastic demand

SIC CODE	COST-TO-SALES PERCENTAGE ACROSS ALL INDUSTRY ESTABLISHMENTS	DEMAND ELASTICITY	SUPPLY ELASTICITY	NOTES ON ESTIMATED MARKET IMPACTS[1]
283 (Drugs)	0.01	-1.8	n/a	Impact potential is relative low compared with other industries in this table; basis for this assessment is the low cost and relative lack of cost pass-through potential due to relatively high demand elasticity

[1]Impact assessments in this table are more speculative than those based on both demand and supply elasticity information.
n/a - not available

Table H.13 Small Business Administration's Small Business Size Standards and Assumptions Employed in Developing Small Business Revenue Data

SIC Code	SIC Description	Level of Detail/Assumptions for Developing Small Business Revenue[1]	SBA's Small Business Size Threshold[2]	Alternative(s)
019	General Farms, Primarily Crop		$0.5 million	PM
080	Forestry	See discussion in text	$5 million	PM
102	Copper Ores	Data are for SIC code 10	500 employees	Ozone
103	Lead and Zinc Ores	Data are for SIC code 10	500 employees	PM
141	Dimension Stone	Data are for SIC code 14	500 employees	PM
142	Crushed and Broken Stone	Data are for SIC code 14	500 employees	PM
144	Sand and Gravel	Data are for SIC code 14	500 employees	PM
147	Chemical and Fertilizer Minerals	Data are for SIC code 14	500 employees	PM
149	Miscellaneous Nonmetallic Minerals	Data are for SIC code 14	500 employees	PM
152	Residential Building Construction	Data are for SIC code 15 and are for < $25 million in revenues	$17 million	PM
153	Operative Builders	Data are for SIC code 15 and are for < $25 million in revenues	$17 million	PM
154	Nonresidential Building Construction	Data are for SIC code 15 and are for < $25 million in revenues	$17 million	PM
161	Highway and Street Construction	Data are for SIC code 16 and are for < $25 million in revenues	$17 million	PM
162	Heavy Construction (except Highway)	Data are for SIC code 16 and are for < $25 million in revenues	$17 million	PM
204	Grain Mill Products		500 employees	PM
227	Carpets and Rugs	Data are for SIC codes 224, 227, and 229	500 employees	Ozone
242	Sawmills and Planing Mills	Data are for SIC codes 241 and 242	500 employees	PM
249	Miscellaneous Wood Products	Data are for SIC codes 243, 245, and 249	500 employees	PM
251	Household Furniture	Data are for SIC code 25	500 employees	Ozone
281	Industrial Inorganic Chemicals	Data are for SIC codes 281, 282, and 286	1,000 employees	PM
287	Agricultural Chemicals		1,000 employees	Ozone & PM

SIC Code	SIC Description	Level of Detail/Assumptions for Developing Small Business Revenue[1]	SBA's Small Business Size Threshold[2]	Alternative(s)
295	Asphalt Paving and Roofing Materials	Data are for SIC codes 295 and 299; revenue data were estimated for the 250-499 employee category based on average revenue per establishment for the 500-999 employee category	500 employees	PM
299	Miscellaneous Petroleum and Coal Products	Data are for SIC codes 295 and 299; revenue data were estimated for the 250-499 employee category based on average revenue per establishment for the 500-999 employee category	500 employees	PM
322	Glass and Glassware, Pressed or Blown	Data are for SIC codes 321-3 and are for < 1,000 employees	750 employees	PM
324	Cement, Hydraulic	Data are for SIC codes 324-9 and are for < 1,000 employees	750 employees	Ozone & PM
325	Structural Clay Products	Data are for SIC codes 324-9	500 employees	PM
328	Cut Stone and Stone Products	Data are for SIC codes 324-9	500 employees	PM
329	Miscellaneous Nonmetallic Mineral Products	Data are for SIC codes 324-9	500 employees	PM
331	Blast Furnace and Basic Steel Products	Data are for SIC codes 331 and 339, for < 1,000 employees; revenue data were estimated for 500 to 999 employees based on average revenue per establishment for 2,500 to 4,999 employee category (data for 1,000-2,499 employee size category were not available)	750 employees	PM
333	Primary Nonferrous Metals	Data are for SIC codes 333-5 and are for < 1,000 employees	750 employees	PM
341	Metal Cans and Shipping Containers	Data are for SIC codes 341 and 346	500 employees	Ozone & PM
343	Plumbing and Heating, Except Electric	Data are for SIC codes 343 and 344	500 employees	Ozone & PM
348	Ordnance and Accessories, NEC		500 employees	Ozone
349	Miscellaneous Fabricated Metal Products	Data are for SIC codes 347 and 349	500 employees	Ozone

SIC Code	SIC Description	Level of Detail/Assumptions for Developing Small Business Revenue[1]	SBA's Small Business Size Threshold[2]	Alternative(s)
423	Trucking Terminal Facilities	Data are estimated based on the revenue per establishment ratio for each employment size category for SIC code 42, and applied to the establishment counts by category for SIC code 423	$5 million	PM
458	Airports, Flying Fields, and Services		$5 million	Ozone
491	Electric Services	SBA threshold was converted to revenue value ($276 million); data are for SIC codes 491-3, and value is for < $250 million	4 million megawatt-hours	PM
496	Steam and Air-Condition Supply	Data are for SIC codes 496 and 497, and represent revenues of < $10 million	$9 million	PM
822	Colleges and Universities	See discussion in text	$5 million	PM

[1] A blank in this column means that the data were available for the 3-digit SIC code.
[2] SBA, 1997.

Table H.14 Summary of SIC Codes with Cost to Sales (Revenues) Percentages of 1 Percent or Greater: $PM_{2.5}$ 15 μg/m^3 annual average/65 μg/m^3 24-hour average Alternative[1]

SIC Code	SIC Description	Percentage of Total Establishments Potentially Affected	Percentage of Small Firm to All Firm Revenue[2]
011	Cash Grains	1.0	89
013	Field Crops (except cash grains)	0.6	70
019	General Farms, Primarily Crop	0.9	80
08	Forestry	9.2	60
103	Lead and Zinc Ores	5.6	22
109	Miscellaneous Metal Ores	1.3	22
14	Nonmetallic Minerals, Except Fuels	0.0	72
141	Dimension Stone	10.5	72
142	Crushed and Broken Stone	3.3	72
144	Sand and Gravel	1.1	72
147	Chemical and Fertilizer Minerals	1.7	72
149	Miscellaneous Nonmetallic Minerals	1.0	72
152	Residential Building Construction	12.7	66
153	Operative Builders	5.1	66
154	Nonresidential Building Construction	19.4	66
161	Highway and Street Construction	4.8	54
162	Heavy Construction (except highway)	4.7	54
177	Concrete Work	0.0	87
179	Misc. Special Trade Contractors	0.0	80
179	Misc. Special Trade Contractors	0.0	80
201	Meat Products	0.0	16
202	Dairy Products	0.1	33
203	Preserved Fruits and Vegetables	0.2	20
204	Grain Mill Products	0.9	31
206	Sugar and Confectionery Products	0.5	24
207	Fats and Oils	0.6	53
208	Beverages	0.1	71
209	Misc. Food and Kindred Products	0.1	53
221	Broadwoven Fabric Mills, Cotton	0.3	21
224	Narrow Fabric Mills	0.4	42
227	Carpets and Rugs	0.5	42
229	Miscellaneous Textile Goods	0.1	42
242	Sawmills and Planing Mills	0.3	78
243	Millwork, Plywood & Structural Members	0.1	78
244	Wood Containers	0.1	78
249	Miscellaneous Wood Products	0.4	78
251	Household Furniture	0.0	41
262	Paper Mills	18.6	6
263	Paperboard Mills	10.2	6
267	Misc. Converted Paper Products	0.2	38
281	Industrial Inorganic Chemicals	1.5	14
283	Drugs	0.5	11
284	Soap, Cleaners, and Toiler Goods	0.1	18
285	Paints and Allied Products	0.4	48
286	Industrial Organic Chemicals	2.8	11
287	Agricultural Chemicals	0.6	43
289	Miscellaneous Chemical Products	0.2	48
295	Asphalt Paving and Roofing Materials	2.6	70
299	Misc. Petroleum and Coal Products	0.6	70
301	Tires and Inner Tubes	5.5	23

SIC Code	SIC Description	Percentage of Total Establishments Potentially Affected	Percentage of Small Firm to All Firm Revenue[2]
305	Hose & Belting & Gaskets & Packing	0.1	18
306	Fabricated Rubber Products, NEC	0.2	18
308	Miscellaneous Plastics Products, NEC	0.0	60
321	Flat Glass	0.8	19
322	Glass and Glassware, Pressed or Blown	0.9	19
324	Cement, Hydraulic	8.9	54
325	Structural Clay Products	1.2	47
326	Pottery and Related Products	0.1	47
327	Concrete, Gypsum, and Plaster Products	0.3	47
328	Cut Stone and Stone Products	0.5	47
329	Misc. Nonmetallic Mineral Products	1.1	47
331	Blast Furnace and Basic Steel Products	1.5	19
332	Iron and Steel Foundries	0.5	28
333	Primary Nonferrous Metals	4.9	26
334	Secondary Nonferrous Metals	0.3	19
339	Miscellaneous Primary Metal Products	0.1	19
34	Fabricated Metal Products	0.0	54
341	Metal Cans and Shipping Containers	1.0	47
343	Plumbing and Heating, Except Electric	0.9	62
344	Fabricated Structural Metal Products	0.0	62
346	Metal Forgings and Stampings	0.1	47
347	Metal Services, NEC	0.0	62
348	Ordnance and Accessories, NEC	0.3	8
349	Misc. Fabricated Metal Products	0.1	62
35	Industrial Machinery and Equip.	0.0	35
351	Engines and Turbines	0.5	11
352	Farm and Garden Machinery	0.2	27
353	Construction and Related Machinery	0.1	37
359	Industrial Machinery, NEC	6.1	60
36	Electronic and Other Electric Equip.	0.0	22
361	Electric Distribution Equipment	0.1	28
362	Electrical Industrial Apparatus	0.0	24
363	Household Appliances	0.4	9
366	Communications Equipment	0.1	15
37	Transportation Equipment	0.0	5
371	Motor Vehicles and Equipment	0.4	5
372	Aircraft and Parts	0.1	3
39	Misc. Manufacturing Industries	0.0	65
393	Musical Instruments	0.2	65
399	Miscellaneous Manufactures	1.5	65
411	Local and Suburban Transportation	0.0	55
422	Public Warehousing and Storage	0.0	70
423	Trucking Terminal Facilities	0.7	50
449	Water Transportation Services	0.1	26
458	Airports, Flying Fields, & Services	0.3	21
478	Miscellaneous Transportation Services	0.1	46
49	Electric, Gas, and Sanitary Services	0.0	1
491	Electric Services	1.8	12
496	Steam and air-conditioning supply	14.9	34
502	Furniture and Homefurnishings	0.0	81
503	Lumber and Construction Materials	0.0	73
506	Electrical Goods	0.0	63

SIC Code	SIC Description	Percentage of Total Establishments Potentially Affected	Percentage of Small Firm to All Firm Revenue[2]
508	Machinery, Equipment, and Supplies	0.0	79
509	Miscellaneous Durable Goods	0.0	44
515	Farm-Product Raw Materials	0.2	77
521	Lumber and Other Building Materials	0.0	26
526	Retail Nurseries and Garden Stores	0.0	69
541	Grocery Stores	0.0	27
651	Real Estate Operators and Lessors	0.0	59
653	Real Estate Agents and Managers	0.0	53
723	Beauty Shops	0.0	88
753	Automotive Repair Shops	0.0	91
769	Miscellaneous Repair Shops	0.0	71
806	Hospitals	0.8	1
809	Health and Allied Services, NEC	0.0	54
821	Elementary and Secondary Schools	0.0	0
822	Colleges and Universities	1.2	2
836	Residential Care	0.0	55
863	Labor Organizations	0.0	0
873	Research and Testing Services	0.0	24

[1] Examination of the source category/control measure detail indicates some anomalies concerning SIC codes. For example, Surface Mining - Loading/Storage is associated with SIC code 204 - Grain Mill Products. The likely explanation for these occurrences is miscoding of the SIC codes for point sources, most of which came from the 1985 National Acid Precipitation Assessment Program inventory. For California and Oregon industrial point sources, SIC codes originate from State-supplied plant-level information.

[2] Denotes percentage of all revenues in an SIC codes that is owned by small firms.

Table H.15 Control Measures Affecting County Governments for: Ozone 0.08, 3rd max. , followed by $PM_{2.5}$ 15/50 (98th percentile)

Source Category	Control Measure
Point Source Control Measures	
Internal Combustion (IC) Engines - Gas, Diesel, Liquid Petroleum Gas	Selective Catalytic Reduction
IC Engines- Gas	Low Emission Combustion
IC Engines- Gas	Nonselective Catalytic Reduction
IC Engines- Oil	Selective Catalytic Reduction
Industrial, Commerical, and Institutional (ICI) Boilers	Scrubber
ICI Boilers- Coal	Fabric Filter
ICI Boilers- Coal/Fluidized-Bed Combustion	Selective Noncatalytic Reduction - Urea Based
ICI Boilers- Coal/Stoker	Selective Noncatalytic Reduction - Urea Based
ICI Boilers- Distillate Oil	Low-NOx Burners
ICI Boilers- Distillate Oil	Selective Catalytic Reduction
ICI Boilers- Gas	Fabric Filter
ICI Boilers- Natural Gas	Low-NOx Burners
ICI Boilers- Natural Gas	Oxygen Trim + Water Injection
ICI Boilers- Natural Gas	Selective Catalytic Reduction
ICI Boilers- Oil	Fabric Filter
ICI Boilers- Process Gas	Oxygen Trim + Water Injection
ICI Boilers- Residual Oil	Low-NOx Burners
ICI Boilers- Residual Oil	Selective Catalytic Reduction
Industrial Incinerators	Selective Noncatalytic Reduction
Space Heaters - Natural Gas	Oxygen Trim + Water Injection
Wood Furniture Coating	Incineration
Area and Mobile Source Control Measures	
On-Highway Heavy-Duty Diesel Vehicles	Retrofit Program
Paved Roads	Vacuum Sweeping
Prescribed Burning	Increase Fuel Moisture
Residential Wood Construction	Education & Advisory Program

Source Category	Control Measure
Unpaved Roads - Rural	Chemical Stabilization
Unpaved Roads - Urban	Hot Asphalt Paving

APPENDIX I

BENEFITS ANALYSIS
SUPPORTING INFORMATION

I.1 Particulate Matter Health and Welfare Effects Estimation

I.1.1 Table I.1 PM Health and Welfare Effects Estimation (also used for RH analysis)

Table I.1 PM Health and Welfare Effects Estimation (also used for RH analysis)

Endpoint	Concentration-Response Function		PM Averaging Time		Population[a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
Mortality							
Mortality (long-term exposure)	Pope et al., 1995	log-linear	annual median	annual median [d]	ages 30+	759 (nonaccidental deaths in general pop.)	0.006408
Mortality (short-term exposure) using PM10 indicator	Schwartz et al., 1996a (Boston, Knoxville, St. Louis, Steubenville, Portage & Topeka)	log-linear	2-day average	1-day average [e]	all	803 (nonaccidental deaths in general pop.)	0.001433
Mortality (short-term exposure) using PM2.5 indicator	Ito & Thurston, 1996 (Chicago)	log-linear	2-day average	1-day average [e]	all	803 (nonaccidental deaths in general pop.)	0.000782
	Kinney et al., 1995 (Los Angeles)	log-linear	1-day average		all		
	Pope et al., 1992 (Utah)	log-linear	5-day average		all		
	Schwartz, 1993 (Birmingham)	log-linear	3-day average		all		
	Schwartz et al., 1996a (Boston)	log-linear	2-day average		all		
	Schwartz et al., 1996a (Knoxville)	log-linear	2-day average		all		
	Schwartz et al., 1996a (St. Louis)	log-linear	2-day average		all		
	Schwartz et al., 1996a (Steubenville)	log-linear	2-day average		all		
	Schwartz et al., 1996a (Portage)	log-linear	2-day average		all		
	Schwartz et al., 1996a (Topeka)	log-linear	2-day average		all		
Hospital Admissions							

Endpoint	Concentration-Response Function		PM Averaging Time		Population[a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
All respiratory illnesses, using PM2.5 indicator	Thurston et al., 1994 (Toronto)	linear	1-day average	1-day average	all	n/a	3.45×10^{-8} [f]
All respiratory illnesses, using PM10 indicator	Schwartz et al., 1995 (Tacoma)	log-linear	1-day average	1-day average	age 65+	504 (general pop.)	0.00170
	Schwartz et al., 1995 (New Haven)	log-linear	1-day average		age 65+		
	Schwartz, 1996 (Spokane)	log-linear	1-day average		age 65+		
COPD, using PM10 indicator	Schwartz, 1994a (Birmingham)	log-linear	1-day average	1-day average	age 65+	103 (general pop.)	0.002533
	Schwartz, 1994b (Detroit)	log-linear	1-day average		age 65+		
	Schwartz, 1996 (Spokane)	log-linear	1-day average		age 65+		
Pneumonia, using PM10 indicator	Schwartz, 1994a (Birmingham)	log-linear	1-day average	1-day average	age 65+	229 (general pop.)	0.0013345
	Schwartz, 1994b (Detroit)	log-linear	1-day average		age 65+		
	Schwartz, 1994c (Minneapolis)	log-linear	1-day average		age 65+		
	Schwartz, 1996 (Spokane)	log-linear	1-day average		age 65+		
Congestive heart failure, using PM10 indicator	Schwartz and Morris, 1995 (Detroit)	log-linear	2-day average	1-day average	age 65+	231 (general pop.)	0.00098
Ischemic heart disease, using PM10 indicator	Schwartz & Morris, 1995 (Detroit)	log-linear	1-day average	1-day average	age 65+	450 (general pop.)	0.00056
Respiratory Symptoms/Illnesses not requiring hospitalization							

Endpoint	Concentration-Response Function		PM Averaging Time		Population[a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
Development of chronic bronchitis, using PM10 indicator	Schwartz, 1993		annual mean	annual mean	all	n/a	0.012
Acute bronchitis, using PM2.5 indicator	Dockery et al., 1989	logistic	annual mean	annual mean [d]	ages 10-12	n/a	0.0298
Upper respiratory symptoms (URS), using PM10 indicator	Pope et al., 1991	log-linear	1-day average	1-day average	asthmatics, ages 9-11	38,187 (applied pop.)	0.0036
Lower respiratory symptoms (LRS), using PM10 indicator	Schwartz et al., 1994	logistic	1-day average	1-day average	ages 8-12	n/a	0.0142
Lower respiratory symptoms (LRS), using PM2.5 indicator	Schwartz et al., 1994	logistic	1-day average	1-day average	ages 8-12	n/a	0.01823
Asthma (moderate or worse), using PM2.5 indicator	Ostro et al., 1991	linear (with log pollutant)	daily 8-hour average (9:00 am-4:00 pm)	1-day average	asthmatics, ages 9-11	n/a	0.0006
MRADs, using PM2.5 indicator	Ostro and Rothschild, 1989	log-linear	2-week average	1-day average	ages 18-65	780,000 days/year (applied pop.)	0.00741
RADs, using PM2.5 indicator	Ostro, 1987	log-linear	2-week average	1-day average	ages 18-65	400,531 days/year (applied pop.)	0.00475

Endpoint	Concentration-Response Function		PM Averaging Time		Population[a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
Acute respiratory symptoms (any of 19), using PM10 indicator	Krupnick et al., 1990	logistic	1-day average COH	1-day average	ages 18-65 (study examined "adults")	n/a	0.00046
Shortness of breath (days), using PM10 indicator	Ostro et al., 1995	logistic	1-day average	1-day average [d]	African-American asthmatics, ages 7-12	n/a	0.00841
Work loss days (WLDs), using PM10 indicator	Ostro, 1987	log-linear	2-week average	1-day average	ages 18-65	150,750 days/year (applied pop.)	0.0046
Welfare Endpoints							
Household soiling and damage, using PM2.5 indicator	ESEERCO, 1994	linear	annual mean	annual mean	all households	n/a	2.52 (dollars per $\mu g/m^3$ PM10 per household)

NOTES:

[a] The population examined in the study and to which this analysis applies the reported concentration-response relationship. In general, epidemiological studies analyzed the concentration-response relationship for a specific age group (e.g., ages 65+) in a specific geographical area. This analysis applies the reported pollutant coefficient to all individuals in the age group nationwide.
[b] annual baseline incidence in the applied population per 100,000 individuals in the indicated population.
[c] a single pollutant coefficient reported for several studies indicates a pooled analysis; see text for discussion of pooling concentration-response relationships across studies.
[d] The following studies report a lowest observed pollution level:

Pope et al., 1995	Mortality (long-term exposure)	9 $\mu g/m^3$ $PM_{2.5}$
Dockery et al., 1995	Acute Bronchitis	11.8 $\mu g/m^3$ $PM_{2.5}$ (20.1 $\mu g/m^3$ PM_{10})
Ostro et al., 1995	Shortness of Breath, days	19.63 $\mu g/m^3$ PM_{10}

Since these studies did not examine the concentration-response relationship for concentrations below the reported levels, this analysis does not estimate benefits for ambient concentration reductions below these concentrations. The remaining studies did not report lowest observed concentrations.
[e] All 1-day averages are 24-hour averages, 2-day averages are 48-hour averages, etc.

* See U.S. EPA 1997 for citations

I.2 Ozone Health and Welfare Effects Estimation

I.2.1 Table I.2 Ozone Health and Welfare Estimation

Table I.2 Ozone Health and Welfare Effects Estimation

Endpoint	Concentration-Response Function		Ozone Averaging Time		Population [a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
Mortality (Short-Term Exposure)							
	Anderson et al., 1996	log-linear	1-day average [d]	1-day average	all	803 (nonaccidental deaths in general pop.)	0.001126
	Hoek et al., 1997 (in press)	log-linear	1-day average	1-day average	all		0.001705
	Ito & Thurston, 1996	log-linear	1-day average	1-day average	all		0.000677
	Kinney et al., 1995	log-linear	daily 1-hour max.	daily 1-hour max	all		0.00
	Loomis et al., 1996 (HEI)	log-linear	daily 1-hour max	daily 1-hour max	all		0.000182
	Moolgavkar et al., 1995	log-linear	1-day average	1-day average	all		0.000611
	Ostro et al., 1996	log-linear	daily 1-hour max	daily 1-hour max	all		0.00019
	Samet et al., 1996, 1997 (HEI)	log-linear	1-day average	1-day average	all		0.000936
	Verhoeff et al., 1996	log-linear	daily 1-hour max	daily 1-hour max	all		0.000956
Hospital Admissions							
All respiratory Illnesses	Schwartz, 1996 (Spokane)	log-linear	daily 1-hour max	daily 1-hour max	age 65+	504 (general pop.)	0.008562
All respiratory Illnesses	Schwartz, 1995 (New Haven)	log-linear	1-day average	1-day average	age 65+	504 (general pop.)	0.0014

Endpoint	Concentration-Response Function		Ozone Averaging Time		Population [a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
All respiratory Illnesses	Schwartz, 1995 (Tacoma)	log-linear	1-day average	1-day average	age 65+	504 (general pop.)	0.0036
All respiratory Illnesses	Thurston et al., 1994 (Toronto)	linear	daily 1-hour max.	daily 1-hour max.	all	n/a	1.62 X 10^{-8} [e]
All respiratory Illnesses	Thurston et al., 1992 (New York City)	linear	daily 1-hour max.	daily 1-hour max	all	n/a	1.37 X 10^{-8} [e]
COPD	Schwartz, 1994a	log-linear	1-day average	1-day average	age 65+	103 (general pop.)	0.00314
COPD	Schwartz, 1994b	log-linear	1-day average	1-day average	age 65+	103 (general pop.)	0.00549
COPD	Schwartz, 1996 (Spokane)	log-linear	daily 1-hour max.	daily 1-hour max	age 65+	103 (general pop.)	0.004619
Pneumonia	Schwartz, 1994a	log-linear	1-day average	1-day average	age 65+	229 (general pop.)	0.00262
Pneumonia	Schwartz, 1994b	log-linear	1-day average	1-day average	age 65+	229 (general pop.)	0.00521
Pneumonia	Schwartz, 1994c	log-linear	1-day average	1-day average	age 65+	229 (general pop.)	0.002795
Pneumonia	Schwartz, 1996 (Spokane)	log-linear	daily 1-hour max.	daily 1-hour max.	age 65+	229 (general pop.)	0.00965

Endpoint	Concentration-Response Function		Ozone Averaging Time		Population [a]	Annual Baseline Incidence (per 100,000 of indicated population) [b]	Pollutant Coefficient [c]
	Source	Functional Form	Studied	Applied			
Respiratory Symptoms not Requiring Hospitalization							
Acute respiratory symptoms (any of 19)	Krupnick et al., 1990	logistic	daily 1-hour max.	daily 1-hour max.	ages 18-65	n/a	0.00014
Asthma attacks	Whittemore and Korn, 1980 and US EPA, 1993	logistic	daily 1-hour max..	daily 1-hour max..	asthmatics	n/a	0.0019
MRADs	Ostro and Rothschild, 1989	log-linear	daily 1-hr max. (avg. over 2 weeks)	daily 1-hr max. (avg. over 2 weeks)	ages 18-65	780,000 days/year (applied pop.)	0.0022
RRADs	Ostro and Rothschild, 1989	log-linear	daily 1-hr max. (avg. over 2 weeks)	daily 1-hr max. (avg. over 2 weeks)	ages 18-65	310,000 days/year (applied pop.)	0.0054
Welfare Endpoints							
Decreased worker productivity	Crocker and Horst, 1981 and US EPA, 1994	percent change	1-day average	1-day average	laborers	n/a	n/a

NOTES:

[a] The population examined in the study and to which this analysis applies the reported concentration-response relationship. In general, epidemiological studies analyzed the concentration-response relationship for a specific age group (e.g., ages 65+) in a specific geographical area. This analysis applies the reported pollutant coefficient to all individuals in the age group nationwide.
[b] annual baseline incidence in the applied population per 100,000 individuals in the indicated population.
[c] a single pollutant coefficient reported for several studies indicates a pooled analysis; see text for discussion of pooling concentration-response relationships across studies.
[d] All 1-day averages are 24-hour averages, 2-day averages are 48-hour averages, etc.
[e] units on linear pollutant coefficient: hospital admissions per ppb O_3 per exposed individual

* See U. S. EPA 1997 for citations

I.3 Valuation and Aggregation

I.3.1 Introduction

The purpose of this section is to summarize the valuation estimates used to monetize many of the health and welfare benefits categories included in this analysis. In addition, this section describes the procedure this analysis employs to estimate the monetized benefits associated with reductions in premature mortality. For a more detailed description of the procedure used to monetize all other benefits categories, refer to the Benefits Technical Support Document (TSD). (U.S. EPA, 1997a)

Table I.3 presents point estimates for economic values associated with each health and welfare category, by pollutant. Note that there is uncertainty surrounding any estimate of the monetized benefit associated with a unit change in health or welfare effect (e.g., an additional hospital admission avoided). Point estimates are often a central tendency estimate taken from a distribution of possible values. The descriptions of the derivations of the distributions and point estimates of the monetized values (unit dollar values) are presented in the Benefits TSD. (U.S. EPA, 1997a)

Premature Mortality

Reductions in mortality risk are valued in this monetized benefit analysis using two different approaches, as outlined in the Office of Management and Budget's guidance. The high-end estimate uses a value of statistical life saved approach, and the low-end estimated is based on the value of statistical life year extended approach. Individual WTPs for small reductions in mortality risk are summed over enough individuals to infer the value of a statistical life saved or statistical life-year extended. This is different from the value of a particular, identified life saved. The "value of a premature death avoided" then should be understood as shorthand for the "value of a statistical premature death avoided".

The value of a premature death avoided is based on an analysis of 26 policy-relevant value of life studies. A summary of these studies is provided in Table I.4. Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. Each of the 26 studies provides an estimate of the mean WTP to avoid a statistical premature death. Several plausible standard distributions were fit to the 26 estimates of mean WTP. A Weibull distribution, with a mean of $4.8 million and standard deviation of $3.24 million, provided the best fit to the 26 estimates. The central tendency estimate of the WTP to avoid a statistical premature death is the mean of this distribution, $4.8 million. The value of statistical life-year extended was derived from a number of studies, including Moore and Viscusi (1988) and Miller, Calhoun, Arthur (1990)--summarized in Tolley, et. al. (1994). Tolley, et. al. report a range for the value of a statistical life-year of $70,000, $120,000, and $175,000. This analysis uses the midpoint of that range, $120,000 per life-year extended.

The transferability of estimates of the value of a statistical life from the 26 studies to these benefits analyses rests on the assumption that, within a reasonable range, WTP for reductions in mortality risk is linear in risk reduction. In addition, the characteristics of the study subjects and the nature of the mortality risk being valued in the study could affect the transferability of the value of statistical life to this assessment.

Compared with the subjects in wage-risk studies, the population believed to be most affected by PM (i.e., the population that would receive the greatest mortality risk reduction associated with a given reduction in PM concentrations) is, on average, older and probably more risk averse. Citing Schwartz and Dockery (1992) and Ostro et al. (unpublished), Chestnut estimates that approximately 85 percent of those who die prematurely from PM-related causes are over 65 years of age. The average age of subjects in wage-risk studies, in contrast, would be well under 65. At this time, there is insufficient information in the current ozone-related mortality literature to conclude that premature mortality related to ozone exposure is age-dependent.

Table I.3 Economic Valuation of Health and Welfare Effects of PM, Ozone, and Regional Haze
1990 $

Health or Welfare Effect	Pollutant(s)[a]	Valuation Measure[b]	Unit Value (Point Estimate)	Comments
Mortality:				
Statistical Lives Saved	$PM_{10}/PM_{2.5}/O_3$	$ per case	$4.8 million	
Life-Years Saved	$PM_{10}/PM_{2.5}$	$ per life-year	$120,000	
Hospital Admissions:				
All Respiratory Illnesses, all ages	$PM_{10}/PM_{2.5}$	$ per hospital admission	$12,700	The PM value is smaller than for ozone because opportunity cost is excluded from the PM value to avoid double-counting (see the next section). Also, the study estimating a concentration-response function for PM defines "all respiratory illnesses" slight differently from the corresponding ozone study.
	O_3	$ per hospital admission	$13,400	
Pneumonia, age ≥ 65	PM_{10}/O_3	$ per hospital admission	$15,900	
COPD, age ≥ 65	PM_{10}/O_3	$ per hospital admission	$15,700	
Ischemic Heart Disease, age ≥ 65	PM_{10}	$ per hospital admission	$20,600	
Congestive Heart Failure, age ≥ 65	PM_{10}	$ per hospital admission	$16,600	
Emergency Department Visits for Asthma	O_3	$ per hospital admission	$9,000	
Respiratory Ailments Not Requiring a Hospital Admission:				
Chronic Bronchitis	PM_{10}	$ per case	$260,000	

Health or Welfare Effect	Pollutant(s)[a]	Valuation Measure[b]	Unit Value (Point Estimate)	Comments
Upper Respiratory Symptoms (URS)	PM_{10}	$ per symptom-day	$19	
Lower Respiratory Symptoms (LRS)	$PM_{10}/PM_{2.5}$	$ per symptom-day	$12	
Acute Bronchitis	$PM_{10}/PM_{2.5}$	$ per case	$45	
Acute Respiratory Symptoms: Any of 19	PM_{10}/O_3	$ per symptom-day	$18	
Asthma[c]	$O_3/PM_{2.5}$	$ per symptom-day	$32	
Shortness of Breath	PM_{10}	$ per symptom-day	$5.30	
Sinusitis and Hay Fever	O_3	-----	quantified but not monetized	
Restricted Activity:				
Work Loss Day (WLD)	$PM_{2.5}$	$ per day	$83	
Restricted Activity Day (RAD)	$PM_{2.5}$	$ per day	quantified but not monetized	
Minor Restricted Activity Day (MRAD)	$O_3/PM_{2.5}$	$ per day	$38	
Respiratory Restricted Activity Day (RRAD)	$O_3/PM_{2.5}$	-----	quantified but not monetized	
Welfare Effects:				
Worker Productivity (resulting in changes in daily wages)	O_3	change in daily wages	$1 per worker per 10% change in O_3[d]	

Health or Welfare Effect	Pollutant(s)[a]	Valuation Measure[b]	Unit Value (Point Estimate)	Comments
Visibility (residential)	deciview	annual household WTP	WTP per unit decrease in deciview = \$14	
Visibility (recreational)	deciview	annual household WTP		see U.S. EPA 1997 for valuations
Household Soiling Damage	TSP	\$ per household per μg/m[3] PM_{10} (annual cost)	\$2.50	

NOTES:

[a] Attainment for which epidemiological evidence quantifies a concentration-response relationship for the given endpoint
[b] Most unit values quantify the willingness to pay (WTP) to avoid a case of the given effect. However, for those effects measured in terms of symptom-days, the unit value reflects the WTP to avoid one day of the given respiratory symptoms
[c] Asthma is either self-reported asthma or moderate or worse asthma status
[d] Deciview (DV) is a common visibility measure useful for characterizing visibility in terms of perceptible changes independent of baseline conditions. A decrease in deciview corresponds to an increase in visibility. It is related to another common visibility measure, visual range (VR): DV = 10 ln[391 km/VR] where DV is unitless and VR is measured in kilometers

* See U.S. EPA 1997 for citations

Table I.4 Summary of Mortality Valuation Estimates
(millions of 1990 $)

Study	Type of Estimate	Valuation per Statistical Life
Kneisner and Leeth (1991) (U.S.)	Labor Market	0.6
Smith and Gilbert (1984)	Labor Market	0.7
Dillingham (1985)	Labor Market	0.9
Butler (1983)	Labor Market	1.1
Miller and Guria (1991)	Contingent Valuation	1.2
Moore and Viscusi (1988a)	Labor Market	2.5
Viscusi, Magat, and Huber (1991b)	Contingent Valuation	2.7
Gegax et al. (1985)	Contingent Valuation	3.3
Marin and Psacharopoulos (1982)	Labor Market	2.8
Kneisner and Leeth (1991) (Australia)	Labor Market	3.3
Gerking, de Haan, and Schulze (1988)	Contingent Valuation	3.4
Cousineau, Lacroix, and Girard (1988)	Labor Market	3.6
Jones-Lee (1989)	Contingent Valuation	3.8
Dillingham (1985)	Labor Market	3.9
Viscusi (1978, 1979)	Labor Market	4.1
R.S Smith (1976)	Labor Market	4.6
V.K. Smith (1976)	Labor Market	4.7
Olson (1981)	Labor Market	5.2
Viscusi (1981)	Labor Market	6.5
R.S. Smith (1974)	Labor Market	7.2
Moore and Viscusi (1988a)	Labor Market	7.3
Kneisner and Leeth (1991) (Japan)	Labor Market	7.6
Herzog and Schlottman (1987)	Labor Market	9.1
Leigh and Folson (1984)	Labor Market	9.7
Leigh (1987)	Labor Market	10.4
Gaten (1988)	Labor Market	13.5

* Source: Viscusi, 1992

There is also reason to believe that those over 65 are, in general, more risk averse than the general population while workers in wage-risk studies are likely to be less risk averse than the general population. Although Viscusi's list of recommended studies excludes studies that consider only much-higher-than-average occupational risks, there is nevertheless likely to be some selection bias in the remaining studies, i.e., these studies are likely to be based on samples of workers who are, on average, more willing to accept higher risks than the general population. In contrast, older people as a group exhibit more risk averse behavior.

In addition, it might be argued that because the elderly have greater average wealth than those younger, the affected population is also wealthier, on average, than wage-risk study subjects, who tend to be blue collar workers. It is possible, however, that among the elderly, it is largely the poor elderly who are most vulnerable to PM-related mortality (e.g., because of generally poorer health care). If this is the case, the average wealth of those affected by a reduction in PM concentrations relative to that of subjects in wage-risk studies is uncertain.

The direction of bias resulting from the age difference is unclear, particularly because age is confounded by risk aversion (relative to the general population). It could be argued that, because an older person has fewer expected years left to lose, his/her WTP to reduce mortality risk would be less than that of a younger person. This hypothesis is supported by one empirical study, Jones-Lee et al. (1985), that found the value of a statistical life at age 65 to be approximately 90 percent of what it is at age 40. Citing the evidence provided by Jones-Lee et al., Chestnut (1995) estimates a weighted average value of a statistical life based on the approximate age distribution for the U.S. population age 65 and older. This results in an adjustment to the value of a statistical life for those 65 and over of 75 percent of what it is for those under 65.

The greater risk aversion of older people, however, implies just the opposite. Citing Ehrlich and Chuma (1990), IEc (1992) notes that "older persons, who as a group tend to avoid health risks associated with drinking, smoking, and reckless driving, reveal a greater demand for reducing mortality risks and hence have a greater implicit value of a life year." That is, the more risk averse behavior of older individuals suggests a greater WTP to reduce mortality risk.

There is substantial evidence that the income elasticity of WTP for health risk reductions is positive, although there is uncertainty about the exact value of this elasticity. Individuals with higher incomes (or greater wealth) should be willing to pay more to reduce risk, all else equal, than individuals with lower incomes or wealth. Whether the average income or level of wealth of the population affected by PM reductions is likely to be significantly different from that of subjects in wage-risk studies, however, is unclear, as discussed above.

Finally, there is some evidence (see, for example, Violette and Chestnut, 1983) that people will pay more to reduce involuntarily incurred risks than risks incurred voluntarily. If this is the case, WTP estimates based on wage-risk studies may be downward-biased estimates of WTP to reduce involuntarily incurred PM-related mortality risks.

Hospital Admissions

The value to an individual of avoiding a hospital admission is measured by the individual's WTP to avoid the hospital admission. This value is the amount of money such that the individual would be indifferent between having the money and avoiding the hospital admission. An individual's WTP will include, at a minimum the amount of money he pays for medical expenses and the loss in earnings. In addition, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself.

The total value to society of an individual's avoiding a hospital admission, then, might be thought of as having two components: (1) the cost of illness (COI) to society, including the total medical costs plus the value of the lost productivity, as well as (2) the individual's WTP to avoid the disutility of the illness itself (e.g., the pain and suffering associated with the illness). It is useful to note that although medical expenditures are to a significant extent shared by society, via medical insurance, Medicare, etc. However, the limited evidence comparing individual WTPs to social COI suggests that individual WTPs to avoid morbidity effects generally do in fact exceed the total COIs associated with those effects.

In the absence of estimates of social WTP to avoid hospital admissions for specific illnesses (components 1 plus 2 above), estimates of total COI (component 1) are typically used as lower-bound estimates. Because these estimates do not include the value of avoiding the disutility of the illness itself (component 2), they are biased downward. This analysis adjusts the COI estimate upward by multiplying an estimate of the ratio of WTP to COI to better approximate total WTP to avoid a hospital admission.

The average physician charges of the first day of hospital care for asthma or COPD is estimated as $94; average physician charges for subsequent days of hospital care are estimated to be $35. Average physician charges associated with hospital care for asthma or COPD are assumed to provide reasonably good estimates of average physician charges associated with hospital stays for the other illness categories considered here.

To estimate the opportunity cost of a day spent in the hospital for an individual aged 65 or older, it is assumed that such an individual is not in the workforce. As an approximation, it is assumed that, for the young, the elderly, and any other unemployed individuals the opportunity cost of a day spent in the hospital is one-half the median daily wage, or $41.50. Thus, the opportunity cost associated with a hospital admission is simply equal to $41.50 times the average number of days of the hospital stay.

To derive unit dollar values for hospital admissions for respiratory illness based on the Thurston study, which considered individuals of all ages, it is assumed that half of the PM-related hospital admissions are among individuals who are not employed, including the young and the elderly. Because the value of work loss days for those in the labor force is considered as a separate endpoint, only the opportunity cost for those outside of the workforce is included.

Since COI estimates do not measure values associated with pain and suffering, as well as other reductions in well-being from illness, they significantly understate the true WTP to avoid illness. For this reason, an adjustment factor is employed to scale the hospital admission COI estimate upward to estimate WTP. Using evidence from a range of estimates that examine WTP to COI ratios (Rowe and Chestnut, 1986; Rowe et al., 1984; and Rowe and Neither cut, 1987), the hospital admissions COI estimate is multiplied by a factor of 2. This factor is based on results from three studies providing evidence on WTP/COI ratios for the same study population addressing the same change in the same health effect. While this adjustment approach is based on limited evidence, the resulting hospital admissions valuation estimate is not clearly biased.

There is substantial uncertainty associated with the adjustment factor of 2. Acknowledging that the adjustment factor may vary from one endpoint to another, the factor is taken to have a continuous uniform distribution from 1.5 to 2.5, with a mean of 2. This distribution is both simple and consistent with the point estimate of 2.

The hospital charge component of COI is generally an order of magnitude greater than the other two components (physician charge and opportunity cost). Sample mean hospital charges, as well as standard errors of the means, are provided by Elixhauser et al., 1993. An symptotic normality of the sample mean can be invoked because these sample means are generally based on very large samples.

The physician charge and opportunity cost are relatively small components of the COI associated with a hospital admission. Including estimates of uncertainty surrounding these two small components of WTP to avoid a hospital admission is therefore largely "fine tuning." These components are omitted from the uncertainty analysis because information concerning their distributions is lacking. The following distributional form is used for the COI associated with each of the hospital admission classifications: a normal distribution with mean = the point estimate (i.e., the mean hospital charge + physician charge + opportunity cost) and standard deviation = the standard error of the mean hospital charge reported in the Elixhauser et al. study.

<u>Chronic Bronchitis</u>

Chronic bronchitis is one of the only morbidity endpoints that may be expected to last from the initial onset of the illness throughout the rest of the individual's life. WTP to avoid chronic bronchitis would therefore be expected to incorporate the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) associated with the illness. Two studies, Viscusi et al. (1991) and Krupnick and Cropper (1992) provide estimates of WTP to avoid a case of chronic bronchitis. The study by Viscusi et al., however, uses a sample that is larger and more representative of the general population than the study by Krupnick and Cropper (which selects people who have a relative with the disease). The valuation of chronic bronchitis in this analysis is therefore based on the distribution of WTP responses from Viscusi et al. (1991).

Both Viscusi et al. and Krupnick and Cropper, however, defined a case of severe chronic bronchitis. It is unclear what proportion of the cases of chronic bronchitis predicted to be associated with exposure to pollution would turn out to be severe cases. The incidence of pollution-related chronic bronchitis was based on Abbey et al. (1993), which considered only new cases of illness. While a new case may not start out being severe, chronic bronchitis is a chronic illness which may progress in severity from onset throughout the rest of the individual's life. It is the chronic illness which is being valued, rather than the illness at onset.

The WTP to avoid a case of pollution-related chronic bronchitis is derived by starting with the WTP to avoid a severe case of chronic bronchitis, as described by Viscusi et al. (1991), and adjusting it downward to reflect (1) the decrease in severity of a case of pollution-related chronic bronchitis relative to the severe case in the Viscusi study, and (2) the elasticity of WTP with respect to severity. Because elasticity is a marginal concept and because it is a function of severity (as estimated from Krupnick and Cropper), WTP adjustments were made incrementally, in one percent steps. At each step, given a WTP to avoid a case of CB of severity level *sev*, the WTP to avoid a case of severity of 0.99**sev* was derived. This procedure is iterated until the desired severity level was reached and the corresponding WTP estimate is derived. Because the elasticity of WTP with respect to severity is a function of severity, this elasticity changes at each iteration. If for example, it is believed that a pollution-related case of chronic bronchitis is of average severity, that is 50 percent reduction in severity from the case described in the Viscusi study, then the iterative procedure would proceed until the severity level was half of what it started out to be.

The derivation of the WTP to avoid a case of pollution-related chronic bronchitis is based on three components, each of which is uncertain: (1) the WTP to avoid a case of severe chronic bronchitis, as described in the Viscusi study, (2) the severity level of an average pollution-related case of chronic bronchitis (relative to that of the case described by Viscusi), and (3) the elasticity of WTP with respect to severity of the illness. These three sources of uncertainty make the WTP estimate uncertain. Based on assumptions about the distributions of each of the three uncertain components, a distribution of WTP to avoid a pollution-related case of chronic bronchitis is derived by Monte Carlo methods. The mean of this distribution, which is $260,000, is taken as the central tendency estimate of WTP to avoid a pollution-related case of chronic bronchitis.

The distribution of WTP to avoid a case of pollution-related chronic bronchitis is generated by Monte Carlo methods, drawing on distribution estimates related to: (a) the distribution to avoid a severe case of chronic bronchitis (mean = $720,000); (b) the distribution of the severity level of an average case of pollution-related chronic bronchitis (represents a 50 percent reduction in severity from a severe case); and (c) the elasticity of WTP to avoid a case of chronic bronchitis (mean = 0.18 and standard deviation = 0.0669). On each of 16,000 iterations, (1) a value is selected from each distribution, and (2) a value for WTP is generated by the iterative procedure, in which the severity level is decreased by one percent on each iteration on each iteration and the corresponding WTP value is derived. The mean of the resulting distribution of WTP to avoid a case of pollution-related chronic bronchitis is $260,000.

I.4 Sensitivity Analyses

I.4.1 Introduction

This section presents results associated with several benefits sensitivity analyses. These sensitivity analyses include: (1) examining the sequence of a PM following ozone analysis and (2) examining the results of using a proportional air quality rollback procedure to adjust ozone concentrations.

I.4.2 Sequenced Analyses

The PM and ozone benefits estimates presented in chapter 12 represent benefits estimated for air quality changes incremental to partial or full attainment of the current standards. However, the benefits estimates of the alternative PM and ozone standards do not reflect any possible overlap with each other. For example, partial attainment benefits of the 15/50 $PM_{2.5}$ and .08, 3rd max. ozone alternatives are estimated incremental from partial attainment of the current standards. However, these estimates do not reflect any overlap of benefits that may occur between the 15/50 $PM_{2.5}$ and .08, 3rd max. ozone alternatives since the estimates are calculated independently of each other.

It is important to know if significant benefits overlap exists between the $PM_{2.5}$ and ozone alternatives because the total benefits associated with the combined PM and ozone NAAQS is relevant information. However, lack of adequate air quality modeling data precluded the estimation of the ozone following PM analysis. Therefore, the sensitivity analysis was conducted for the PM following ozone sequence, using the proposed standards as case studies.

This sensitivity analysis was conducted using a preliminary set of air quality data that does not exactly match the air quality data used to estimate benefits as presented in chapter 12. Therefore, the results presented in this appendix are not directly comparable to the benefits results presented in chapter 12. Although the preliminary air quality data used in this sensitivity analysis does not represent the final and most accurate set of air quality data, the results of this analysis may provide insight into the magnitude and/or direction of the benefits results when considering the sensitivity factors.

In a PM following ozone analysis, the ozone benefits results are unaffected (e.g., identical to ozone-only analysis) because the benefits of the ozone standard are calculated incremental to the current ozone standard, regardless of whether a PM alternative follows the ozone analysis. Therefore, the comparison of most interest is the comparison between the PM-only analysis and the PM following ozone analysis. These partial attainment results are estimated incremental to partial attainment of the current ozone and PM_{10} NAAQS as well as the .08, 3rd max. ozone standard and are presented in Table I.5.   The high end benefits range for the PM-only analysis is approximately $59 billion to $109 billion while the high end benefits range for the PM following ozone analysis is approximately $55 billion to $104 billion. These results indicate that while some individual endpoints may be slightly overestimated when summing the ozone-only and PM-only results, total benefits estimates would not significantly be overestimated using either set (PM-only or PM following ozone) of results. Also, note that the total benefits estimates are often reported at the 2 significant figure level. Given this level of rounding, there is little detectable difference between the two analyses. Therefore, although individual estimates may be slightly overstated when the PM and ozone NAAQS are summed, total benefits are not expected to be overstated.

I.4.3 Proportional Air Quality Rollback for Ozone

The ozone benefits estimates presented in chapter 12 are associated with ozone air quality changes calculated by a quadratic air quality rollback procedure. Recall that a rollback procedure is necessary due to lack of adequate air quality modeling data. The Agency recognizes that the choice of a rollback procedure may significantly affect the benefits results. Therefore, a sensitivity analysis was conducted (using the preliminary air quality data set) to ascertain the influence the choice of an air quality rollback procedure could have.

Table I.5 Sensitivity Analysis of Sequenced PM and Ozone Alternatives
PM : National Annual Monetized Health and Welfare Benefits[1]
Estimates are incremental to the .08 ppm, 3rd max. ozone and current PM NAAQS (50 μg/m^3 annual; 150 μg/m^3 daily)
(millions of 1990 $; year = 2010)

ENDPOINT[2]		**Partial Attainment Scenario (High End)**	
		PM - Only	**PM Following Ozone**
	Annual $PM_{2.5}$ (μg/m^3)	**15**	**15**
	Daily $PM_{2.5}$ (μg/m^3)	**50**	**50**
***Mortality[3]:short-term exposure** **long-term exposure**		$27,000 $78,000	$27,000 $76,000
***Chronic Bronchitis**		$23,000	$20,000
Hospital Admissions: *all respiratory (all ages) all resp. (ages 65+) pneumonia (ages 65+) COPD (ages 65+) *congestive heart failure *ischemic heart disease		 $80 $110 $50 $40 $40 $50	 $80 $110 $50 $40 $40 $50
***Acute Bronchitis**		$2	$1
***Lower Respiratory Symptoms** ***Upper Respiratory Symptoms** shortness of breath asthma attacks		$7 $1 $1 $14	$4 $1 $1 $13
***Work Loss Days**		$270	$270
***Minor Restricted Activity Days (MRADs)**		$1,000	$1,000
Household Soiling		$960	$400
Visibility		$6,170	$6,031
TOTAL MONETIZED BENEFITS using short-term PM mortality using long-term PM mortality		 $59,000 $109,000	 $55,000 $104,000

[1] numbers may not completely agree due to rounding

[2] only endpoints denoted with an * are aggregated into total benefits estimates

[3] mortality estimates must be aggregated using either short-term exposure or long-term exposure but not both due to double-counting issues

The alternative ozone air quality rollback procedure employed in this sensitivity analysis is referred to as proportional (also called linear) rollback procedure. This method for adjusting PM concentrations decreases baseline PM concentrations on all days by the same percentage. (Recall that quadratic rollback as employed in chapter 12 reduces non-peak ozone values (e.g., wintertime ozone values) by a smaller proportion compared to peak ozone values (e.g., ozone concentrations at design-value monitors). This sensitivity analysis is estimated using the current ozone standard, partial attainment scenario since all subsequent benefits results are estimated incremental to partial attainment of the current standard.

The results of the quadratic rollback procedure compared to the proportional rollback procedure are presented in Table I.6. Note that unlike chapter 12, a smaller number of categories is presented in Table I.6 The choice of a rollback procedure affects only ozone concentration-response functions since ancillary PM air quality changes are estimated using the source-receptor model and are unaffected by the choice of an ozone air quality rollback procedure. In addition, other benefits categories such as nitrogen deposition and air toxics are estimated using the VOC or NO_x emission reductions as reported in the cost analysis. Therefore, only categories that are estimable and are affected by the choice of the ozone air quality rollback procedure are presented in Table I.6.

An examination of the results in Table I.6 indicate that in general, the ozone health and welfare benefits estimated using a proportional rollback procedure are approximately 2 times greater when compared to the benefits estimates calculated with air quality changes using a quadratic air quality rollback procedure. The directional result of this sensitivity analysis (larger benefits estimates using a proportional rollback procedure compared to a quadratic rollback procedure) is consistent with expectations regarding the results. As explained in section 12.6 of chapter 12, a proportional air quality rollback procedure adjusts baseline ozone concentrations on all days by the same percentage. Alternatively, the quadratic air quality rollback procedure adjusts baseline ozone concentrations using a quadratic formula that reduces non-peak ozone

Table I.6 Sensitivity Analysis of Proportional Ozone Air Quality Rollback Procedure
Ozone : National Annual Monetized Benefits of Selected Health and Welfare Categories[1]
(billions of 1990 $; year = 2010)

	Partial Attainment Scenario	
	Quadratic Rollback	**Proportional Rollback**
ENDPOINT[2]	**.12 ppm, 1 hour**	**.12 ppm, 1 hour**
***Mortality**	$0.57	$1.1
Hospital Admissions:		
*all respiratory (all ages)	$0.007	$0.013
all respiratory (ages 65+)	$0	$0.038
pneumonia (ages 65+)	$0.010	$0.019
COPD	$0.003	$0.006
emer. dept. visits for asthma	$0.002	$0.004
***Acute Respiratory Symptoms** (any of 19)	$0.001	$0.002
Asthma Attacks	$0	$0
Minor Restricted Activity Days (MRAD's)	$0	$0
***Commodity Crops**	$0.038	$0.075
***Fruits and Vegetables**	$0.150	$0.270
***Worker Productivity**	$0.014	$0.029
TOTAL MONETIZED BENEFITS	$0.77	$1.5

*This table does not represent total benefits associated with the standard, only represents benefits associated with a selected collection of benefits categories affected by the choice of an ozone air quality rollback procedure for the high-end estimate. For example, ancillary PM benefits are not listed here because they are unaffected by the ozone air quality rollback procedure.

[1] numbers may not completely agree due to rounding

[2] only endpoints denoted with an * are aggregated into total benefits estimates

concentrations by a smaller percentage than peak ozone concentrations. The difference between the two procedures is that proportional rollback reduces the majority of the baseline ozone concentrations by a greater percentage when compared to the quadratic rollback procedure. All inputs (e.g., concentration-response functions, valuation estimates, etc.) other than air quality changes are constant between the two analyses. Given that the air quality change is greater using proportional rollback, the benefits results showing larger benefits estimates associated with proportional rollback compared to quadratic rollback is consistent with the relative air quality changes.

I.5 Ozone Benefits Using Clinical Studies

Clinical studies of air pollution involve exposing human subjects to various levels of air pollution in a carefully controlled and monitored laboratory situation. The physical condition of the subjects is measured before, during, and after the pollution exposure. The advantage of clinical studies is that they often can isolate cause-effect relationships between pollutants and certain human health effects. However, there are also drawbacks to using clinical studies for a comprehensive benefits analysis. Drawbacks include limitations on studying severe effects or effects caused by long-term exposure and limitations to the potential study scope due to ethical considerations. However, data estimated from clinical concentration - response functions provide useful and relevant information and are presented here to support the benefits analysis effort. Clinical models are available only for ozone-related exposures and are therefore, only applicable to the ozone benefits analysis.

Table I.7 presents information associated with each clinical concentration-response function. Health endpoints evaluated by the clinical models include: change in forced expiratory volume (DFEV) of ≥ 10%, ≥ 15%, ≥ 20%; coughs, pain upon deep inhalation (PDI), and lower respiratory symptoms.

Each clinical model identifies the change in health effect as a rate; for example, as a per capita value. In order to identify the aggregate population impact, it is necessary to specify the population affected. The clinical analysis evaluates the concentration-response functions for three sub-population groups: outdoor children, outdoor workers, all other adults other than outdoor workers. These results are then summed to provide a total estimate of benefits.

When evaluating the clinical studies, the concentration-response functions provide an estimate of the number of times (incidences) that a health symptom would occur over a 16-hour day (8 am to 12 am). However, valuation estimates that are used to estimate the economic value of avoiding these health effects are estimated in terms of dollars per avoided “symptom day.” For example, evaluation of a clinical coughing model over a 16-hour day would yield the total number of times a cough is expected to occur during this time period given a particular level of ambient ozone. This estimate does not differentiate between multiple coughs experienced by one person versus one cough experienced by many people.

Due to the definition of a symptom day as reported in the contingent valuation surveys, it is necessary to convert the number of incidences of a health symptom into a comparable count of the number of symptom days. This conversion is accomplished by applying each concentration-response function to the daily time period specified by the model (e.g.,two-hour period) reported as having the highest ozone concentration during that day. This time period corresponds to the highest probability of response among the affected population for that day and as such, this daily period will capture the maximum number of people who would experience a health symptom as a result of ozone exposure if activity patterns were constant across the day. This period is used to define the “incidence-day” (i.e., symptom-day) estimates for each concentration-response model.

Table I.7 Clinical Model Descriptive Characteristics

#	Health End-Point	Citation	Study Exposure Period	Benefit Analysis Exposure Period	Functional Form	Alpha	Beta	d	e	r^2	Concentration Value When Incidence=0
1	$DFEV_1 \geq 10\%$	Avol et al. (1984)	1.33 hours	1 hour	Linear	-0.2395	3.-4388			0.98	0.0696
2	$DFEV_1 \geq 15\%$	Avol et al. (1984)	1.33 hours	1 hour	Linear	-0.2400	2.-9713			0.99	0.0808
3	$DFEV_1 \geq 20\%$	Avol et al. (1984)	1.33 hours	1 hour	Linear	-0.2395	2.-6825			0.99	0.0893
4	$DFEV_1 \geq 10\%$	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.3225	2.-3500			0.95	0.1372
5	$DFEV_1 \geq 15\%$	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.2600	1.600			0.93	0.1625
6	$DFEV_1 \geq 20\%$	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.2375	1.-2500			0.89	0.1900
7	$DFEV_1 \geq 10\%$	McDonnell et al. (1983)	2.5 hours	2 hours	Logistic		0.-6420	5.-5996	-27.-2927	0.99	
8	$DFEV_1 \geq 15\%$	McDonnell et al. (1983)	2.5 hours	2 hours	Logistic		0.-4968	9.-4948	-45.-3838	1.00	

#	Health End-Point	Citation	Study Exposure Period	Benefit Anal-ysis Expo-sure Period	Functional Form	Alpha	Beta	d	e	r^2	Concentration Value When Inci-dence=0
9	$DFEV_1 \geq$ 20%	McDon-nell et al. (1983)	2.5 hours	2 hours	Logistic		0.-3347	12.-0073	-60.-4547	1.00	
10	$DFEV_1 \geq$ 10%	Seal et al. (1993)	2.33 hours	2 hours	Probit	-1.0276	0.-7917			0.99	
11	$DFEV_1 \geq$ 15%	Seal et al. (1993)	2.33 hours	2 hours	Probit	-0.6639	0.-8401			0.99	
12	$DFEV_1 \geq$ 20%	Seal et al. (1993)	2.33 hours	2 hours	Probit	-0.3259	0.-9192			0.97	
13	$DFEV_1 \geq$ 10%	FHM[2]	8 hours	8 hours	Linear	-0.0980	5.-0000			1.00	0.0196
14	$DFEV_1 \geq$ 15%	FHM	8 hours	8 hours	Linear	-0.2087	4.-9000			1.00	0.0426
15	$DFEV_1 \geq$ 20%	FHM	8 hours	8 hours	Linear	-0.1462	2.-9250			0.98	0.0500
16	Lower Respiratory Symptoms	Avol et al. (1984)	1.33 hours	1 hour	Linear	-0.2084	2.-6824			0.99	0.0777

#	Health End-Point	Citation	Study Exposure Period	Benefit Analysis Exposure Period	Functional Form	Alpha	Beta	d	e	r^2	Concentration Value When Incidence=0
17	Moderate to Severe Lower Respiratory Symptoms	Avol et al. (1984)	1.33 hours	1 hour	Linear	-0.0902	0.-5206			0.94	0.1733
18	Cough	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.2650	3.-0000			0.97	0.0883
19	Pain Upon Deep Inhalation	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.4550	3.-8000			0.79	0.1197
20	Moderate to Severe Cough	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.1626	0.-8675			-0.33[1]	0.1874
21	Moderate to Severe Pain Upon Deep Inhalation	Kulle et al. (1985)	2 hours	2 hours	Linear	-0.5250	3.-0000			0.72	0.1750
22	Cough	McDon-nell et al. (1983)	2.5 hours	2 hours	Probit	-2.0954	1.-2098			0.99	
23	Pain Upon Deep Inhalation	McDon-nell et al. (1983)	2.5 hours	2 hours	Probit	-1.6071	1.-5124			0.96	
24	Moderate to Severe Cough	McDon-nell et al. (1983)	2.5 hours	2 hours	Linear	0.0062	1.-2604			0.70	-0.0049

#	Health End-Point	Citation	Study Exposure Period	Benefit Analysis Exposure Period	Functional Form	Alpha	Beta	d	e	r^2	Concentration Value When Incidence=0
25	Moderate to Severe Pain Upon Deep Inhalation	McDonnell et al. (1983)	2.5 hours	2 hours	Linear	-0.0427	1.-1512			0.96	0.0371
26	Cough	Seal et al. (1993)	2.33 hours	2 hours	Lognormal	0.2469	1.-9248			0.97	
27	Pain Upon Deep Inhalation	Seal et al. (1993)	2.33 hours	2 hours	Lognormal	0.2464	2.-3641			0.99	
28	Moderate to Severe Cough	Seal et al. (1993)	2.33 hours	2 hours	Linear	-0.1445	1.-3704			0.97	0.1054
29	Moderate to Severe Pain Upon Deep Inhalation	Seal et al. (1993)	2.33 hours	2 hours	Probit	-0.3209	0.-9317			0.96	
31	Cough	FHM	8 hours	8 hours	Linear	-0.2928	5.-0750			0.54	0.0577
32	Pain Upon Deep Inhalation	FHM	8 hours	8 hours	Linear	0.7372	10.-1750			1.00	-0.0725
34	Moderate to Severe Cough	FHM	8 hours	8 hours	Linear	-0.1747	2.-3000			0.88	0.0760
35	Moderate to Severe Pain Upon Deep Inhalation	FHM	8 hours	8 hours	Linear	-0.3087	3.-7000			0.93	0.0834

1. The data do not support a meaningful exposure-response relationship for this health end-point. The negative

r^2 value is an indicator of this situation.
2. FHM: Folinsbee et. al. (1988), Horstman et. al. (1990), and McDonnell et. al. (1991).
* See Mathtech, Inc. (1997).

Table I.8 presents valuation information. (Neuman et al, 1993) Note that valuation estimates are only available for two endpoints: any cough and any PDI.

Table I.8 Willingness-to-Pay Estimates (1990 $)

	WTP Value Per Incidence-Day		
Health Endpoint	Low Estimate	Best Estimate	High Estimate
Cough	$1.26	$7.00	$13.84
PDI	$1.26	$4.41	$28.04

The clinical benefits estimates presented here represent benefits attributable to air quality changes within the identified ozone nonattainment and transport areas. The definition of these areas is described in chapter 4. The estimation of post-control ozone air quality is described in chapter 12.

Benefits estimates presented in chapter 12 represent ozone air quality changes projected to occur nationwide due to ozone control measures applied in the ozone cost analysis (see chapter 7). This clinical benefits analysis uses a slightly different procedure for estimating benefits compared to chapter 12. The clinical benefits model does not reflect potential benefits associated with projected air quality changes outside the identified ozone nonattainment and identified transport areas. Although control measures applied inside the ozone attainment areas are projected to affect air quality outside of the nonattainment area boundaries, the clinical model is data-intensive (hourly ozone data for a full calendar year for each county in the continental U.S.).

A test run of the model showed that benefits estimated for nationwide ozone air quality changes provided benefits results only slightly higher (five percent) when compared to benefits estimates calculated only for air quality changes within the ozone nonattainment areas. (Mathtech, 1997) Based on this slight difference, a decision was made to apply the model only to air quality changes within the nonattainment areas. Given this methodology, the benefits presented here are slightly underestimated due to the limited geographic scope.

The results of this clinical model benefits analysis are presented in Tables I.9 and I.10. The quantified reductions in health effects are presented in Table I.9 while the monetized benefits associated with those reductions are presented in Table I.10. These results cannot be combined with the benefits results presented in Chapter 12, which use epidemiological models to estimate benefits. Some overlap exists between coughs and some of the epidemiologic-measured endpoints such as hospital admissions, respiratory symptoms, or bronchitis. The same concern applies to the other clinical study endpoints.

Table I.9 Outdoor Workers, Children, and Rest of Adult Population
Partial Attainment
Incidence-Days Incremental from the Current Ozone NAAQS
(Year = 2010)

Endpoint	**0.08, 5th max**	**0.08, 4th max.**	**0.08, 3rd max.**
DFEV≥ 10%	2,901,420	2,926,986	3,504,604
DFEV≥ 15%	2,088,001	2,096,770	2,440,114
DFEV≥ 20%	1,011,808	1,006,651	1,129,725
Any Cough	2,223,280	2,216,085	2,464,995
Moderate to Severe Cough	329,761	320,525	331,801
Pain Upon Deep Inhalation	6,081,851	6,155,051	7,462,323
Moderate to Severe PDI	455,712	447,848	477,422
Lower Resp. Symptoms	144,160	140,773	134,825
Moderate to Severe Lower Resp. Symp.	0	0	0

Table I.10 Outdoor Workers, Outdoor Children, Rest of Adult Population
Partial Attainment
Incremental from the Current Ozone NAAQS
(millions of 1990$; year = 2010)

Endpoint	**0.08, 5th max.**	**0.08, 4th max.**	**0.08, 3rd max.**
DFEV≥ 10%	n/e	n/e	n/e
DFEV≥ 15%	n/e	n/e	n/e
Any Cough	$15.563	$15.513	$17.255
Moderate to Severe Cough	n/e	n/e	n/e
Pain Upon Deep Inhalation	$26.821	$27.144	$32.909
Moderate to Severe PDI	n/e	n/e	n/e
Lower Resp. Symp.	n/e	n/e	n/e
Mod. To Severe Lower Resp. Symptoms	n/e	n/e	n/e
Total Monetized Benefits	$42.384	$42.656	$50.164

n/e = not estimated

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APPENDIX J

OZONE MORTALITY META-ANALYSIS

APPENDIX J.1
ASSESSMENT AND SYNTHESIS OF AVAILABLE EPIDEMIOLOGICAL EVIDENCE OF MORTALITY ASSOCIATED WITH AMBIENT OZONE FROM DAILY TIME-SERIES ANALYSES

1.0 OVERVIEW OF AVAILABLE LITERATURE

1.1 Purpose and scope of this literature review

This document reviews and summarizes the available epidemiologic evidence concerning the relationship between ambient ozone concentrations and human mortality risks. The evidence is reviewed for the purposes of developing a quantitative procedure for estimating the change in number of premature deaths expected for each of the proposed NAAQS revision options. This quantification procedure is intended to be used as part of the Regulatory Impact Assessment (RIA) of the proposed NAAQS revisions. Its purpose, therefore, is to quantify, to the extent feasible given available information, the expected benefits of the proposed NAAQS revisions in terms of expected reductions in premature mortality throughout the country.

The literature relevant to this issue has been evolving rapidly, with many new research findings becoming available in the past two years. Many recent studies, therefore, are not discussed in the most recent version of the U.S. Environmental Protection Agency's criteria document for ozone (U.S. EPA, 1996). In order to take advantage of all available information, this review includes, but is not limited to, those studies discussed in the criteria document. The goals of the RIA process are to be as inclusive as possible in quantifying the expected costs and benefits of the proposed regulatory changes.

The goals of the RIA process may lead to a somewhat different approach to and interpretation of the literature than that taken in the criteria document and staff paper process. The focus of the latter is to determine what standard to set to protect public health, which is a somewhat different question than the quantification of the health effect changes expected as a result of one standard versus another. Given the goals of the RIA, the analysis errs on the side of reflecting all the expected benefits and costs, even if these cannot be precisely quantified.

This section reviews the literature on ozone and mortality and discusses key factors in evaluating the studies. This is followed by a discussion of the criteria used to select studies for a quantitative analysis of the association between ozone and mortality, and a review of each of the studies selected. The last section describes the quantitative method used to synthesize the information from multiple studies, including the methodology used to incorporate uncertainty into the analysis.

1.2 Overview of the literature on ozone and daily mortality

Table 1 lists 28 daily time-series epidemiology studies identified in the literature review that report results on a possible association between daily ozone concentrations and daily mortality. These studies were conducted in various urban areas throughout the world. Of these studies, 16 were conducted in the United States or Canada, 8 were conducted in Europe, and the remainder were conducted elsewhere, including Mexico City, Sao Paulo, Santiago, and Brisbane.

Of the 28 studies listed in Table 1, 21 were published or presented since 1995, illustrating the rapid expansion in this body of research in the last two and a half years. The studies show mixed findings as to whether there is a statistically significant association between daily ozone concentrations and daily mortality in each of the study areas. Overall, 15 of the studies report a statistically significant relationship between ozone and mortality, with the more recent studies tending to find statistical significance more often than the earlier studies.

1.3 Issues in evaluating the literature

Table 1 is a comprehensive list of studies, including some that report only qualitative results such as statements that ozone was not statistically significant, as well as conference papers and other manuscripts that may not be considered peer reviewed. As part of the process of evaluating the evidence presented by this body of literature, each study must be evaluated as to the soundness of the data and the analysis techniques and the conclusions drawn by the authors. This section highlights the key issues considered in the literature review. Section 2 goes into more detail as to the specific selection criteria developed for choosing studies to be used in the quantitative assessment.

Evaluation and interpretation of the studies is needed to assess the likelihood that the relationship between ozone and mortality is real. Studies must be assessed individually and as a whole to draw appropriate conclusions. Some of the key considerations for reviewing the studies are discussed in Bradford Hill's presidential address (Hill, 1965). Although he presents a number of guidelines for evaluating whether the associations observed in epidemiological studies are causal, he also notes that it is not necessary to meet or evaluate all of the guidelines before resolving to address the potentially harmful exposure. This review evaluates the studies in light of those principles most appropriate to the ozone mortality literature, but does not give a formal one-by-one evaluation of Hill's criteria.

The discussion below focuses on three key factors in evaluating the studies: whether covariates that might be confounding the ozone mortality relationship have been adequately addressed, whether the studies have sufficient data and statistical power to draw meaningful inferences, and whether there is consistency in findings across different studies as well as coherence between the findings in this body of literature and other research findings with regard to health effects of ozone.

Table 1: Epidemiological Evidence on the Relationship Between Daily Mortality and Exposure to Ambient Ozone

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Anderson et al., 1996 (APHEA project)	London 1987-1992	8-hr avg and daily 1-hr max (1-day lag)	8-hr avg; with black smoke in the model: 1.029 (1.015 - 1.042)	included	Authors note that ozone effects remain signif. after NO_2 and SO_2 are added to the model.
Cifuentes and Lave, 1997	Philadelphia 1983-1988	daily 1-hr max	1.008 (1.000 - 1.017)	excluded: not in or accepted to a peer reviewed journal	
Dockery et al., 1992	St. Louis; Kingston- Harriman, TN Sept 1985-Aug 1986	daily avg	St. Louis 1.0073 (0.9705 - 1.0735) East. TN 0.9839 (0.9017 - 1.0735)	excluded: no copollutants in model	
Hoek et al., 1997 (in press)	Rotterdam, The Netherlands 1986-1991	daily avg	1.044 (1.007 - 1.079)	included	Ozone was measured in $\mu g/m^3$. To convert to ppb, concentrations in $\mu g/m^3$ were divided by 1.96 (see note at end of table).
Ito and Thurston, 1996	Cook County, Illinois 1985-1990	2-day avg	1.017 (1.002 - 1.029)	included	

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Katsouyanni et al., 1993	Athens, Greece July 1987	daily 1-hr max	(See comment)	excluded: no copollutants in model; July only	Ozone was measured in $\mu g/m^3$. To convert to ppb requires knowing the conversion factor for the temperature in the study, which was substantially higher (July only) than the other studies for which conversions were made. The authors use smoke, SO_2, and ozone as alternative indices of air pollution but do not include more than one pollutant in any model. In each model, the air pollution index was binary. None of the air pollution indices was significant.
Kinney and Ozkaynak, 1991	Los Angeles County 1970-1979	daily 1-hr max (total oxidants) 1-day lag	1.0059 (1.0033 - 1.0086)	excluded: measured oxidants, not ozone	This study measured total oxidants, rather than ozone specifically.
Kinney and Ozkaynak, 1992 (Abstr.)	New York City April - Sept. 1971 - 1976	daily 1-hr max	1.0085 n.a.	excluded: not in or accepted to a peer reviewed journal	Although the authors do not report a standard error, they report that the coefficient was statistically significant at $p < 0.001$.
Kinney et al., 1995	Los Angeles County 1985-1990	daily 1-hr max	1.000 (0.989 - 1.010)	included	

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Loomis et al., 1996 (HEI)	Mexico City 1991-1992	daily 1-hr max	0.995 (0.987 - 1.004)	included	This study presents results from many models; some results are based on daily 1-hr max ozone whereas others are based on daily avg ozone. The result shown here is from a model with both TSP and SO_2, using daily 1-hr max ozone. Results from this paper were, in general, not significant.
Moolgavkar et al., 1995	Philadelphia 1973-1988	daily avg, 1-day lag	1.0154 (1.0045 - 1.0260)	included	
Ostro, 1995	Southern California summers, 1980-1986	daily avg	No PM proxy: 1.005 (1.000 - 1.012) with estimated $PM_{2.5}$: 1.0025 (0.9951 - 1.010)	excluded: summer only	
Ostro et al., 1996	Santiago, Chile 1989-1991	daily 1-hr max	OLS: 0.986 (0.977 - 1.000) Poisson regr : 0.995 (0.986 -1.005)	included	
Ozkaynak et al., 1995 (conf. paper)	Toronto, Canada 1972-1990	daily 1-hr max	1.0107 (1.0021 - 1.0194)	excluded: not in or accepted to a peer reviewed journal	

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Saldiva et al., 1994	Sao Paolo, Brazil May 1990-April 1991	3-day moving avg	1.0315 (0.8933 - 1.1911)	excluded: not all population (age 5 or under)	
Saldiva et al., 1995	Sao Paolo, Brazil May 1990-April 1991	daily avg and daily 1-hr max	daily avg: 0.9673 (0.8963 - 1.0438) daily 1-hr max: 1.0099 (0.9896- 1.0307)	excluded: not all pop. (age 65+)	
Samet et al., 1996, 1997 (HEI)	Philadelphia 1974-1988	2-day avg	1.024 (1.008 - 1.039)	included	This study considered ozone with only TSP and ozone with several other pollutants, including TSP (shown here). In both cases ozone was statistically significant.
Sartor et al., 1995	Belgium summer 1994	daily avg	n.a.	excluded: does not report quantitative result; summer only	O_3 and temperature, both lagged one day, were correlated with daily mortality. This study focused primarily on a heat wave in the summer of 1994. Because temp. and ozone were highly correlated, "additive regression models with these two variables were unstable and unreliable, impeding to establish the true relationship between the number of daily deaths and these two environmental factors."

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Schwartz, 1991	Detroit 1973-1982	avg of 1-hr peaks; avg of daily means	n.a.	excluded: no co-pollutants in model; does not report quantitative result	Ozone was "highly insignificant as a predictor of daily mortality." Unclear whether TSP and SO2 were also in the model containing ozone.
Shumway et al., 1988	Los Angeles County 1970-1979	avg of daily maxima at 6 monitors	n.a.	excluded: does not report quantitative results	Ozone was not included among the variables ultimately chosen for the regression models. The authors note the "near collinearity of temperature and ozone levels."
Simpson et al., 1997	Brisbane, Australia 1987-1993	?	n.a.	excluded: not in or accepted to a peer reviewed journal	Described in Thurston, 1997: "When all pollutants [SO_2, NO_2, and particulate matter, indicated by nephelometer readings] were included in the model, only ozone and particulate matter remained significant."
Sunyer et al., 1996 (APHEA project)	Barcelona, Spain 1985-1991	daily 1-hr max	1.023 (1.0006 - 1.041)	excluded: no copollutants in model	Ozone was measured in $\mu g/m^3$. To convert to ppb, concentrations in $\mu g/m^3$ were divided by 1.96 (see note at end of table). Although several pollutants are considered, there do not appear to be any copollutant models; each pollutant seems to be considered in a separate model.

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Thurston 1997 (AWMA presentation)	Nine U.S. cities 1981-1990	daily 1-hr max	Atlanta — 1.019 (1.012 - 1.027) Chicago — 1.017 (1.012 - 1.022) Detroit — 1.024 (1.017 - 1.032) Houston — 1.005 (1.000 - 1.010) Los Angeles — 1.007 (1.006 - 1.009) Minneapolis — 1.017 (1.005 - 1.029) New York — 1.019 (1.016 - 1.022) San Francisco — 1.022 (1.008 -1.035) St. Louis — 1.012 (1.006 - 1.019)	excluded: no copollutants in model; not in or accepted to a peer reviewed journal	95% confidence intervals are calculated from reported relative risks and t statistics for the ozone coefficients in the log-linear regressions.
Touloumi et al., 1997 (in press)	Several European cities	daily 1-hr max	Fixed effects model: 1.018 (1.009 - 1.026) Random effects model: 1.027 (1.005 - 1.049)	excluded: a meta-analysis of several cities; fixed effects assumptions rejected	This is a meta-analysis of the results from several European cities in the APHEA project. Random effects model found preferable for meta-analysis. Ozone was measured in µg/m^3. To convert to ppb, concentrations in µg/m^3 were divided by 1.96 (see note at end of table).
Verhoeff et al., 1996	Amsterdam 1986-1992	daily 1-hr max (2-day lag)	with black smoke: 1.014 (0.984 - 1.046) with PM_{10}: 1.024 (0.974 -1.078)	included	Ozone was measured in µg/m^3. To convert to ppb, concentrations in µg/m^3 were divided by 1.96 (see note at end of table).

Study	Study Location/ Duration	O_3 Exposure Measure (ppb)	Relative Risk and 95% CI for a 25 ppb Increase in O_3*	Included or Excluded (If Excluded, Reason)	Comments
Wyzga and Lipfert, 1995	Philadelphia 1973-1990	daily avg (1-day, 2-day, 3-day)	1.0185 (n.a.) — 0 day lag 1.0308 (n.a.) — lag up to 1 day 1.0526 (n.a.) — lag up to 2 days	excluded: not in or accepted to a peer reviewed journal	Although standard errors corresponding to each reported coefficient were not given, a "typical" standard error of 0.0120 was given. The authors note that "the standard errors shown are reasonably constant over the range of lags." Using this std. error, all three relative risks are statistically significant.
Wyzga and Lipfert, 1996	Philadelphia 1973-1980	daily avg	age < 65: 1.024 (1.0003 - 1.0489) age 65+: 1.0001 (0.9810 - 1.0197)	excluded: not in or accepted to a peer reviewed journal	This study considered only two separate age groups: < 65 and 65+, but not all pop.
Zmirou et al., 1996 (APHEA project)	Lyon, France 1985-90	daily mean and daily 1-hr max	daily mean : 1.029 (0.951 - 1.117) daily 1-hr max: 1.039 (0.941 - 1.157)	excluded: no copollutants in model	Ozone was measured in $\mu g/m^3$. To convert to ppb, concentrations in $\mu g/m^3$ were divided by 1.96 (see note at end of table).

* Results are considered statistically significant if the lower bound of the 95% confidence interval is greater than or equal to one. Ozone was measured in µg/m^3 in the following studies: Verhoeff et al.,1996; Hoek et al., 1997; Sunyer et al., 1996; Touloumi et al., 1997; Katsouyanni et al., 1993; and Zmirou et al., 1996. To convert to ppb (vol.), concentrations in µg/m^3 were divided by 1.96 for all the studies except Katsouyanni et al., 1993. The conversion factor depends on the temperature in the study area. At 0˚ C (32˚ F) the factor is 2.144. Schwartz, 1995 (a study of respiratory hospital admissions in New Haven, Connecticut and Tacoma, Washington) used 1.96 to convert from µg/m^3 to ppb. The mean temperature in each of these cities was given as 52˚ F (about 11˚ C). The mean (or median) temperatures given in the other locations for which conversions were necessary were all about the same as in New Haven and Tacoma, except for in the Katsouyanni study, which considered only July [(Verhoeff et al.,1996 — 10˚ C; Hoek et al., 1997 — 10˚ C; Zmirou et al., 1996 — 12˚ C; Sunyer et al., 1996 — 11˚ C in winter and 20˚ C in summer; and Touloumi et al., 1997 — 13.3˚ C (an average of the six city-specific means given in the paper.)].

1.3.1 Covariates and other model specification issues

The accuracy of an estimate of a concentration-response function reported by a study depends on the study design. In general, critical considerations in evaluating the design of a daily time-series epidemiological study include the adequacy of the measurement of ambient ozone and the consideration of potentially important health determinants and confounding factors such as the following:

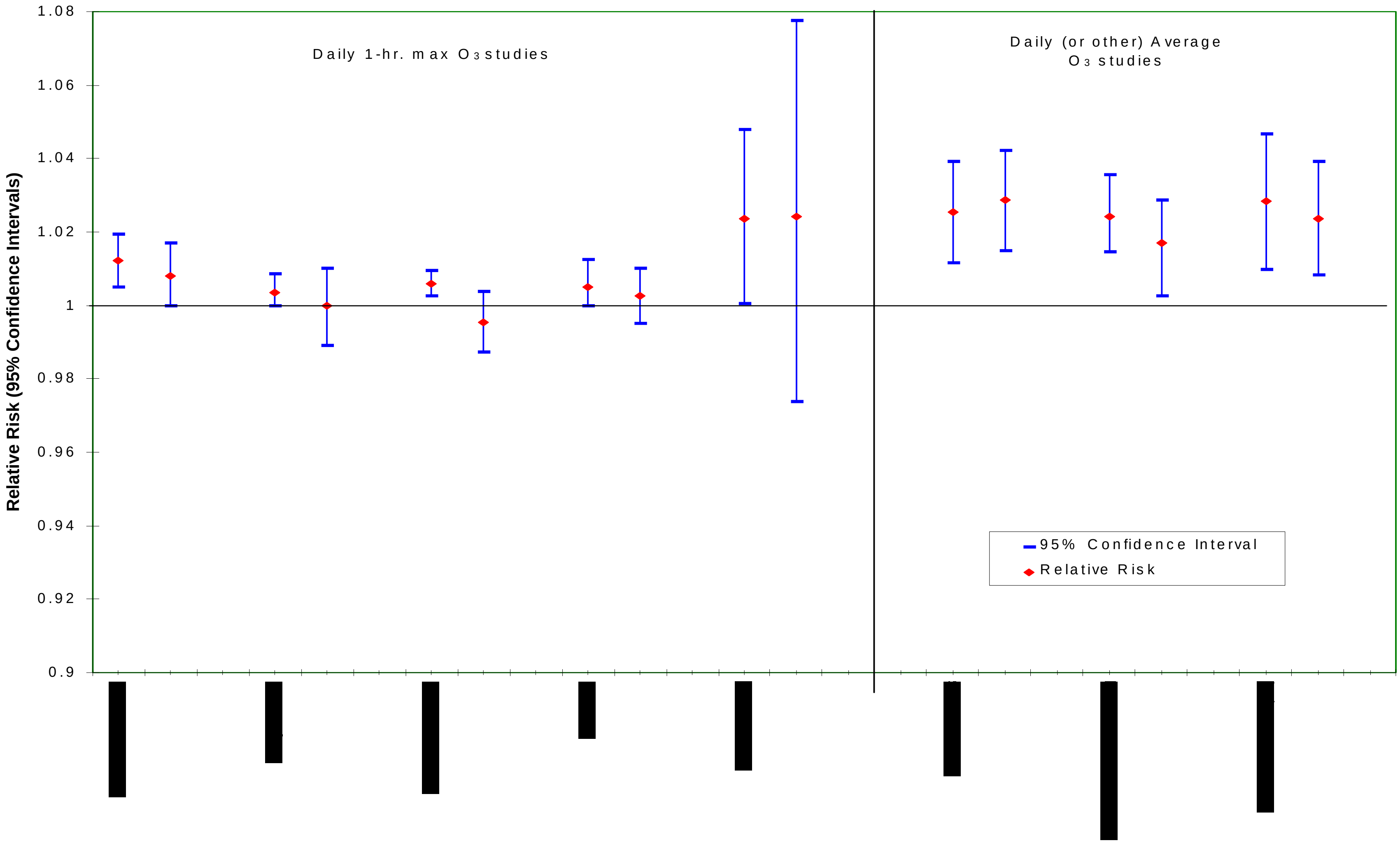
- copollutant air quality
- confounding effects of weather and season on mortality.

Ozone is a photochemically formed pollutant, so its presence and level of concentration are inevitably related to meteorological conditions, such as heat waves, that may themselves contribute to mortality risks, as well as to other air pollutants, such as some types of fine particulates, that tend to form and accumulate under similar conditions. Because particulate matter has been found to be associated with mortality risks, it is important to control for particulate matter concentrations when analyzing the potential mortality risk associated with ozone if the two pollutants are correlated. Some studies (listed in Table 1) have done this and some have not. Ozone and particulate matter are more highly correlated in some locations than in others. Examining results obtained for both pollutants in copollutant models across different locations may help sort out whether there appears to be an independent effect of each pollutant.

Figure 1 shows relative risks associated with a 25 ppb increase in ozone based on the results of single pollutant (ozone only) models and copollutant (ozone and PM or some proxy for PM) models from the same study, for several studies. In six out of the eight studies, the relative risk for ozone from a single pollutant model is higher than the relative risk for ozone from a copollutant model. In two cases (Anderson et al., 1996, and Verhoeff et al., 1996), however, the relative risk for ozone from the copollutant model is higher. The addition of PM or a proxy for PM to the model also increases the width of the 95% confidence interval of the relative risk for ozone in many (although not all) cases. The graph indicates that the association between ozone and mortality cannot be wholly attributable to confounding effects from PM.

All the studies reported in Table 1 have at least included a measure of daily temperature in the analysis, but the treatment of daily weather conditions and seasonal patterns in the data varies in the level of statistical sophistication. More recent studies tend to explore these potentially confounding factors more thoroughly with techniques such as smoothing to remove seasonal trends and nonlinear modeling to account for the effects of temperature extremes on daily mortality risks. A few authors have noted that a high level of collinearity between daily ozone and daily temperature in their data has made it difficult to draw conclusions about whether there may be an independent effect of ozone on mortality risk. For example, Sartor et al. (1995) noted that the high correlation between ozone and temperature made the models unstable when

Figure 1: Relative Risks of Mortality Associated With a 25 ppb Increase in Ozone from Ozone-Only Models (Left Bar) and Copollutant Models (Right Bar)



both of these variables were included, although the association was evaluated for only one summer. Shumway et al. (1988) also noted problems with high collinearity between temperature and ozone. All of the studies selected for the quantitative assessment included variables for daily temperature and seasonal trends in the ozone model. Sine/cosine functions have been frequently used to adjust for seasonal trends in daily mortality. Several of the studies, especially those using at least six years of daily data, found a statistically significant ozone effect after carefully controlling for daily weather conditions and seasonal patterns in the data.

Several of the studies considered different model specifications of weather, with varying degrees of complexity. The study that focused most particularly on the sensitivity of the air pollution-mortality relationship to different methods of controlling for weather (Samet et al., 1996, 1997) found that the approach used to characterize weather had no meaningful effect on relative risks associated with air pollution. This is consistent with a similar finding that the PM/mortality relationship was relatively insensitive to different methods of adjusting for weather (U.S. EPA, 1996).

1.3.2 Power of the studies

The effects of air pollutants on daily mortality incidence in a population are likely to be small compared to all the other factors that affect daily mortality incidence. It therefore takes a considerable amount of data for the effect to be measurable at a level of statistical significance, even if the effect is real. There is no set rule as to how many observations are needed, but most daily time-series studies use at least one to three years of data. The datasets have tended to become larger in more recent studies as longer series of air quality monitoring data have become available over time.

Table 2 illustrates an interesting relationship across the studies in Table 1; those with more years of data tend to be more likely to report a statistically significant ozone effect on daily mortality. Of the seven studies since 1995 that report finding no statistically significant ozone effect, the average number of years of data was less than four. Of the 13 studies since 1995 that report a statistically significant ozone effect, the average number of years of data was about 10. A similar pattern is seen in the pre-1995 studies. Table 2 is a simplistic analysis of this issue, but the pattern illustrated is suggestive of the possibility that it takes many years of data before the ozone effect can be separated from the daily weather and seasonal patterns with which it tends to be correlated.

1.3.3 Consistency and coherence of the studies

Consistent and coherent epidemiological findings in repeated studies in various locations also support an inference of causality in the observed relationship between ozone and mortality. Thus, a key consideration in the evaluation of the epidemiological studies is the consistency and coherence of the findings to date. The evaluation of consistency and coherence relies on a series of judgments of the quality literature and thus must be a qualitative one.

Consistency refers to whether the estimated relationship between ozone and mortality is similar across different locations and circumstances. This does not mean that the findings have to be identical for each study because there are many legitimate reasons why an ozone effect on mortality incidence may vary from location to location, including variations in lifestyle and climate that may affect the population's exposure to outdoor air pollutants. However, if there truly is a causal relationship, we would expect to see repeated findings of a statistically significant relationship of a reasonably comparable magnitude in many different studies.

Table 2. Years of Data Used versus Finding a Statistically Significant Ozone Coefficient

Study Finding Regarding Ozone Effect	Studies Released Before 1995		Studies Released 1995 to 1997	
	Number of Studies*	Mean Number of Years of Data**	Number of Studies	Mean Number of Years of Data
No Statistically Significant Effect	4 studies	3.0 years	7 studies	3.7 years
Statistically Significant Effect	2 studies	8.0 years	13 studies	9.9 years

*Two studies did not report quantitative results or did not report sufficient information to determine whether results were statistically significant. The total number of studies in this table therefore is 26.

** A few studies reported that their data sets contained less data than the number of calendar years that they covered because of missing data. For example, Kinney et al. (1995) used six years of calendar data, but had only every six day PM_{10} measurements; their effective amount of data was therefore only one year. The figures reported here reflect the effective amount of data when sufficient information is reported by the authors to make an adjustment.

Of those studies selected (discussed in the following section) that meet the criteria for the quantitative assessment, several do not find a statistically significant effect of ozone on mortality. Of those that find a statistically significant effect, the magnitude of the effect is roughly comparable. Figures 2 and 3 show the estimated relative risk and 95% confidence interval for a 25 ppb change in ozone concentration from each of the studies in Table 1 that reports quantitative results. These figures show both the results selected for the quantitative assessment as well as those that were eliminated for one reason or another. Figure 2 shows the results estimated for daily high-hour ozone concentrations. Figure 3 shows the results estimated for a daily average ozone concentration. These are shown on separate graphs because a 25 ppb change in the daily high-hour is not comparable to a 25 ppb change in the daily average; these two sets of relative risk results, therefore, are not directly comparable.

The studies are suggestive of a consistent association, but uncertainties remain. It is possible that the inconsistencies between the studies are due to some of the factors discussed

Figure 2: Results of Epidemiology Studies on Daily 1-Hour Maximum Ozone and Daily Mortality: Relative Risk and 95% CI for a 25 ppb Increase in O_3

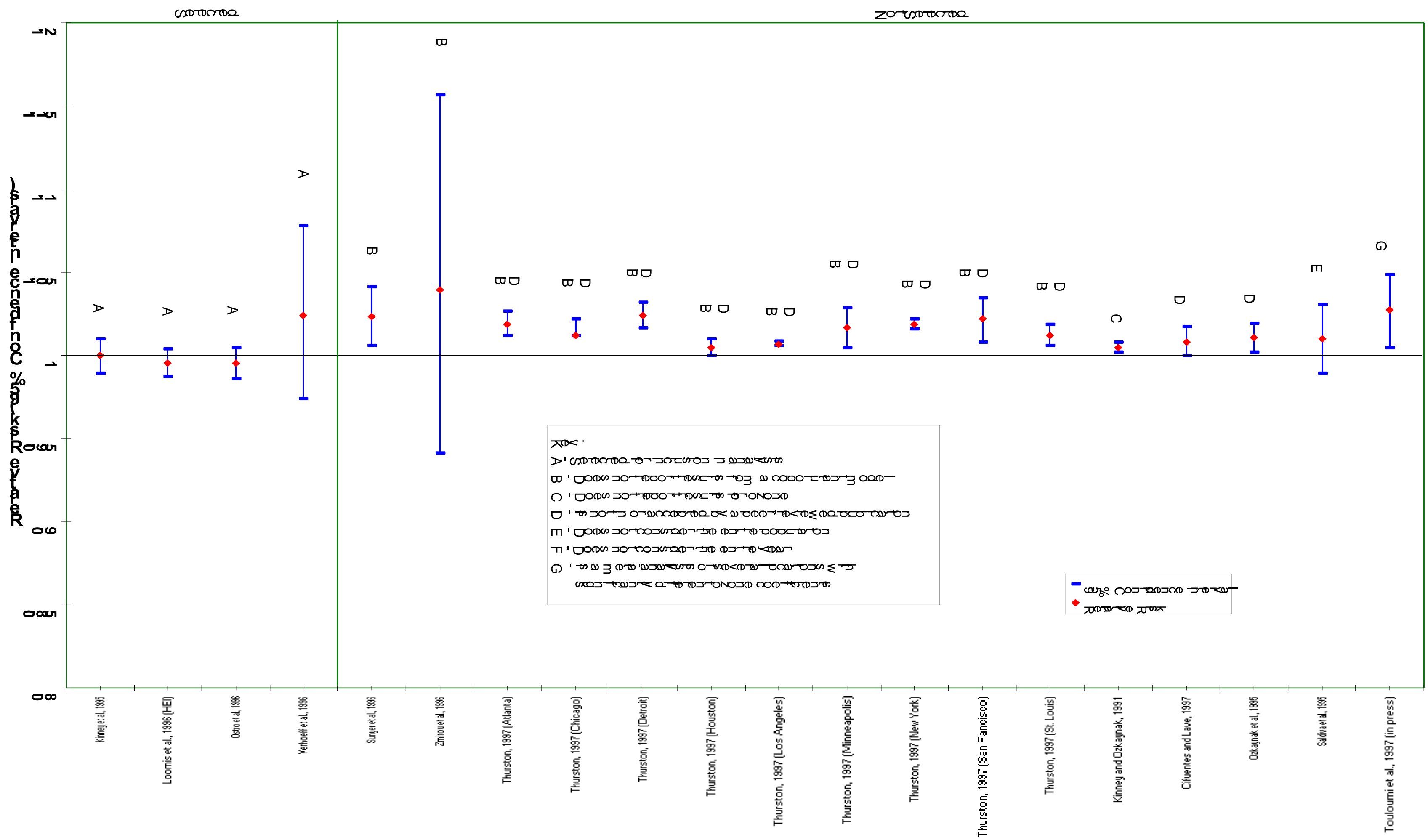
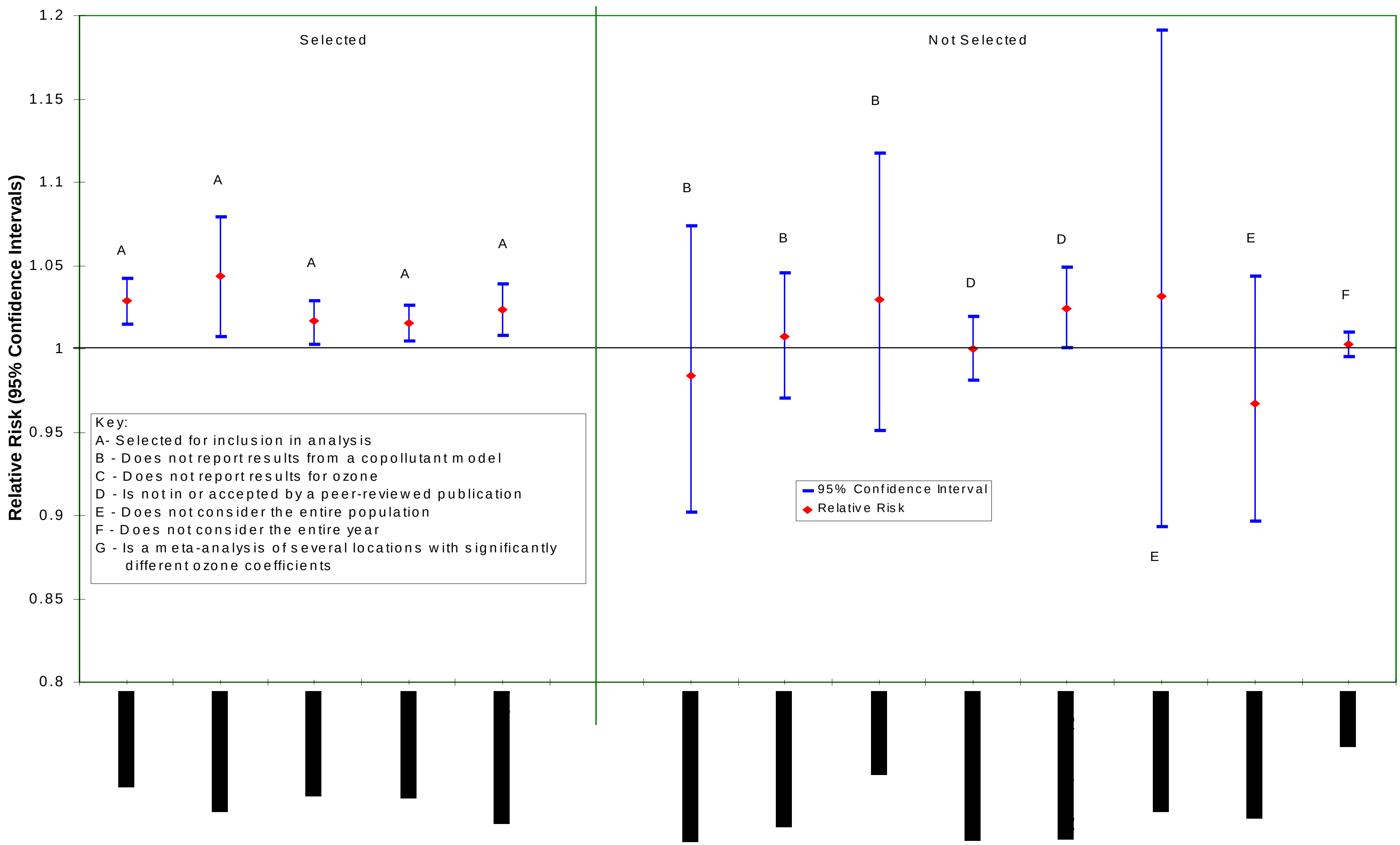


Figure 3: Results of Epidemiology Studies on Daily (or Other) Average Ozone and Daily Mortality: Relative Risk and 95% CI for a 25 ppb Increase in O_3



previously, such as statistical power. Nevertheless, although the studies point to the likelihood of an effect, it still cannot be concluded that there is an unambiguously statistically significant relationship between ozone and mortality. The quantitative assessment methodology takes the uncertainties into account by reflecting the full range of the findings, including those studies that do not find a statistically significant ozone-mortality relationship.

Coherence refers to whether the ozone mortality relationship makes sense given other available evidence concerning health effects associated with ozone exposure. All of this evidence is fully reviewed in the ozone criteria document (U.S. EPA, 1996). There is a wide range of evidence that ozone is an irritant to the respiratory system, including evidence from clinical, laboratory, and epidemiologic studies. Health effects of a serious nature have been associated with daily fluctuations in ozone concentrations, including respiratory hospital admissions and aggravation of chronic respiratory diseases such as asthma. There is at this time no clearly delineated biological mechanism that can explain how ozone exposure may result in premature mortality, but it is plausible that such a relationship may exist given the other available evidence of ozone health effects.

1.4 Key uncertainties in ozone mortality benefits estimation

For a quantitative assessment of the reduction in premature mortality expected as a result of the proposed changes to the NAAQS, we want to answer the following question: How many additional premature deaths will be avoided for each of the standard alternatives under consideration, relative to what would be expected under current standards?

One of the strengths of epidemiology studies is that they analyze actual mortality incidence in human populations at ambient pollution concentrations. Subjects are studied in their normal environment and the mortality incidence is directly observed. A major challenge for epidemiology studies is the difficulty in isolating with confidence the effects of a specific air pollutant such as ozone when this may be just one of many complex factors that influence human mortality.

Any quantitative mortality risk assessment faces challenges in the form of incomplete information, making it necessary to employ a variety of assumptions. Most of the assumptions necessary in the quantitative assessment of changes in mortality incidence in association with alternative NAAQS for ozone are the same as those required for all of the health effects estimates based on epidemiologic studies.

The concentration-response function is a key element of the quantitative assessment. The accuracy the assessment depends, in part, on (1) how well the concentration-response functions used in the assessment have been estimated (e.g., whether they are unbiased estimates of the relationship between mortality and ambient ozone concentration in the original study locations), (2) how applicable these functions are to locations and times other than those in which they were estimated, and (3) the extent to which these relationships apply to the range of the ozone concentrations to which they are being applied in the assessment.

2.0 SELECTION CRITERIA FOR QUANTITATIVE ANALYSIS

Several criteria were used to select studies for inclusion in the quantitative analysis, and, within selected studies, to select from among several reported results. A study was included in the quantitative analysis only if it:

1. measures daily mortality (i.e., is a time series study)
2. reports quantitative results for ozone
3. is in or has been accepted by a peer-reviewed publication
4. reports results from a copollutant model, including PM or some proxy for PM in the model with ozone, as well as some measure of temperature and season
5. considers the entire population (rather than only a subset of the population) in the study location
6. considers the whole year (rather than only a season or seasons)
7. considers only a single location or, if it is a meta-analysis of several locations, has been unable to reject the hypothesis that the ozone coefficient is the same in all locations considered.

The reasonable selection of a single ozone result from among two or more ozone results reported in the same study is facilitated, in almost all cases, by the following two criteria:

8. PM (PM_{10} or $PM_{2.5}$) is preferable to other measures of particulate matter
9. More pollutants in the model is preferable to fewer pollutants.

Each of these study and result selection criteria is discussed more fully below. Reporting a statistically significant positive result for ozone is not a criterion for study selection, nor does statistical significance or size of coefficient (or relative risk) affect the criteria for result selection within a study. Table 3 lists the final selection of studies and, for each study selected, the final selection of ozone results. Figure 4 depicts the selected ozone results as the relative risks (and 95% confidence intervals) associated with a 25 ppb increase in ozone. Figures 2 and 3 show that the studies eliminated because of the quantitative assessment selection criteria did not on the whole find substantially higher or lower ozone effects than the selected studies.

Table 3: Studies and Ozone Results Selected for Quantitative Analysis of the Relationship between Daily Mortality and Exposure to Ambient Ozone*

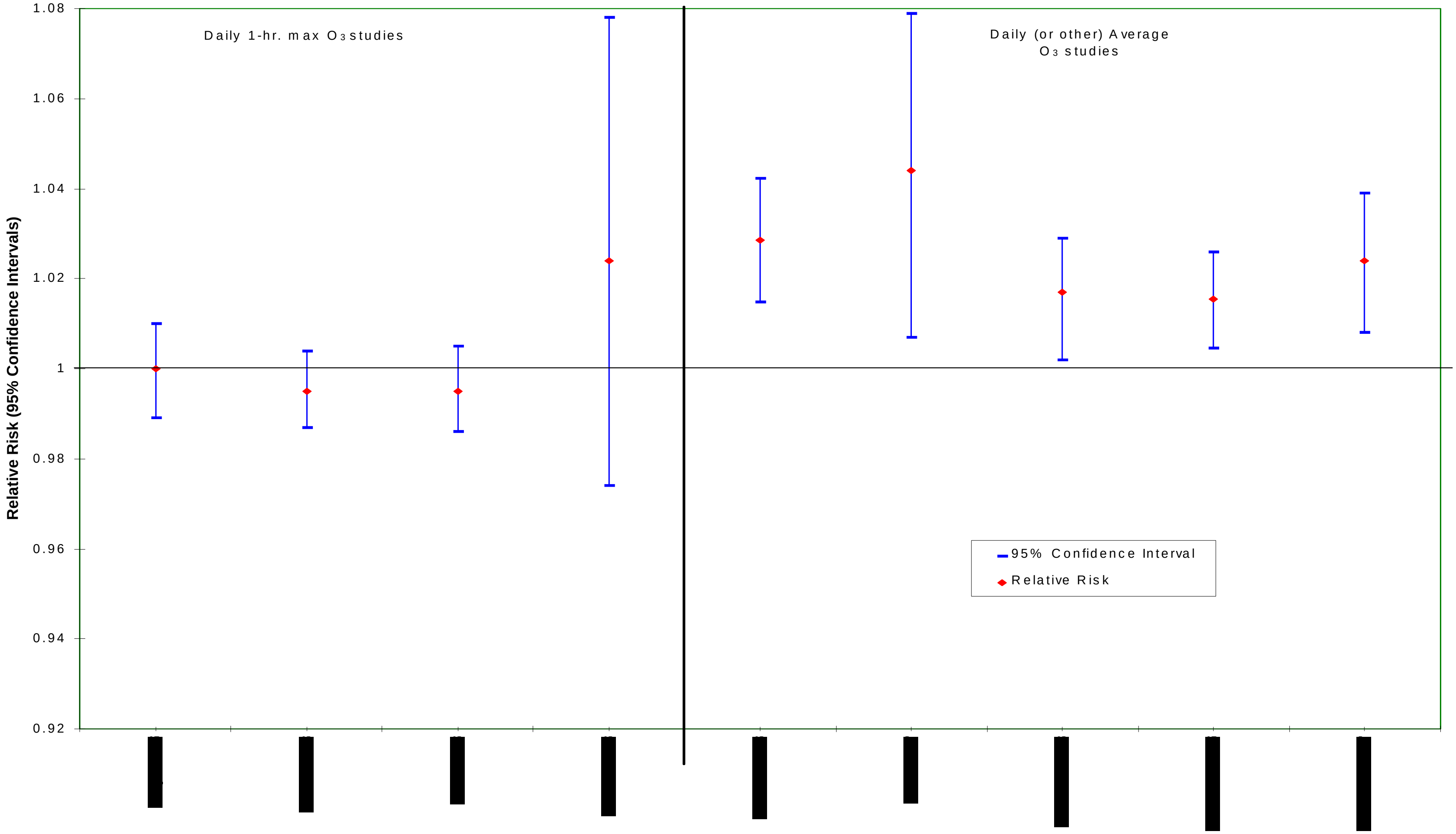
Study	Study Location/ Duration	Copollutants in model	Means and Ranges (or Std. Devs.) of PM (or Proxy) ($\mu g/m^3$) and O_3 (ppb)**	O_3 Exposure Measure (ppb)**	Ozone Lag	Relative Risk and 95% CI for a 25 ppb Increase in O_3**	Comments
Anderson et al., 1996 (APHEA project)	London 1987-1992	black smoke	black smoke: 14.6 (3-95) O_3 8-hr avg: 15.5 (1-74)	8-hr avg (1 day lag)	none	1.029 (1.015 — 1.042)	Authors note that ozone effect remains significant after NO_2 and SO_2 are added to the model.
Kinney et al., 1995***	Los Angeles County 1985-1990	PM_{10}	PM_{10}: 58 (15-177) O_3 1-hr max: 70 (3-201)	daily 1-hr max	1-day lag	1.000 (0.989 — 1.010)	
Loomis et al., 1996 (HEI)****	Mexico City 1991-1992	TSP, SO_2	TSP: n.a. (86-460) O_3 1-hr max: n.a. (26-319)	daily 1-hr max	none	0.995 (0.987 — 1.004)	(Results are taken from Table 14 in the paper.)
Ostro et al., 1996****	Santiago, Chile 1989-1991	PM_{10}	PM_{10}: 115 (30-367) O_3 1-hr max: 53 (11-264)	daily 1-hr max	1-day lag	0.995 (0.986 — 1.005)	The result from the Poisson regression model has been chosen.

Study	Study Location/ Duration	Copollutants in model	Means and Ranges (or Std. Devs.) of PM (or Proxy) (µg/m^3) and O_3 (ppb)**	O_3 Exposure Measure (ppb)**	Ozone Lag	Relative Risk and 95% CI for a 25 ppb Increase in O_3**	Comments
Verhoeff et al., 1996****	Amsterdam 1986-1992	PM_{10}	PM_{10}: 38 (n.a.-191) O_3 1-hr max: 22 (n.a. — 154) (converted from µg/m^3 to ppb)	daily 1-hr max	2-day lag	1.024 (0.974 -1.078)	O_3 was measured in µg/m^3. To convert to ppb, ozone concentrations in µg/m^3 were divided by 1.96 (see note at the end of the table). The result from the model with PM_{10} (rather than black smoke) has been chosen.
Hoek et al., 1997 (in press)	Rotterdam, The Netherlands 1986-1991	TSP (1 day lag) SO_2 (1 day lag)	TSP: 42 (21 — 287) O_3: 13.7 (0.5 — 67.3) (converted from µg/m^3 to ppb)	daily avg	1-day lag	1.044 (1.007 — 1.079)	O_3 was measured in µg/m^3. To convert to ppb, ozone concentrations in µg/m^3 were divided by 1.96 (see note at the end of the table).
Ito and Thurston, 1996	Cook County, Illinois 1985-1990	PM_{10}	PM_{10}: 40.7 ± 19.1 O_3: 38.1 ± 19.9	2-day avg	avg of 0-day and 1-day lags	1.017 (1.002 — 1.029)	

Study	Study Location/ Duration	Copollutants in model	Means and Ranges (or Std. Devs.) of PM (or Proxy) (μg/m^3) and O_3 (ppb)**	O_3 Exposure Measure (ppb)**	Ozone Lag	Relative Risk and 95% CI for a 25 ppb Increase in O_3**	Comments
The following studies will be used to generate a single distribution for Philadelphia:							
Moolgavkar et al., 1995***	Philadelphia 1973-1988	TSP, SO_2	TSP: n.a. (14.5 — 338) O_3: n.a. (0.0 — 159)	daily avg	1-day lag	1.0154 (1.0045 — 1.0260)	
Samet et al., 1996, 1997 (HEI)****	Philadelphia 1974-1988	TSP, SO_2, NO_2, LCO	TSP: 67.3 (14.5 — 222.0) O_3: 19.8 (0 — 90.0)	2-day avg	avg of 0-day and 1-day lags	1.024 (1.008 — 1.039)	The result from the model with several copollutants has been chosen.

* To be included among the studies used in the quantitative analysis, a study must satisfy all the study selection criteria; one study (Samet et al., 1996) satisfied the study selection criteria but was omitted from the quantitative analysis to avoid redundancy problems.
**Ozone was measured in μg/m^3 in Verhoeff et al.,1996, and Hoek et al., 1997. To convert to ppb (vol.), concentrations in μg/m^3 were divided by 1.96. The conversion factor depends on the temperature in the study area. At 0˚ C (32˚ F) the factor is 2.144. Schwartz, 1995 (a study of respiratory hospital admissions in New Haven, Connecticut and Tacoma, Washington) used 1.96 to convert from μg/m^3 to ppb. The mean temperature in each of these cities was given as 52˚ F (about 11˚ C). The mean (or median) temperatures given in the other locations for which conversions were necessary were about the same as in New Haven and Tacoma (Verhoeff et al., 1996 — 10˚ C; and Hoek et al., 1997 — 10˚ C).
***Results from study were quantified and monetized in the December 1996 RIA in support of Ozone NAAQS.
Neither the 812 Retrospective study (October 1996, Draft) nor the Ozone Staff Paper Risk Assessment use or cite any ozone-mortality studies.
****This study presents more than one ozone result. A single result has been selected (see Section 2.5: Selecting from among multiple results reported from a study: Criteria 8 and 9).

Figure 4: Results of Studies Selected for Inclusion in Quantitative Analysis: Relative Risks and 95% CI for a 25 ppb Increase in O_3



2.1 Basic inclusion criteria: Criteria 1, 2, and 3

The first three criteria are the basic criteria used to ensure that the studies have usable (quantitative) results on daily mortality and that the analyses are of peer-reviewed quality. To require that the results be quantitative does not need comment. There are a few studies that estimate the relationship between long-term (e.g., annual) ozone and mortality using cross-sectional analyses. Although these may be valid studies, the majority of studies estimate the relationship between daily ozone and daily mortality. Because the relationship between long-term ozone and mortality may be different from that between daily ozone and mortality, these two types of studies cannot be combined in a quantitative analysis. The preponderance of daily studies therefore indicates the exclusion of the long-term studies from this analysis.

2.2 Consideration of key covariates: Criteria 4, 8, and 9

2.2.1 Copollutants

There is substantial evidence that there is a relationship between particulate matter (PM) air pollution and mortality. Although there is always a potential problem of separating the effects of confounded copollutants, the evidence for an association between PM and mortality is, to date, greater than for other pollutants in the typical "air pollutant mix." To the extent that PM and ozone are correlated, omitting PM from the model could tend to bias the estimate of the ozone coefficient. To avoid falsely attributing PM effects to ozone, it was required that any ozone result included in the analysis be from a model that included PM or some proxy for PM in the model (Criterion 4). (See Figure 1 for a comparison of ozone results with and without a PM measure in the model.) Because PM is clearly preferable to a proxy for PM, when there was a choice between the two, the model with PM was chosen (Criterion 8).

For the same reason that models with PM or a proxy for PM were required, models with more pollutants were preferred over models (in the same study) with fewer pollutants (Criterion 9). The omission of a pollutant that may be correlated with both ozone and mortality could result in biased estimates of the ozone coefficient (and other coefficients) in the model. Because the evidence for an association with mortality is strongest for PM, the inclusion of other pollutants in the model was not a study selection criterion; however, in choosing among multiple models within a single study, it provides a reasonable criterion by which to select a single, preferable result.

2.2.2 Weather and seasons

Many studies have noted the correlation between weather variables (temperature, in particular) and ozone, as well as the seasonality of ozone (which peaks in the summer). Because temperature is known to be associated with mortality, and because mortality is known to have an annual cycle, it is essential that temperature and seasonality be controlled in the model.

2.3 Consistency criteria: Criteria 5 and 6

Like the first criterion, Criteria 5 and 6 ensure that all the studies included in the quantitative analysis are measuring the same thing: the relationship between daily ozone concentrations and daily mortality for the entire population in a location over the course of the year. The few studies that analyzed separate seasons do not show a consistent pattern. In addition, statistically significant results are not limited to the "high" ozone season. Limiting the analysis to individual seasons, however, substantially reduces the number of observations, thereby also reducing the power of the analysis to detect effects. For consistency with the annual air quality analysis of proposed changes to the NAAQS, and to ensure that a minimum of a full year of data are included in the analysis, Criterion 6 requires that the result is based on a full-year analysis rather than a season-specific analysis. Because most studies that report season-specific results also report full-year results, this criterion serves more as a means of selecting from among multiple results from within a study than as a means of selecting studies.

Most studies estimated the ozone-mortality relationship for the entire population in a location. Because this relationship may vary by age group, it would be inconsistent to pool the results of all-population studies with those from studies limited to certain age groups. Therefore Criterion 5 requires that the results apply to the entire population rather than to a subset of the population.

2.4 Ensuring that each study represents a single location: Criterion 7

Criterion 7 excludes any study that is itself a pooling of the results from several separate locations with statistically significantly different ozone-mortality relationships. The reason for this criterion goes beyond consistency and has to do with the necessity of assigning weights to the studies that are input to the quantitative analysis, described in Section 4. There is no clear way to assign a weight to a meta-analysis when pooling its results with the results of single-location studies. (If the meta-analysis was unable to reject the hypothesis that all locations considered were the same, then it could be treated as a single-location study, making it roughly comparable to other single-location studies.)

In pooling the results of multiple studies, the quantitative analysis (described in Section 4) assigns a random effects weight to each study. Random effects weights are designed to give less weight to a coefficient from a study the greater its standard error, and to reflect the lower reliability of estimates with larger standard errors. The standard error associated with an estimate is the square root of the "within-study variance" of a single-location study. The greater the within-study variance, the less reliable the study result. The within-study variance of a meta-analysis, however, has two components: the standard errors of the estimates of location-specific coefficients in the meta-analysis (the within-study variances), and the between-location variance. Only the first component reflects true uncertainty and the corresponding lack of reliability of estimates. The second component reflects actual variability among locations. This variability among locations within the meta-analysis does not imply uncertainty or a lack of reliability. The "within-study variance" of a meta-analysis is therefore not comparable to the within-study variance of a single-location study. A random effects weight applied to a meta-analysis as if it were a single-location study would therefore give too little weight to the study. The correct weighting scheme to incorporate the results of a meta-analysis is unclear.

Only one ozone-mortality meta-analysis (Touloumi et al., 1997) is in the literature. Because this study rejected the hypothesis that the ozone-mortality relationship is the same in all the locations considered (several cities in Europe), it cannot be included in the quantitative analysis as if it were a single location. The results of this study, however, are presented separately.

2.5 Selecting from among multiple results reported from a study: Criteria 8 and 9

Several studies report results from more than one analysis satisfying the first seven criteria (e.g., if they consider several different models). Loomis et al. (1996) report relative risks from many different models. However, according to Criterion 9, the result from a model that includes both TSP and SO_2 is selected over the other results reported in that study. Verhoeff et al. (1996) report an ozone relative risk from a model in which particulate matter is measured as black smoke and one from a model in which particulate matter is measured as PM_{10}. According to Criterion 8, the result from the model with PM_{10} is selected. Samet et al. (1997) report an ozone result from a model including TSP and one from a model in which TSP, SO2, NO2, and LCO are all included in the model with ozone. According to Criterion 9, the latter result is selected.

After consideration of Criteria 8 and 9, only one study among those satisfying Criteria 1 through 7 with more than a single ozone result remains. Ostro et al. (1996) report results from both OLS and Poisson regression models. Because there is no obvious way to select between these two models, consistency with other studies is used as a criterion. Because the Poisson regression model is more commonly used, the result from the Poisson regression model is selected over the OLS result in Ostro et al. (1996). (Because the results of the two models are very similar, the selection of one model over the other will make little difference in the analysis.)

3.0 SUMMARY OF SELECTED STUDIES

3.1 Anderson et al., 1996. Air pollution and daily mortality in London: 1987-92

This study was one of several studies in the APHEA collaborative project investigating the relationship between daily levels of air pollutants and daily mortality in cities throughout Europe. A time series of daily counts of mortality for all ages and all causes of death except accidents was constructed for the Greater London area from April 1987 to March 1992. Data on mean daily temperature and humidity were obtained from central London. Both eight hour (9 a.m. to 5 p.m.) average and daily 1-hour maximum ozone concentrations were measured at a single monitor located near Victoria station in central London. Concentrations of nitrogen dioxide (daily average and daily 1-hour maximum), black smoke (daily average), and sulfur dioxide (daily average) were also monitored. The statistical analysis followed the APHEA protocol. Daily death count was the dependent variable in autoregressive log-linear regression models with Poisson errors ("Poisson regression" models). Independent variables included temperature and humidity and the various pollution variables (although not all pollution variables were included in all models), as well as adjustments for time and seasonal trends, day of the week, holidays, and an influenza epidemic that occurred during the study period. The authors reported that the "U-shaped" relation between daily temperature and mortality was best adjusted for by fitting three separate linear terms for (1) < 5° C, (2) > 20° C, and (3) 5-20° C. Relative humidity was adjusted for by a single linear term.

Both 8-hour average and 1-hour maximum ozone were considered in single-pollutant models; 8-hour average ozone was also considered in models that included black smoke. In the single-pollutant models, both 8-hour average and daily 1-hour maximum ozone were statistically significant. The authors reported a relative risk of 1.024 [95% C.I. (1.011, 1.038)] when ozone was measured as an 8-hour average, and a relative risk of 1.026 [95% C.I. (1.013, 1.039)] when ozone was measured as a daily 1-hour maximum, associated with an increase from the 10th to the 90th percentile concentration (an increase of 24 ppb for the 8-hour average and 31 ppb for the 1-hour maximum). When black smoke was also in the model with 8-hour average ozone, the relative risk became 1.027 [95% C.I. (1.014, 1.041)].

3.2 Kinney et al., 1995. A sensitivity analysis of mortality/PM_{10} associations in Los Angeles

This study investigated the relationship between daily mortality (excluding suicides, accidental deaths, and nonresident deaths) and daily pollution in Los Angeles County from January 1, 1985, to December 31, 1990. Because the focus of the paper was on the sensitivity of the PM_{10}/mortality associations to the analytic methods used, however, the time series of data used comprised only those days with PM_{10} data (364 days). Death counts were obtained from the National Center for Health Statistics death certificate tapes. Data on 24-hour average PM_{10} (collected every six days), daily 1-hour maximum O_3, and daily 1-hour maximum CO were obtained from the U.S. Environmental Protection Agency's Aerometric Information and Retrieval System (AIRS). The PM_{10} data were taken from monitors at four sites, and the data on O_3 and CO were each collected from monitors at eight sites. In a single pollutant model with only ozone, and with same-day temperature and relative humidity and sine/cosine functions to adjust for seasonal trends, the relative risk associated with a 143 ppb increase in ozone was 1.02 [95% C.I. (1.00, 1.05)]. In a copollutant model with both ozone and PM_{10}, and with the same weather and season variables as in the single pollutant model, the relative risk became 1.00 [95% C.I. (0.94, 1.06)]. The authors concluded that "the O_3 effect on mortality, if any, is weaker than that of PM_{10}."

3.3 Loomis et al., 1996. Ozone exposure and daily mortality in Mexico City: A time-series analysis

This study was conducted under the auspices of the Health Effects Institute (HEI). Daily death counts in Mexico City's Federal District (which includes about half of the population of

Mexico City's metropolitan area) were obtained for the period from 1990 through 1992 from the Instituto Nacional de Estadistica, Geografia, e Informatica. Daily levels of SO_2, CO, O_3, and nitrogen oxides, as well as several meteorological variables, were taken from nine monitoring stations. TSP was measured at 19 monitoring stations. Although the authors describe the "basic metric of exposure" to ozone as the daily 1-hour maximum, four other measures of ozone, including the daily average, were also examined. The basic model used was the Poisson regression model. Daily death counts were regressed on pollution variables as well as minimum temperature and several time-related variables, including a sine-cosine function to remove seasonal trends. The results of a variety of models (considering different types of mortality, different age groups, different regions within Mexico City, different lag structures for pollutants, different combinations of pollutants and other variables, different measures of ozone, and variations on the functional form) are reported. Although the ozone effect was positive and statistically significant in a few single pollutant models, it was generally not significant in copollutant models.

3.4 Ostro et al., 1996. Air pollution and mortality: Results from a study of Santiago, Chile

This study investigated the relationship between daily death counts in metropolitan Santiago (excluding accidental deaths and deaths of residents that occurred outside the metropolitan area) and daily air pollution levels for 1989 through 1991. Because of missing data, however, data were available for all pollutants and for weather variables on a total of 779 days. Data were collected on PM_{10} (daily average), SO_2 (1-hour maximum), NO_2 (1-hour maximum), and O_3 (1-hour maximum), as well as daily minimum and maximum temperature and daily average humidity. Ordinary Least Squares (OLS) regression and Poisson regression were both used to examine the relationship between mortality and air pollution. Although most emphasis was placed on PM_{10}, the investigators conducted several sets of sensitivity analyses, one of which considered the effects of pollutants other than PM_{10}. Each of the other pollutants was considered both with and without PM_{10} in the model. In all cases, one-day lagged minimum temperature and binary variables for the hottest and coldest 10% of the days, as well as seasonal adjustments, were included. The relative risk associated with an increase of 52.8 ppb ozone in the single pollutant (ozone only) model for the summer only was 1.02 and was marginally statistically significant [95% C.I. = (1.00-1.05)]. The relative risk from the corresponding copollutant model (summer only) was still 1.02 but was no longer statistically significant. Relative risks from full-year models were not significant.

3.5 Verhoeff et al., 1996. Air pollution and daily mortality in Amsterdam

Daily death counts for the city of Amsterdam were obtained from the Municipal Population Register for the period 1986-1992. (Because the mortality data did not contain cause of death, accidental deaths presumably were not removed from the data.) Air pollution monitoring data were obtained from the Amsterdam Environmental Research Institute. Black smoke was measured daily at four sites throughout the study period; TSP was measured every 3 days at four sites from 1986 to 1988; in 1988 this was changed to PM_{10}. SO_2, CO, and O_3 were measured continuously at 11, 5, and 5 sites, respectively. Because TSP and PM_{10} were highly correlated during the period in which both were measured (Pearson correlation coefficient = 0.95), TSP concentrations measured during 1986-1988 were converted into PM_{10} concentrations via linear regression. With the exception of O_3, which was measured as the daily 1-hour maximum, all pollutants were measured as daily averages. Daily average concentrations of black smoke and TSP were also available in the city of Rotterdam (about 80 km from Amsterdam) during the entire study period. Because these were correlated with the corresponding concentrations in Amsterdam (r = 0.6 for black smoke and r = 0.85 for TSP), the Rotterdam data were used to predict daily concentrations of black smoke and PM_{10} in Amsterdam when local data were unavailable.

The effects of air pollution on daily mortality counts were examined using Poisson regression in models that included, in addition to pollutants, both weather variables and variables to account for seasonal and other time trends. Two dummy variables were created to characterize "warm" and "cold" days. The "warm" dummy was set to 0 if temperature was $\leq$ 16.5° C; it was set to temperature minus 16.5° C otherwise. The "cold" dummy was similarly assigned a zero if temperature was $\geq$ 16.5° C and was set equal to 16.5° C minus temperature otherwise. Temperature lags of up to 2 days were considered. When same-day ozone, 1 day lagged ozone, and 2 day lagged ozone were each considered in single pollutant models, the relative risks associated with a 100 $\mu g/m^3$ increase in ozone were all greater than 1.0 (1.018, 1.001, and 1.049, respectively). However, only the relative risk for the 2 day lagged ozone was statistically significant. When 2 day lagged ozone and PM_{10} were both included in a model, the relative risk associated with a 100 $\mu g/m^3$ increase in ozone was 1.050, although it was not statistically significant.

3.6 Hoek et al., 1997 (in press). Effects of ambient particulate matter and ozone on daily mortality in Rotterdam, the Netherlands

This study investigated the relationship between daily mortality and daily air pollution in Rotterdam from 1983 to 1991, although consistent data on the gaseous pollutants (SO_2, CO, and O_3) were available from only 1986 to 1991. Daily death counts, including only deaths of residents of Rotterdam but without information on cause of death, were obtained from the Municipal Registry of the city of Rotterdam. Data on daily TSP and black smoke concentrations were obtained from the Rijnmond Environmental Protection Agency (DCMR). Data on daily SO_2, CO, and O_3 were obtained from the National Air Quality Monitoring Network of the National Institute of Public Health and the Environment (RIVM). Each of these monitoring networks has one site in the center of Rotterdam. Poisson regression models, including weather variables (temperature and relative humidity) and adjustments for long-term trends, seasonal trends, and influenza incidence, were used to examine the association between air pollutants and mortality. The authors note that the association between temperature and mortality in the Netherlands is "highly nonlinear." They therefore use nonparametric smoothers to adjust for temperature. Although concentrations of TSP, black smoke, SO_2 and CO were all positively correlated, ozone concentration was negatively correlated with the other pollutants. Ozone, lagged one day, was significantly associated with mortality in a two pollutant model that included TSP. The relative risk for an increase from the 5th percentile to the 95th percentile ozone concentration (an increase of 34.2 ppb) was 1.06 (95% C.I. = [1.01, 1.11]).

3.7 Ito and Thurston, 1996. Daily PM_{10}/mortality associations: An investigation of at-risk subpopulations

This study analyzed the relationship between daily mortality and air pollution in Cook County, Illinois, from 1985 to 1990 for the total population and for racial and gender subpopulations. (Results discussed here are for the whole population.) Because Cook County encompasses the city of Chicago, it has the third largest urban population in the nation. Daily death counts were obtained from the National Center for Health Statistics (NCHS). Accidental deaths and deaths occurring outside the county of residence were excluded. Data on PM_{10} (from six sites), SO_2 (from five sites), CO (from three sites), and O_3 (from five sites) were obtained from EPA's Aerometric Information Retrieval System (AIRS). The authors used Poisson regression models, including weather and pollutant variables, and sine/cosine series to adjust for long-term and seasonal trends, a linear time trend variable, and day-of-week dummy variables. The authors investigated several different specifications of temperature and found that a parabolic, "dual-lag" structure fit the best. This adjustment for temperature was used in all the analyses. Among the pollution variables, PM_{10} and O_3 (2-day averages) were most consistently associated with mortality. In single pollutant models, with weather and time- and seasonal-trend adjustments, PM_{10} and O_3 were each significantly associated with mortality. When PM_{10} and O_3 were both in the same model, the relative risks associated with each were slightly smaller but still statistically significant [for PM_{10}, RR = 1.04; 95% C.I. = (1.01, 1.07) for an increase of 100 $\mu g/m^3$; for ozone, RR = 1.07 95% C.I. = (1.01, 1.12) for an increase of 100 ppb]. PM_{10} and O_3 were negatively correlated (r = -0.37).

3.8 Moolgavkar et al., 1995. Air pollution and daily mortality in Philadelphia

This study analyzed the relationship between daily mortality and air pollution in Philadelphia from 1973 through 1988. Daily death counts were obtained from the National Center for Health Statistics. Accidental deaths and suicides were excluded. In contrast to some other studies, however, these authors chose not to exclude deaths in Philadelphia of nonresidents or deaths of Philadelphia residents that occurred outside of Philadelphia. Air pollution measurements were obtained from EPA's AIRS. Daily averages (averaged over all monitors) of TSP, SO_2, and O_3 were used in the analyses. All analyses used Poisson regression models, which included quintiles of temperature and indicators for years. Most analyses were done separately by season. In single pollutant models, ozone was associated with mortality only in the summer, defined as June, July, and August [RR = 1.15, 95% C.I. = (1.09, 1.21) for an increase of 100 ppb in the previous day's ozone]. The summertime association of ozone with mortality persisted, however, when the other two pollutants were added to the model [RR = 1.15, 95% C.I. = (1.07, 1.24)]. One analysis treated the entire dataset of 16 years as a single time series (not separated into seasons). In this analysis, indicator variables were used to adjust for seasons and for years, and quintiles of temperature within season were also included. All three pollutants were included in the model. The relative risk associated with a 100 ppb increase in the previous day's ozone was 1.063 [95% C.I. = (1.018, 1.108)].

3.9 Samet et al., 1996, 1997. Particulate air pollution and daily mortality: Analyses of the effects of weather and multiple air pollutants

This study reports the results of Phase I.B of the Particle Epidemiology Evaluation Project, sponsored by the Health Effects Institute (HEI). Analyses were based on time series of mortality and air pollution data from 1974 through 1988 in Philadelphia. Data on TSP, $SO_{2,}$ $NO_{2,}$ CO, and O_3 were obtained from EPA's AIRS. The concentrations of TSP, SO_2, NO_2, and CO were "moderately" correlated with one another; ozone concentration was correlated with concentrations of the other pollutants to a much lesser degree. The signs of the correlations of ozone and the other pollutants varied by season. Ozone was negatively correlated with each of the other pollutants in the winter and positively correlated with each in the summer. (The signs of the correlations for spring and fall varied by pollutant.) Ozone was, in general, not highly correlated with TSP. The correlations of largest magnitude were in the winter and summer (-36.7 in winter, and 36.8 in summer). Based on preliminary explorations, two-day averages (i.e., averages of same day and previous day pollutant levels) were used for all pollutants. Although several models were analyzed, all were of the Poisson regression form.

Particular emphasis was placed on adjustments for weather. In the final model, a nonlinear adjustment for temperature was approximated by four linear terms corresponding to specified temperature cutpoints. Multipollutant models included TSP, SO_2, NO_2, CO, and O_3 and controlled for weather and long-term trends. Unmeasured time trends were controlled for by smoothing spline functions of time. Based on a series of preliminary analyses, the final model included separate effects of TSP for three age groups, and all-age effects of each of the other pollutants, as well as variables for weather and time trends. The relative risk of ozone-related mortality associated with an increase of one interquartile range (20.2 ppb) of ozone reported from this model was 1.019 [95% C.I. = (1.007, 1.032)].

4.0 QUANTITATIVE APPROACH

The basic approach of the quantitative analysis is to use the selected ozone-mortality concentration-response relationships and their statistical confidence intervals to estimate a probability distribution of expected national incidence of ozone-related mortality associated with changes in ozone concentrations resulting from specified proposed NAAQS. The analysis may be thought of as having three basic steps. The first step is the selection of study results to include in the analysis, described in Section 2.

In the second step, a distribution of expected national incidence of ozone-related mortality associated with changes in ozone concentrations resulting from a specified proposed NAAQS is derived from each study. Given the ozone coefficient and standard error from a study, and given the appropriate air quality data, a distribution of the national incidence of ozone-related mortality is derived. This distribution describes the probability that the national incidence of ozone-related mortality associated with a given proposed NAAQS falls within any specified range, if the ozone coefficient appropriate for the entire nation is the ozone coefficient in the study location. If there are N studies in the quantitative analysis, N such distributions of national ozone-related mortality incidence are derived in step 2.

In the third step, a *single* distribution of expected national incidence of ozone-related mortality associated with changes in ozone concentrations resulting from a specified proposed NAAQS is derived from the N distributions derived in step 2. The first step, study and result selection, was described in Section 2. The second and third steps, and the basic assumptions underlying the quantitative analysis, are described below.

4.1 Assumption about underlying variability in the relationship between ozone and daily mortality: the fixed effects model versus the random effects model

It is possible that the relationship between ozone and daily mortality is the same everywhere — i.e., that there is a single ozone coefficient that all studies are attempting to estimate. If this is the case, differences in ozone coefficients reported by studies conducted in different locations are due to sampling error and differences in study design. If we believe this model, then we want an estimate of the ozone coefficient and a standard error of that estimate.

It is also possible, however, that the relationship between ambient ozone concentrations and daily mortality differs from one location to another (for example, because of differences in population composition and behavior patterns that may affect susceptibility and exposure to outdoor ozone). If this is the case, differences among reported coefficients may be due not only to sampling error and differences in study design but also to the fact that the studies are estimating different parameters. This model is more plausible and more general than the model of a single ozone coefficient that applies everywhere. (The model of a single ozone coefficient may be thought of as a special case of the general model — the case in which the variability among ozone coefficients is zero.)

The model that assumes that there is a single ozone coefficient in the concentration-response function is called the fixed effects model. The model that allows the possibility that the estimates from different studies may in fact be estimates of different ozone coefficients, rather than just different estimates of a single ozone coefficient, is called the random effects model. The way the results from different studies are combined (in particular, the way different studies are weighted) to obtain a single estimate (of the one ozone coefficient, under the fixed effects model; of the mean of the ozone coefficients, under the random effects model) will depend on the underlying model assumed. This is explained more fully, and an example is given, in the appendix.

A random effects model is the more reasonable model in this situation. Under this model, there is a distribution of ozone coefficients throughout the United States. The mean of this distribution may be used in a national analysis and the distribution itself may be used to characterize the uncertainty surrounding a "national coefficient."[1] To use the random effects model properly requires that (1) each input study represents a single location, (2) each location is represented only once, and (3) the estimated relationship is between the same variables in all studies — that is, that the ozone-mortality coefficients from the studies are all comparable.

Study selection Criterion 7 ensures that the first condition is met. There are, however, several studies in the set of selected studies that estimated the ozone-mortality relationship in Philadelphia in the same or overlapping time periods. The second condition therefore is not met. To meet the second condition, the Philadelphia results from several studies are pooled, as described in Section 4.2.

Although study selection Criteria 1, 5, and 6 are designed to ensure that the third condition is met, the ozone-mortality coefficients from the selected studies are still not entirely comparable. Some studies estimate the relationship between mortality and daily 1-hour maximum ozone whereas other studies estimate the relationship between mortality and daily (or some other) average ozone. This problem can be solved, however, by replacing the reported ozone coefficient for each study with the national incidence of ozone-related mortality that would be predicted by using that ozone coefficient and the appropriate ozone averaging time for that coefficient. This translates all results into "national incidence space" so that the results from different studies are comparable and can be used to estimate a distribution of national ozone-related mortality incidence. The method for doing this is described in Section 4.3.

4.2 Between-study redundancy: avoiding over-representing a single location

Two studies satisfying the study selection criteria listed in Section 2 have estimated a relationship between ozone and daily mortality in Philadelphia for the same or overlapping time periods. Including both of them in the Monte Carlo procedure described below would be giving Philadelphia twice the weight of other locations in that procedure. The two Philadelphia studies and their time periods are:

- Moolgavkar et al., 1995 (1973-1988)
- Samet et al., 1996, 1997 (1974-1988).

To include Philadelphia as one of the locations on which a probability distribution for the national ozone-related mortality incidence is based, the Monte Carlo procedure (as described in

[1] Although each county in the United States may have its own ozone-mortality coefficient, it is infeasible to use county-specific coefficients in a national analysis. Because the national incidence of ozone-related mortality is a continuous function of these ozone-mortality coefficients, it can be shown that there exists a coefficient that, if applied in all counties, would yield the same result as the set of county-specific coefficients (Intermediate Value Theorem). Although this coefficient is unknown, a good candidate for this value is the mean of the distribution of ozone-mortality coefficients.

Section 4.4 below) was carried out first on the two Philadelphia studies to produce a Philadelphia-based probability distribution of national ozone-related mortality incidence. This Philadelphia-based distribution was then used along with the other location-specific distributions generated in the first step of the Monte Carlo procedure described in Section 4.4.

4.3 Using studies that measured daily 1-hour maximum ozone and studies that measured daily average ozone (or some variant of the daily average)

Among the 9 studies that satisfy the selection criteria, 4 measured daily 1-hour maximum ozone concentrations and 5 measured daily average (or some other average) ozone concentrations. In order to aggregate the results from these studies, a conversion to one type of measure (i.e., either daily 1-hour maximum or daily average, but not both) is necessary. The peak-to-mean ratios necessary to make such conversions, however, are not available for all of the study locations.

Given that 1-hour maximum and daily average ozone modeling data are both available for the air quality scenarios being evaluated, there is an alternative to converting to either type of ozone measure. Using the ozone data appropriate for a selected study (either 1-hour maximum or daily average) and the ozone coefficient reported by the study, a national ozone-related mortality incidence can be generated. Further, given the standard error of the reported ozone coefficient as well, a distribution of national ozone-related mortality incidences can be generated. This procedure (described more fully in step 1 of Section 4.4 below) converts all study-specific ozone results, some of which correspond to 1-hour maximum ozone levels and some of which correspond to daily average ozone levels, to study-specific national ozone-related mortality incidence results.

4.4 The Monte Carlo method of estimating a probability distribution of the national incidence of ozone-related daily mortality

Given a set of studies, some of which use 1-hour maximum ozone and some of which use daily average ozone, the following steps will be used to aggregate the results of these studies to estimate a probability distribution for the national ozone-related incidence of mortality (deaths avoided) corresponding to a given increase (decrease) in ozone concentrations[2]:

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[2]Note that all discussion of national ozone-related mortality is specific to a given set of changes in ozone concentrations throughout the United States. A different set of changes in ozone concentrations would result in a different national ozone-related mortality.

1. *For each acceptable study,*[3] *estimate the probability distribution of national ozone-related mortality incidence that would be predicted, given the ozone coefficient and the reported standard error of that coefficient from the study*. The proposed method to do this is as follows: Let β denote the reported ozone coefficient from the study, and let s.e.(β) denote the reported standard error of the estimate of the ozone coefficient. Then a normal distribution with mean equal to β and standard deviation equal to s.e.(β) describes the probability distribution of what the ozone coefficient is in the location in which the study was conducted. Using the ozone data appropriate to the study (i.e., either daily 1-hour maximum or daily average), calculate the national ozone-related mortality incidence that would be predicted using the (n - 0.5)th percentile of the normal probability distribution described above, for n = 1, 2, 3, ..., 100. That is, calculate the national mortality incidence that would be predicted by using the 0.5th percentile point of the distribution of β's implied by the study, the 1.5th percentile point, and so on.

This step puts all studies, whether they use daily 1-hour maximum ozone or daily average ozone, into "national mortality incidence space" so that they are all comparable. That is, this step produces for each study a probability distribution of national ozone-related mortality incidence corresponding to the probability distribution of ozone coefficients based on the study's estimate of the coefficient and standard error of the estimate.

2. *Generate a single probability distribution of national ozone-related mortality incidence, based on the results of all the acceptable studies*. Such a single distribution is generated from the study-specific distributions by Monte Carlo methods. On each of many iterations, an estimate of the national ozone-related mortality incidence is generated by the following two-step procedure:

> 2a. *Randomly select a study from the set of acceptable studies, using random effects weights*. The probability of selection of a study is a function of both the variance of the estimate from the study (the within-study variance) and the variance among estimates from different studies (between-study variance). This random effects weighting is described in the attached appendix. To calculate random effects weights, both the within-study variance of each study and the between-study variance will have to be calculated in national incidence space — that is, from the distributions of national incidences generated in step 1.
>
> Other considerations could conceivably be incorporated into the weighting scheme (for example, the representativeness of the study location for an analysis of the ozone-mortality relationship within the United States). There is insufficient information, however, to derive nonarbitrary weights that would incorporate such potential considerations. (The degree to which the representativeness of non-U.S. locations is a

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[3]Two of the acceptable studies (i.e., studies that satisfy the study selection criteria) were conducted in the same location. This issue of location redundancy is discussed in Section 4.2. The Monte Carlo procedure assumes that each location is represented only once.

concern is itself unclear.) Therefore the random effects weights described in the appendix will be used.

2b. *Randomly select an estimate of the national ozone-related mortality from the distribution of estimates (corresponding to the 100 percentile points) derived in step 1 for the selected study*. The normal probability distribution of incidence for each study is approximated by a histogram in which each bar is centered at one of 100 percentile points (0.5th percentile, 1.5th percentile, 2.5th percentile, ..., 99.5th percentile). Each percentile point therefore has a 1/100 probability of selection — i.e., the random selection in step 2b is from a discrete uniform distribution. (Note that each percentile point is at the center of a segment supporting 1/100th of the probability mass of the normal distribution. Therefore the percentile points are not evenly spaced. They get closer together as they approach the mean of the normal distribution.)

Repeating steps 2a and 2b many times will generate a probability distribution of estimated national ozone-related mortality incidence. The mean of this distribution is the same as the random effects meta-analysis estimate of the mean (see appendix). The shape of the distribution, however, will depend on the information in the underlying studies — how different their estimates are from each other and the relative variances around those estimates. An alternative approach would be to impose a shape on the distribution (e.g., a normal distribution or a beta distribution). The Monte Carlo approach is preferable, however, because it generates a distribution that is most consistent with the existing information.

Probability statements about the national ozone-related mortality incidence can be based on this distribution. For example, if the 5th percentile point of the distribution is denoted as $m_{0.05}$, then there is a 5% probability that the national ozone-related mortality incidence is less than $m_{0.05}$. Similarly, if the 95th percentile point of this distribution is denoted as $m_{0.95}$, then there is a 95% probability that the national ozone-related mortality incidence is less than $m_{0.95}$. There is, then, a 90% probability that the national ozone-related mortality incidence is within the interval $[m_{0.05}, m_{0.95}]$.

4.5 Treatment of incidence values less than zero

The resulting (Monte Carlo) distribution of national ozone-related mortality incidence is a composite picture of what the available information tells us about the relationship between a given change in ozone concentrations across the United States and the corresponding change in national mortality. This distribution, however, will have some probability mass to the left of zero, because some of the studies reported statistically insignificant relative risks (or ozone coefficients), and a few studies actually reported (statistically insignificant) relative risks less than 1.0 (or, equivalently, negative ozone coefficients).

It is biologically implausible that exposure to ozone is beneficial. The question, then, is what to do with the probability mass to the left of zero. Redistributing the probability mass below zero to be at zero guarantees that any estimate will be nonzero and that the mean of the distribution will be positive. This, however, produces a biased estimate of the true mean ozone-related national mortality. (Even if the truth is that the ozone-mortality effect is zero, this procedure guarantees a positive estimate.) The point estimate of national ozone-related mortality, then, should be based on the unadjusted distribution.

For the purpose of making probabilistic statements, however, it is reasonable to redistribute the probability mass to the left of zero to be at zero. Suppose, for example, that 3% of the probability distribution of national ozone-related mortality incidence is to the left of zero. The reasonable inference is that, based on the available information, there is a 3% chance that exposure to ozone has no effect on the risk of premature mortality. Similarly, if 20% of the probability distribution is below zero, then it is reasonable to infer that, based on the available information, there is a 20% chance that exposure to ozone has no effect on the risk of premature mortality. If the 5th percentile of the distribution is to the right of zero, then any probability mass to the left of zero will have no impact on anything that is likely to be reported in the quantitative analysis.

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Appendix J.2: Pooling the Results of Different Studies

J.2.0 Introduction

Many studies have attempted to determine the influence of ozone pollution on human health. Usually this involves estimation of a parameter β in a concentration-response function, which may be linear or nonlinear, as discussed above. Each study provides an estimate of β, along with a measure of the uncertainty of the estimate. Because uncertainty decreases as sample size increases, combining data sets is expected to yield more reliable estimates of β. Combining data from several comparable studies in order to analyze them together is often referred to as meta-analysis.

For a number of reasons, including data confidentiality, it is often impractical or impossible to combine the original data sets. Combining the *results* of studies in order to produce better estimates of β provides a second-best but still valuable way to synthesize information (DerSimonian and Laird, 1986). This is referred to as "pooling results" in this report. Pooling requires that all of the studies contributing estimates of β use the same functional form for the concentration-response function. That is, the β's must be measuring the same thing.

One method of pooling study results is simply averaging all reported β's. This has the advantage of simplicity, but the disadvantage of not taking into account the uncertainty of each of the estimates. Estimates with great uncertainty are given the same weight as estimates with very little uncertainty. For example, consider the three studies whose results are presented in Table J.1.

Table J.1 Three Sample Studies

Study	Estimate of β	Standard Deviation	Variance
Study 1	0.75	0.35	0.1225
Study 2	1.25	0.05	0.0025
Study 3	1.00	0.10	0.0100

The average of the three estimates is 1.0. However, the Study 2 estimate has much less uncertainty associated with it (variance = 0.0025) than either the Study 1 or Study 3 estimates. It seems reasonable that a pooled estimate that combines the estimates from all three studies should therefore give more weight to the estimate from the second study than to the estimates from the first and third studies. A common method for weighting estimates involves using their variances. Variance takes into account both the consistency of data and the sample size used to obtain the estimate, two key factors that influence the reliability of results.

The exact way in which variances are used to weight the estimates from different studies in a pooled estimate depends on the underlying model assumed. The next section discusses the two basic models that might underlie a pooling and the weighting scheme derived from each.

J.2.1 The fixed effects model

The fixed effects model assumes that there is a single true concentration-response relationship and therefore a single true value for the parameter β. Differences among β's reported by different studies are therefore simply the result of sampling error. That is, each reported β is an estimate of the same underlying parameter. The certainty of an estimate is reflected in its variance (the larger the variance, the less certain the estimate). Pooling that assumes a fixed effects model therefore weights each estimate under consideration in proportion to the inverse of its variance.

Suppose there are n studies, with the ith study providing an estimate β_i with variance v_i (I = 1, ..., n). Let

$$S = \sum \frac{1}{v_i} ,$$

denote the sum of the inverse variances. Then the weight, w_i, given to the ith estimate, β_i, is

$$w_i = \frac{1/v_i}{S} .$$

This means that estimates with small variances (i.e., estimates with relatively little uncertainty surrounding them) receive large weights, and those with large variances receive small weights.

The estimate produced by pooling based on a fixed effects model is just a weighted average of the estimates from the studies being considered, with the weights as defined above. That is,

$$\beta_{fe} = \sum w_i * \beta_i .$$

The variance associated with this pooled estimate is the inverse of the sum of the inverse variances:

$$v_{fe} = \frac{1}{\Sigma \ 1/v_i} .$$

Table J.2 shows the relevant calculations for this pooling for the three sample studies summarized in Table J.1.

Table J.2 Fixed Effect Model Calculations

Study	β_i	v_i	$1/v_i$	w_i	$w_i*\beta_i$
1	0.75	0.1225	8.16	0.016	0.012
2	1.25	0.0025	400	0.787	0.984
3	1.00	0.0100	100	0.197	0.197
Sum			∑ = 508.16	∑ = 1.000	∑ = 1.193

The sum of weighted contributions in the last column is the pooled estimate of β based on the fixed effects model. This estimate (1.193) is considerably closer to the estimate from Study 2 (1.25) than is the estimate (1.0) that simply averages the study estimates. This reflects the fact that the estimate from Study 2 has a much smaller variance than the estimates from the other two studies and is therefore more heavily weighted in the pooling.

The variance of the pooled estimate, v_{fe}, is the inverse of the sum of the inverse variances, or 0.00197. (The sums of the β_i and v_i are not shown, since they are of no importance. The sum of the $1/v_i$ is S, used to calculate the weights. The sum of the weights, w_i, I = 1, ..., n, is 1.0, as expected.)

J.2.2 The random effects model

An alternative to the fixed effects model is the random effects model, which allows the possibility that the estimates β_i from the different studies may in fact be estimates of different parameters, rather than just different estimates of a single underlying parameter. In studies of the effects of ozone on mortality, for example, if the behavior or susceptibility of populations varies among study locations, the underlying relationship between mortality and ambient ozone concentrations may be different from one study location to another. (Suppose, for example, people in one location spend substantially more time outdoors than people in another location; this would violate the assumption of the fixed effects model.)

The following procedure can test whether it is appropriate to base the pooling on the random effects model (versus the fixed effects model):

A test statistic, Q_w, the weighted sum of squared differences of the separate study estimates from the pooled estimate based on the fixed effects model, is calculated as:

$$Q_w = \Sigma_i \frac{1}{v_i} (\beta_{fe} - \beta_i)^2.$$

Under the null hypothesis that there is a single underlying parameter, β, of which all the β_is are estimates, Q_w has a chi-squared distribution with n-1 degrees of freedom. (Recall that n is the number of studies in the meta-analysis.) If Q_w is greater than the critical value corresponding to the desired confidence level, the null hypothesis is rejected. That is, in this case the evidence does not support the fixed effects model, and the random effects model is assumed, allowing the possibility that each study is estimating a different β.

The weights used in a pooling based on the random effects model must take into account not only the within-study variances (used in a meta-analysis based on the fixed effects model) but the between-study variance as well. These weights are calculated as follows:

Using Q_w, the between-study variance, η^2, is:

$$\eta^2 = \frac{Q_w - (n-1)}{\sum 1/v_i - \frac{\sum 1/v_i^2}{\sum 1/v_i}} .$$

It can be shown that the denominator is always positive. Therefore, if the numerator is negative (i.e., if $Q_w < n-1$), then η^2 is a negative number, and it is not possible to calculate a random effects estimate. In this case, however, the small value of Q_w would presumably have led to accepting the null hypothesis described above, and the meta-analysis would be based on the fixed effects model. The remaining discussion therefore assumes that η^2 is positive.

Given a value for η^2, the random effects estimate is calculated in almost the same way as the fixed effects estimate. However, the weights now incorporate both the within-study variance (v_i) and the between-study variance (η^2). Whereas the weights implied by the fixed effects model used only v_i, the within-study variance, the weights implied by the random effects model use $v_i + \eta^2$.

Let $v_i^* = v_i + \eta^2$. Then

$$S^* = \sum \frac{1}{v_i^*} ,$$

and

$$w_i^* = \frac{1/v_i^*}{S^*} .$$

The estimate produced by pooling based on the random effects model, then, is just a weighted average of the estimates from the studies being considered, with the weights as defined above. That is,

$$\beta_{rand} = \Sigma\ w_i^* \ * \ \beta_i \ .$$

The variance associated with this random effects pooled estimate is, as it was for the fixed effects pooled estimate, the inverse of the sum of the inverse variances:

$$v_{rand} = \frac{1}{\Sigma\ 1/v_i^*} \ .$$

The weighting scheme used in a pooling based on the random effects model is basically the same as that used if a fixed effects model is assumed, but the variances used in the calculations are different. This is because a fixed effects model assumes that the variability among the estimates from different studies is due only to sampling error (i.e., each study is thought of as representing just another sample from the same underlying population), whereas the random effects model assumes that there is not only sampling error associated with each study, but that there is also between-study variability — each study is estimating a different underlying β. Therefore, the sum of the within-study variance and the between-study variance yields an overall variance estimate.

J.2.3 An example

This section demonstrates the relevant calculations for pooling using the example in Table J.1 above.

First calculate Q_w, as shown in Table J.3.

Table J.3 Calculation of Q_w

Study	β_i	$1/v_i$	$1/v_i * (\beta_i — \beta_{fe})^2$
1	0.75	8.16	1.601
2	1.25	400	1.300
3	1.00	100	3.725
			$\sum = Q_w = 6.626$

In this example the test statistic $Q_w = 6.626$. The example considers three studies, so Q_w is distributed as a chi-square on two degrees of freedom. The critical value for the 5% level (i.e., corresponding to a 95% level of confidence) for a chi-square random variable on 2 degrees of freedom is 5.99. Because $Q_w = 6.626 > 5.99$, hence the null hypothesis is rejected. That is, the evidence does not support the fixed effects model. Therefore assume the random effects model is appropriate.

Then calculate the between-study variance:

$$\eta^2 = \frac{6.626 - (3 - 1)}{508.16 - \dfrac{170066.65}{508.16}} = 0.0267 \quad .$$

From this and the within-study variances, calculate the pooled estimate based on the random effects model, as shown in Table J.4.

Table J.4 Random Effects Model Calculations

Study	β_i	$v_i + \eta^2$	$1/(v_i + \eta^2)$	w_i*	w_i* x β_i
1	0.75	0.1492	6.70	0.098	0.0735
2	1.25	0.0292	34.25	0.502	0.6275
3	1.00	0.0367	27.25	0.400	0.400
Sum			∑ = 68.20	∑ = 1.000	∑ = 1.101

The random effects pooled estimate, β_{rand}, is 1.101. It's variance, v_{rand}, is 1/(68.2) = 0.015.